A PROPOSED MODEL FOR UNDERSTANDING THE IMPACTS OF CLIMATE CHANGE ON TANGIBLE CULTURAL HERITAGE

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ABSTRACT

A PROPOSED MODEL FOR UNDERSTANDING THE IMPACTS OF CLIMATE CHANGE ON TANGIBLE CULTURAL HERITAGE

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The increasing influence of climate change on tangible cultural heritage in the 21st century has been recently recognized as one of the main threats to cultural heritage. Therefore, studies dwelling on the anticipated impacts of changes in the climate parameters are relatively new.

This study covers the current debate on the anticipated impacts of climate change on tangible heritage. It presents a forecast on how climate change may affect physical, chemical and biological deterioration mechanisms and which traditional materials of construction may be affected and in what way. Thus, a methodological approach was proposed in an effort to guide heritage professionals in view of climate change. To this end, different databases including the inventory of the historic buildings in Turkey and the projection maps, which are the outcomes of Noah's Ark Project and show the anticipated changes in the amplification mechanisms, were gathered by employing ArcGIS 10 software. The overlay maps were produced and evaluated from the perspective of Turkey to determine the cities, which are likely to be under the risk of different deterioration mechanisms that were anticipated to change over the century, and are rich in cultural heritage assets. After determining the case study area as Bursa, Muradiye Complex, the heritage map was produced and then the climate data series of the selected weather stations and periods were obtained. These data series were reclassified to make a trend analysis. Besides, heritage-climate risk maps were produced by employing ArcGIS10 software according to the selected materials and threshold combinations of temperature and relative humidity values. These maps were evaluated to understand the risk level of prevalent deterioration mechanisms. Then, archival records on the remediation processes to address defects of the buildings in the complex were gathered. The latest survey drawings of the buildings were used to calculate the surface areas of various deterioration types. Moreover, a field survey based on observations was conducted and photos were taken. At the last stage, the findings were compared with each other to interpret the prolonged defects and their relationship with climate parameters and/or inaccurate repairs.

The study reveals that the historic environment in Bursa and so the cultural heritage of Turkey have been facing particular threats derived from changing climate parameters. Therefore, the aim is to provide a model to reevaluate short, medium, and long term strategies to manage the effects of these threats to render tangible heritage more resilient in the time of climate change.

Keywords: Tangible Cultural Heritage, Anticipated Impacts of Climate Change, Risk Maps

ÖZ

İKLİM DEĞİŞİKLİĞİNİN SOMUT KÜLTÜREL MİRAS ÜZERİNDEKİ ETKİLERİNİ ANLAMAK İÇİN BİR MODEL OLUŞTURULMASI

Emine Gizem Başkan
Doktora, Yapı Bilimleri, Mimarlık Bölümü
Tez Danışmanı: Prof. Dr. Soofia Tahira Elias-Ozkan
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İklim değişikliğinin somut kültürel miras üzerinde 21. yüzyılda giderek artan etkileri kayıplara neden olan en önemli tehditlerden biri olarak son zamanlarda tanınmıştır. Dolayısıyla, iklim parametrelerindeki değişikliklerden kaynaklanan etkiler üzerinde yapılan çalışmalar göreli olarak oldukça yeni kabul edilebilir.

Bu nedenle, bu çalışma iklim değişikliğinin somut kültürel miras üzerinde oluşturması beklenen etkileri kapsamında yapılan mevcut çalışmaları içererek, iklim değişikliğinin fiziksel, kimyasal ve biyolojik bozulma mekanizmalarını nasıl etkileyeceği ve hangi geleneksel yapı malzemesinin nasıl etkileneceği hususlarında yapılan öngörüleri sunmaktadır. Bu kapsamda, kültürel miras alanında çalışan uzmanlara rehberlik edebilecek metodolojik bir yaklaşım tasarlanmıştır. Türkiye'deki tarihi yapıların envanteri ile "Noah's Ark" isimli projenin çıktıları olan ve öngörülen değişikliklerin malzeme bozulma mekanizmaları üzerindeki etkilerini gösteren haritalar olmak üzere farklı veri tabanları ArcGIS 10 programı yardımıyla bir araya getirilmiş ve kesişim haritaları üretilmiştir. Bu haritalar, Türkiye açısından değerlendirilerek içinde bulunduğumuz yüzyıl içerisinde değişmesi öngörülen farklı bozulma mekanizmaları açısından risk altında bulunan ve somut kültürel miras açısından zengin olan şehirler belirlenmiştir. Bursa - Muradiye Külliyesi çalışma alanı olarak tespit edildikten sonra kültürel miras haritası oluşturulmuştur. Daha sonra, belirlenen iklim istasyonlarından belirlenen zaman serisi için elde edilen iklim verileri yeniden sınıflandırılmış ve trend analizleri yapılmıştır. Ayrıca, seçilen malzemeler ile sıcaklık ve bağıl nem kombinasyonundan oluşan limit değerler için kültürel miras - iklim haritaları ArcGIS 10 programı kullanılarak üretilmiştir. Bu haritalar, etkin olan bozulma mekanizmalarının risk seviyesi açısından değerlendirilmiştir. Daha sonra, külliyede bulunan yapıların bakım onarım çalışmalarını içeren arşiv kayıtları toplanmış olup, en son yapılan rölöve çizimlerinden ise çeşitli bozulma türlerinin yüzey alanları hesaplanmıştır. Ayrıca, gözlem tekniği ile alanda veri toplanarak yapıların fotoğrafları çekilmiştir. Son aşamada, diğer aşamalarda elde edilenler bir araya getirilerek, devam eden sorunlar ile bu sorunların iklim parametreleri ve daha önce yapılan onarımlar arasındaki ilişkiler çerçevesinde değerlendirilmiştir.

Sonuç olarak Bursa'daki tarihi çevre ve dolayısıyla Türkiye'nin somut kültürel mirasının değişen iklim parametrelerinden kaynaklanan olumsuz koşullarla karşı karşıya kalmakta olduğu ortaya konulmuştur. Bu nedenle, bu çalışmada kısa, orta ve uzun vadede gerçekleştirilecek olan yönetim stratejilerinin iklim değişikliğinin somut kültürel miras üzerindeki olumsuz etkilerini dikkate alacak şekilde yeniden değerlendirilmeleri için model oluşturulması amaçlanmıştır.

Anahtar Kelimeler: Somut Kültürel Miras, İklim Değişikliği Etkileri, Risk Haritaları

To My Parents Melahat and Mehmet BAŞKAN

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LIST OF ABBREVIATIONS

CCPI	The Climate Change Performance Index
CNHPRB	Cultural and Natural Heritage Preservation Regional Board
DEMP	Disaster and Emergency Management Presidency
ECA	Europe and Central Asia
ECHAM5	European Center-Hamburg, Version 5
CCSM3	Community Climate System Model, Version 3
CMIP3	Coupled Model Intercomparison Project
GDM	General Directorate of Meteorology
GCMs	General Circulation Models
HadCM3	Hadley Centre Coupled Model, Version 3
HadGEM2-ES	Hadley Centre Global Environment Model version 2- Earth System
ICCROM	The International Centre for the Study of the Preservation and Restoration of Cultural Property
ICOMOS	International Council on Monuments and Sites
ICSU	International Council for Science
IUCN	International Union for Conservation of Nature
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JMA	Japan Meteorological Agency
MoCT	T.R. Ministry of Culture and Tourism
MoFWA	T.R. Ministry of Forestry and Water Affairs
MoEU	T.R. Ministry of Environment and Urbanization
MoEU- GDEM	T.R. Ministry of Environment and Urbanization - General Directorate of Environmental Management
MoD	T.R. Ministry of Development
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NOAA - ESRL	National Oceanic and Atmospheric Administration - Earth System Research Laboratory

NOAA - NCDC	National Oceanic and Atmospheric Administration - National Climatic Data Center
OECD	Organization for Economic Co-operation and Development
PPM	parts per million
RCPs	Representative Concentration Pathways
RegCM3	Regional Climate Model Version 3
SMS	State Meteorological Service
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

The world is in an age of facing the adverse impacts of changing climate globally. Over the past two decades, the impacts of climate change have grown larger in scale and sharper in outline. Consequently, search for prediction of climate change's impacts, and for mitigation and adaptation strategies are not only commonplace but also obligatory. That is why it is currently attracting interest at both research and policy levels. The impacts of climate change is usually analyzed for several sectors such as energy, agriculture, water, food security, forestry, transportation and health *etc.* but few studies have specifically quantified the effects of changes on tangible cultural heritage[1]. As the world comes to grips with the potential scope of climate change, it is becoming clear that the actual and projected impacts of climatic change pose a key threat to many tangible cultural heritage assets as well. Indeed, the conservation of such site/ buildings, and their economic, social and cultural contribution to society are being challenged by the changes in temperature, rainfall patterns, frequency and intensity of flooding, and a potential increase in storms, rising sea level and coastal erosion. Without taking wide-ranging adaptation and preventive measures to limit further damages, it may lead to heritage assets being irreversibly damaged or lost. It is, therefore, important to develop a number of adaptation strategies including new tools and methodologies capable of managing the transformational pressures of the changing climate at international, national and local levels to safeguard authenticity and historic integrity of both the properties and their wider context.

Within this framework, the statement of the problem, the objectives of the study, and the procedure followed are presented in this chapter. The chapter is concluded with the disposition of the various chapters within the thesis.

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[1] Buildings and historic places, monuments, such as temples, pyramids, and public monuments, artifacts significant to the archaeology, architecture, science or technology of a specific culture *etc.* and considered worthy of preservation for the future, are included in tangible cultural heritage (UNESCO, 2014a).

1.1. Argument

Buildings are constructed and strengthened with a view to enduring weather conditions over a period of decades / centuries. However, over time many historic buildings are influenced by environmental parameters, and suffer various weathering mechanisms. Weathering covers all physical, chemical and biological changes of materials under the influence of natural and man-made environmental conditions. During the weathering processes, mostly, more than one factor or all factors are involved and responsible for the changes. These changes, which trigger problems both in compositional and structural characteristics of materials, have been considered as a part of the total performance of a building. Therefore, understanding weathering processes and performance of building materials against these processes (durability) are important subjects to be understood both in engineering and cultural heritage conservation studies.

As these mechanisms are directly related to climate, an increase of a few degrees in temperature will probably speed up or decelerate the degradation processes which affect building materials and built heritage. Besides, a changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather events including increased flooding, heat waves, and drought *etc*. These events may pose a grave danger, and make historic buildings more vulnerable to certain types of disasters. In other words, capacity and performance of a building to resist disasters may be severely reduced. If a protected building is severely damaged, it will not be possible to get it back in its original form. The building can probably be reconstructed with new materials but the original building will be lost forever. In this regard, information should be provided on how climate change affects historic buildings, and how various methods can protect these buildings to secure the future of buildings at risk.

As regards Turkey, the heritage of many civilizations in Anatolia, enriched over the centuries with the addition of the newcomers, has turned Turkey into a well-blended mosaic of cultures. One of the world’s most diverse tangible cultural heritages is in Turkey together with exceptional ancient architecture, built environment and artifact collections. Unfortunately, tangible heritage in Turkey is also facing the risks of deterioration and degradation, which are accelerated by the potential pressures of climate change. Although a lot of research has already done in the area of causes and mechanisms of deterioration, there is currently a gap of knowledge about the risks pattern of changing climate on tangible cultural heritage, and lack of studies on adaptation strategies for sustainable management of the future threats. However, there is no time to wait for all the research to be completed before suggestions are produced on how to manage the tangible heritage in view of climate change.

With respect to the aspects mentioned so far, there is an intense need for research initiatives addressing more effective and efficient management responses / strategies, which are capable of helping heritage managers implement relevant actions to cope with the changes posed by climate change on tangible heritage. It is important to produce risk and vulnerability maps for cultural heritage assets, which overlay climate data and locations of heritage assets so that an overview of the risks to different aspects of tangible heritage can be obtained to be used in management strategies. Therefore, this study is focused on presenting the anticipated impacts of changing climate on tangible heritage in Turkey over the century with the aim of increasing awareness about the links between the conservation of tangible heritage and the rapidly developing discipline of climate change; and using the spatial analysis approach employing ArcGIS 10 to identify tangible heritage in a region which will be the most affected with the aim of providing inputs that may be used to reformulate heritage management strategies for handling detrimental consequences.

1.2. Objectives

The main objectives of this study are listed below:

1. to understand the relation between climate change and tangible heritage, with an eye on how to protect and adapt the latter to the former;
2. to investigate the climate parameters and trends which are most critical to tangible heritage in Turkey;

3. to identify the nature and scale of the threats posed by climate change, and the likely vulnerabilities of tangible heritage in Turkey in a potentially more severe climate;
4. to improve the understanding of the risks of potential climate change and vulnerabilities of tangible heritage;
5. to integrate currently separate data-sets related to deteriorations of historical materials and climate change projections by using Geographic Information Systems (GIS);
6. to highlight future adaptation needs for the regions under the increasing risks.

1.3. Procedure

The first phase of the study consisted of a literature survey to gain a general understanding of tangible cultural heritage, climate change, the external physical, chemical and biological agents of material deterioration mechanisms that likely to be altered by changing pattern of the climate system, their inter-relationships to one another, and the susceptibilities or vulnerabilities of materials. This was based on an overview of publications found in the libraries of Middle East Technical University (METU), Bilkent University and the Higher Education Council of Turkey; as well as electronic database of scientific papers.

The information gathered from the literature, such as the hierarchical maps (climate maps, heritage climate maps, damage maps, risks maps and thematic maps), which were produced within the Noah's Ark Project, were evaluated by using ArcGIS10 from the perspective of Turkey by taking into account the number of listed buildings. The overlay maps were produced to determine the risk areas, where the risks of different deterioration mechanisms are likely to increase and the number of listed buildings is high. According to result of the overlay maps, the case study area was selected as Bursa, and the buildings selected belong to the Muradiye Complex.

The Complex was visited to take photographs and understand the ongoing remedial works. Bursa Regional Directorate of Foundations, Bursa Cultural, Natural Heritage Preservation Regional Board and the Metropolitan Municipality of Bursa were visited to obtain archival records of the complex. Then, the Ministry of Forestry and Water Affairs (MoFWA) - General Directorate of Meteorology (GDM) were visited to get the climate data series of the selected period (1965-2014) and weather stations.

Trend analyses of precipitation and temperature values were conducted and combined threshold of temperature and relative humidity (RH) were mapped in ArcGIS10 according to selected materials – stone, timber and metal. The results were compared with the archival records of the buildings in the complex, and the projections.

Finally, whole information was analyzed and the outcome variables were obtained to make heritage management professionals reevaluate management strategies to improve the stability of the heritage assets against changes in climate parameters.

1.4 Disposition

The study is presented in seven chapters. This first chapter is composed of the statement of the problem, the objectives and disposition of subject matter that follows in the remaining chapters.

The second chapter presents a literature review on general aspects of cultural heritage and natural and man-made threats; the current state of climate change within the framework of the observations and the projections in Europe and Turkey; the relation between tangible heritage and climate change within the limits of building materials and deterioration mechanisms; and the materials regarding the Bursa and Muradiye Complex.

The third chapter presents the material used to conduct the research. The archive review on Muradiye Complex in Bursa, especially details of its building materials, previous and prevalent damages, and records on remedial works, and on climate data focusing Bursa are given in this chapter.

The forth chapter presents the methodology used to conduct the research. It gives details about the steps of producing overlay maps by utilizing ArcGIS 10 software.

The fifth chapter presents the reorganized archival records according to the chronological order of events on the Muradiye Complex in Bursa, which was selected as the case study area, were collected from Bursa-Cultural and Natural Heritage Preservation Regional Board.

The sixth chapter presents the spatial analysis conducted with the help of ArcGIS 10 software.

In the final Chapter, the conclusions of the study are formulated, and an outlook for further studies is given.

A list of relevant datasets for all chapters is provided as Appendixes.

CHAPTER 2

LITERATURE REVIEW

The literature review covers topics related to tangible cultural heritage and traditional building materials in Turkey; deterioration processes that affect traditional building materials; current debate on climate change; changing trends in atmospheric composition and microclimate parameters that will affect the deterioration processes; and understanding behaviors of building materials in view of the climate change's impacts.

2.1. Tangible Cultural Heritage in Turkey

One of the world's most diverse tangible cultural heritages is in Turkey together with exceptional ancient architecture, built environment and artefact collections. Throughout history, as Anatolia has been the stage of many civilizations, it contains a number of specific cultural intersection points and the majestic architecture of numerous buildings and monuments constructed over Hellenistic, Roman, Byzantine, Seljuk Turks, Ottoman periods, *etc*. It sheds light on every stage of human thought and civilization. Hence, building practices of Anatolia were enriched and enhanced by a great variety of social and political factors as well as geographical characteristics observed distinctively in its different territories.

This wide-ranging diversity in Turkey is mainly protected with the law entitled the '*Law for the Conservation of Cultural and Natural Property numbered 2863'*. It was brought into force in 1983; and still in force today. It defines the framework for the protection of cultural heritage with some updates and changes which were actualized in different times. This law explains the concept of cultural properties as "all movable and immovable properties located aboveground, underground or underwater, of prehistoric or historic periods, that are either related to science, culture, religion and fine arts or are marked by the value of originality in terms of science and culture which are objects of social life in prehistoric and historic periods" in the Article 3. In addition to this definition, in the Article 6 of the Law, its scope is specified as the following criteria: "the immovable property built until the end of the 19^{th} century; the immovable property created after the mentioned date that the Ministry of Culture and Tourism (MoCT) deems necessary to be protected considering its importance and characteristics; immovable cultural property situated in the conservation site; the buildings and areas that witnessed the significant historical events throughout the period of Independence War and the foundation of the Turkish Republic. In addition, the houses, which were used by Mustafa Kemal Pasha, the founder of the Turkish Republic, notwithstanding the time that they were built, have to be protected because of their significance in Turkey's national history." Archeological sites, castle, historic barrack, bridges, ancient palaces, waterside residences and mansions, mosques, masjids, soup kitchens, cemeteries, bedesten, bazaar, church, frescoes, mural ruins, chimney rocks, *etc.* are some of the examples of immovable cultural heritage (Law for the Conservation of Cultural and Natural Property, 1983).

Together with criteria above mentioned, the following considerations are determined in the '*Regulation on the Identification and Registration of Immovable Cultural and Natural Property to be Protected':* "*for detached or single buildings*; that the immovable property be special with respect to its structure, decoration, structural status, material, construction technology and format within the scope of the range of artistic, architectural, historical, aesthetic, local, archaeological values; *for urban conservation sites;* that the detached building having the property of cultural property to be protected demonstrate architectural, historical uniformity or traditional urban texture as a whole; *for archaeological conservation sites;* that they possess qualities in terms of written information, superficial ruins, scientific research, environmental observations, ecological observations, scientific estimations and topographical structure; *for urban-archaeological conservation sites;* that traditional urban texture where everyday life continues and archaeological sites exist together; *for historical conservation sites;* that it be ascertained that important historical events took place according to the written information and historical research" (MoCT, 2012b).

According to Article 7of the '*Law on the Conservation of Cultural and Natural Property'*, the determination of the immovable cultural properties to be protected is made by the Ministry directly or with the help of other institutions or enterprise experts. The statistical data on these properties by cities is published by the Ministry's General Directorate for Cultural Heritage and Museums every year. It encompasses different types: sites (archaeological, urban, urban-archaeological, and historical) and buildings (residential, religious, cultural, administrative, military, industrial and commercial, tombs, martyrs' memorial, monuments, ruins, and streets). The total number of the immovable cultural heritage is 112,159 in Turkey by 2014 year-end data (Tables 2.1 and 2.2).

Table 2.1. Statistics of immovable cultural heritage properties under the responsibility of the General Directorate for Cultural Heritage and Museums (2014-Year-End Data)
(Source. Ministry of Culture and Tourism, 2015)

TYPES of PROPERTIES	Sub-Categories	Number
SITES	Archaeological	12,725
	Urban	265
	Urban-Archaeological	32
	Historical	159
	Others	436
	Total	**13,617**
BUILDINGS	Residential	64,599
	Religious	9,141
	Cultural	10,701
	Administrative	2,661
	Military	1,068
	Industrial and Commercial	3,686
	Tombs	3,747
	Martyrs' memorial	257
	Monuments	338
	Ruins	2,283
	Streets	61
	Total	**98,542**

Table 2.2. Statistics of buildings' types under the responsibility of the General Directorate for Cultural Heritage and Museums by cities (2014-Year-End Data) (Source. Ministry of Culture and Tourism, 2015)

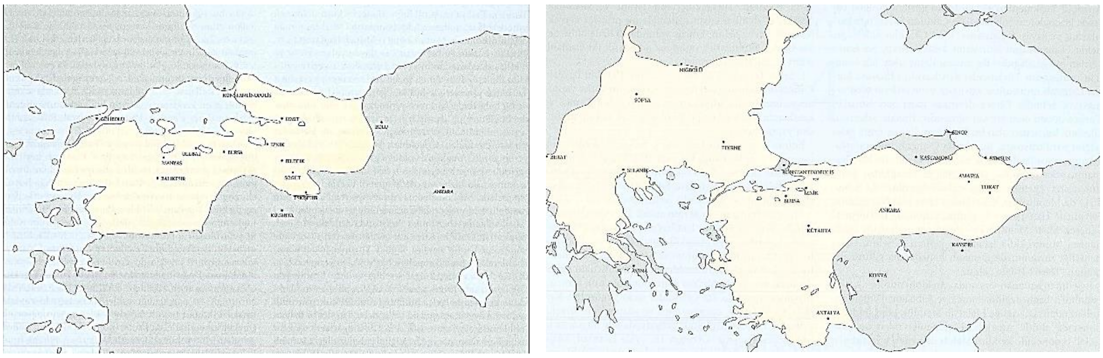
	CITY	Civil Archirecture	Religious	Cultural	Administrative	Military	Industrial and Commercial	Tombs	Martyrs' Memorial	Monuments	Ruins	Streets	SUM
1	ADANA	275	61	90	38	35	83	33	5	0	90	3	713
2	ADIYAMAN	11	48	31	3	4	4	6	0	2	23	0	132
3	AFYON	434	163	183	29	4	36	43	8	6	5	0	911
4	AĞRI	1	7	3	1	5	0	11	9	0	2	0	39
5	AMASYA	217	108	136	15	3	5	55	4	0	11	1	555
6	ANKARA	1,249	219	176	170	7	84	22	2	34	20	0	1,983
7	ANTALYA	1,410	180	454	31	83	77	156	0	15	228	3	2,637
8	ARTVİN	102	65	61	5	26	4	5	0	0	4	0	272
9	AYDIN	506	117	221	61	25	84	100	5	9	33	1	1,162
10	BALIKESİR	2,324	177	156	87	12	68	73	6	12	32	2	2,949
11	BİLECİK	223	58	48	30	0	9	19	2	4	8	0	401
12	BİNGÖL	3	18	8	2	3	0	13	0	3	8	0	58
13	BİTLİS	270	106	79	3	16	1	20	1	0	5	0	501
14	BOLU	498	57	54	11	2	32	15	2	1	4	1	677
15	BURDUR	96	33	56	2	2	59	29	0	0	19	1	297
16	BURSA	3,166	411	300	77	49	42	160	4	13	68	1	4,291
17	ÇANAKKALE	1,016	136	159	43	28	69	140	70	29	20	4	1,714
18	ÇANKIRI	127	76	53	8	0	6	22	2	1	2	4	301
19	ÇORUM	105	74	62	7	7	0	12	0	0	2	1	270
20	DENİZLİ	420	100	87	36	7	26	69	0	0	14	0	759
21	DİYARBAKIR	528	158	195	64	9	3	44	3	0	13	0	1,017
22	EDİRNE	538	142	270	53	48	98	145	9	12	69	0	1,384
23	ELAZIĞ	55	68	53	22	8	2	12	1	1	7	0	229
24	ERZİNCAN	195	66	56	14	8	0	29	4	4	11	0	387
25	ERZURUM	179	175	113	30	63	32	43	14	7	21	0	677
26	ESKİŞEHİR	1,237	133	85	64	9	175	27	2	2	4	0	1,738
27	GAZİANTEP	771	68	73	16	4	18	11	0	3	5	0	969
28	GİRESUN	251	95	124	16	10	4	20	1	2	13	0	536
29	GÜMÜŞHANE	58	128	91	5	12	2	10	2	1	8	0	317
30	HAKKARİ	0	16	4	0	0	0	8	0	0	2	0	30
31	HATAY	498	95	102	44	13	43	26	2	3	35	2	863
32	ISPARTA	266	91	72	25	5	22	27	3	0	9	1	521
33	İÇEL	408	126	167	45	34	152	115	1	5	75	1	1,129
34	İSTANBUL	24,979	1,136	2,077	467	69	491	532	11	70	594	6	30,432
35	İZMİR	4,268	410	537	226	28	721	121	1	26	85	4	6,427
36	KARS	348	69	60	56	59	38	13	19	3	14	0	679
37	KASTAMONU	1,305	147	170	37	20	59	48	0	4	8	0	1,798
38	KAYSERİ	557	199	198	48	9	24	37	0	1	18	3	1,094
39	KIRKLARELİ	168	41	50	33	14	33	8	2	1	4	0	354
40	KIRŞEHİR	9	20	13	0	1	1	7	0	0	32	0	83
41	KOCAELİ	523	51	139	46	33	39	61	1	3	69	2	967
42	KONYA	457	406	355	66	8	91	57	5	4	43	0	1,492
43	KÜTAHYA	768	205	137	27	4	32	39	6	5	12	0	1,235
44	MALATYA	97	70	50	13	1	1	16	2	3	5	0	258
45	MANİSA	825	172	153	74	32	319	52	1	1	17	0	1,646
46	K.MARAŞ	233	41	48	6	23	41	14	1	3	12	0	422
47	MARDİN	832	156	75	15	3	30	24	0	0	7	0	1,142
48	MUĞLA	2,601	223	713	43	22	158	377	0	7	147	1	4,292
49	MUŞ	6	19	12	2	8	0	11	7	1	2	0	68
50	NEVŞEHİR	912	200	98	26	7	32	18	0	2	8	0	1,303
51	NİĞDE	126	121	81	10	1	1	11	0	0	6	0	357
52	ORDU	286	50	45	8	7	5	46	0	0	7	0	454
53	RİZE	270	43	136	3	7	3	27	0	0	5	1	495
54	SAKARYA	304	46	32	17	13	50	16	2	1	14	0	495
55	SAMSUN	392	119	113	49	4	25	62	1	2	10	2	779
56	SİİRT	21	52	36	1	2	0	11	1	0	1	0	125
57	SİNOP	346	57	45	17	16	3	23	0	3	16	1	527
58	SİVAS	318	134	86	47	3	12	29	2	2	7	0	640
59	TEKİRDAĞ	399	46	108	22	4	16	42	3	10	27	0	677
60	TOKAT	429	131	92	16	1	11	23	0	0	11	0	714
61	TRABZON	1,055	244	300	40	15	56	74	2	2	18	1	1,807
62	TUNCELİ	9	26	27	1	4	0	21	0	1	4	0	93
63	ŞANLIURFA	1,216	107	138	19	8	14	33	2	1	17	14	1,569
64	UŞAK	178	66	96	17	0	22	14	1	1	1	0	396
65	VAN	5	56	47	12	8	1	25	1	3	8	0	166
66	YOZGAT	65	59	41	22	1	6	21	0	0	4	0	219
67	ZONGULDAK	87	17	28	23	4	6	91	0	0	42	0	298
68	AKSARAY	232	175	62	13	1	62	14	0	1	27	0	587
69	BAYBURT	46	25	20	10	5	0	17	7	0	6	0	136
70	KARAMAN	153	128	108	5	1	0	26	0	1	8	0	430
71	KIRIKKALE	30	15	8	10	0	7	2	0	0	0	0	72
72	BATMAN	14	34	19	3	6	2	10	0	0	5	0	93
73	ŞIRNAK	17	31	27	1	4	0	2	0	0	2	0	84
74	BARTIN	346	17	24	1	16	4	35	0	0	31	0	474
75	ARDAHAN	14	28	16	4	22	0	22	11	1	14	0	132
76	IĞDIR	12	7	4	1	20	0	22	3	3	1	0	73
77	YALOVA	48	10	17	12	0	2	2	0	0	5	0	96
78	KARABÜK	1,436	79	191	19	1	7	40	0	0	8	0	1,781
79	KİLİS	283	32	23	5	2	10	2	0	2	1	0	360
80	OSMANİYE	26	20	16	8	8	1	22	3	1	22	0	127
81	DÜZCE	111	26	8	3	2	10	7	0	0	8	0	175
													98,542

As a result of welcoming several different civilizations throughout its history, Turkey has always been a reservoir of a large number of unique and valuable cultural properties. As regards Ottoman Empire, which covered a vast territory, ruled over a period of about 700 years. Numerous changes have been observed in the character of Ottoman architecture over the course of this lengthy era. The architectural heritage of the Ottomans is mainly divided into three periods: the early formative phase, the classical period, and the late period. As it is a very broad subject to deal, the study is delimited to the early periods of Ottoman Architecture. Therefore, tangible cultural heritage in Turkey are presented from the viewpoint of monumental buildings and traditional materials of construction in the early periods of Ottoman Architecture in the following sub-sections.

2.1.1. Monumental Buildings

In this section, very brief information on the monumental buildings in the early periods of Ottoman Architecture is presented to understand the types of buildings and the development of architecture of this period.

When the weakening and disintegration period of the Seljuk State in the late thirteenth and the early fourteenth centuries, the Ottoman state was one among many small principalities in Anatolia that emerged as a result of the instability of that time. This small state in northwest Anatolia, located on the frontiers of the Islamic world, gradually expanded through Byzantine territories and conquered lands in Anatolia and the Balkans (Figure 2.1) (Yalman, 2002). The expansion of territories by the Ottoman State resulted in the development of the Ottoman architecture and the emergence of a new style. They encountered the medieval cultures of Western Europe and Byzantium, as well as the past, classical cultures of northwest Asia Minor. Therefore, a distinctive feature of Ottoman architecture derived from two main sources: Islamic and European artistic traditions (Ousterhout, 2004). This new style can be traced in architectural developments in Bursa, Edirne, Western Anatolia, Istanbul and the Balkans during the 14^{th} and 15^{th}centuries. Ottoman history of architecture was mainly developed around the axis between Bursa and Edirne, before the conquest of Istanbul. The key buildings were constructed in the Ottoman capitals (Bursa, Edirne, İstanbul) which were the sole centers of imperial administration. Besides, they had been places where the manifestation of economic power was displayed. In parallel with political and economic power, social and cultural activities have mainly been conducted in these capitals. As they have hosted diversity and richness produced or harbored by the Ottoman Empire, they have a special place in Ottoman architecture (Kuban, 2010).



(a) (b)

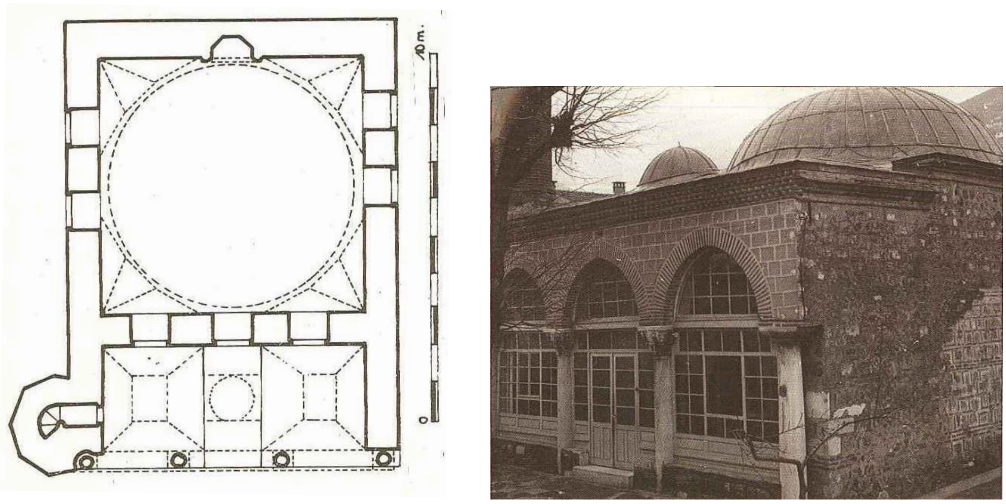
Figure 2.1. The maps show (a) the borders at the end of the reign of Orhan Ghazi (1362); (b) the borders before the conquest of Istanbul (1451)
(Source. Kuban, 2010)

The early Ottoman architecture covers the adaptation of existing buildings and the construction of new buildings. As the changing Ottoman community (i.e. from an immigrant tribe to an empire) had growing and varying needs, they constructed several public buildings and edifices in various sizes and forms. Ottoman architects found a medium to reinterpret what they had learnt from previous Turkish and Islamic civilizations and enhance their construction techniques when they encountered and worked with local architects / builders from newly acquired regions. This interaction satisfied the increasing demands of a flourishing community with the annexation of new lands to Ottoman territory [Kuran, 1964; and Bursa Metropolitan Municipality - Bursa Site Management Unit (coord.), 2013].

The earliest Ottoman buildings, which are still in existence, in the North-Western Anatolia, especially İznik and Bursa. The architectural monuments in Bursa and İznik, which have been key places in Early Ottoman history in terms of establishing organizational and institutional structure of the Empire, and witnessing transformation of a small Western Anatolian principality into a fairly large Balkan state, display the formative period of the Ottoman State very clearly (Kuban, 2010). In İznik, the domed mosque with an extension towards the front that indicates the new Ottoman style of architecture beforehand, original stalactite capitals, tiled minarets, imarets, the first development of the inverted T plan scheme and the beginning of Ottoman madrasa type, the first tombs in The Ottoman style, and a type of wall construction with one course of hewn stone and three of brick. İznik, therefore, contained the seeds of the development of subsequent Ottoman Architecture (Aslanapa, 1971). Bursa, which is the first capital city of Ottoman State, was defined by social complexes (*külliye*) consisting of public buildings such as mosques, madrasahs, hamams, public kitchens and tombs in the context of waqf system (public charity foundation system) (WH Committee Decisions, 2015). The Ottoman Architecture, which got its start in Iznik, underwent a brilliant development and reached monumental scale in Bursa (Aslanapa, 1971). Apart from İznik and Bursa, after the second half of the fourteen century, Edirne was declared as the new capital city. It also became a city of monuments symbolizing the key stages in Ottoman history, although it had held the title of being a capital for a short period before the conquest of Istanbul. As the construction of the Muradiye Imaret, the Edirne Palace and the *Üç Şerefeli* Mosque during the reign of Murad II is the sign of an intense architectural activity, and of the initiation of a great new imperial style (classical period) in architecture such as dome style, Edirne has also gained an important place in the history of Ottoman architecture (Kuban, 2010).

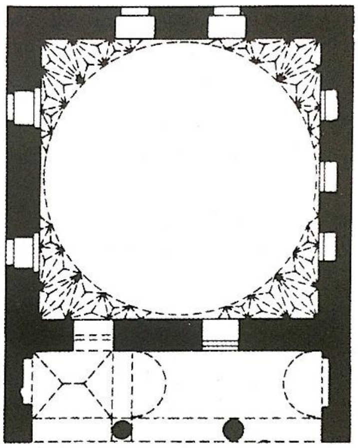
As it was mentioned above, the early Ottoman Architecture became a period of searching new ideas. They constructed many buildings which reflect the development process of the early period architecture in terms of plan, facade and ornamentation and forming an archetype. The simplest plan, an oblong room covered by a tiled pitched roof or an interior wooden dome formed the earliest Ottoman mosques. Then, the domed square, which became the archetype, was used in a variety ways. At the beginning, the domed-square mosques were small and simple whereas later they evolved as having monumental proportions which reflects the Ottoman concern for the integration of space (Freely, 2011). That is to say, this early period of Ottoman Architecture witnessed three major types of mosques in terms of exterior form and organization of inner space : (1) the single-unit mosque, (2) the iwan mosque (inversed T plan or 'Bursa type'), and (3) the multi-unit mosque.

The typical single-unit mosque consists of a square, or near square, prayer room surmounted by a dome; a two- or three-bay portico for late comers surmounted by vaults, domes, or a combination of the two; and a minaret which is placed either on the east or west wall. The most important example of the single-unit mosque is *Alaeddin Bey* Mosque in Bursa (1326) followed by *Hacı Özbek* Mosque in İznik (1333) (Figures 2.2 and 2.3) (Kuran, 1968; and Aslanapa, 1971).



(a) (b)

Figure 2.2. (a) The plan of the Alaeddin bey Mosque; (b) exterior view of the mosque (portico for late comers)
[Source. (a) Vakıflar Genel Müdürlüğü Yayınları, 1983, and (b) Osmangazi Municipality, 2006]

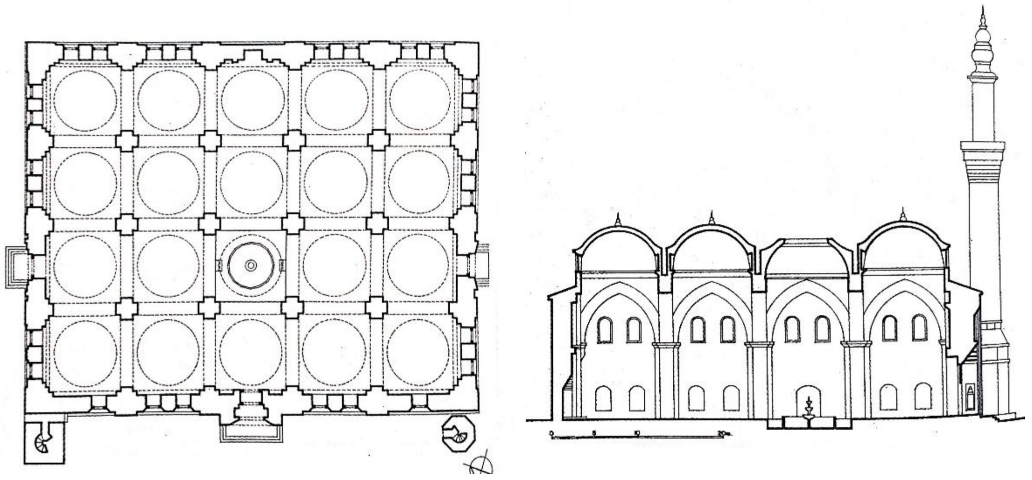


(a) (b)

Figure 2.3. (a) The plan of the Hacı Özbek Mosque; and (b) exterior view of the mosque

[Source. (a) Goodwin, 1971; and (b) Ministry of Culture and Tourism, 2015]

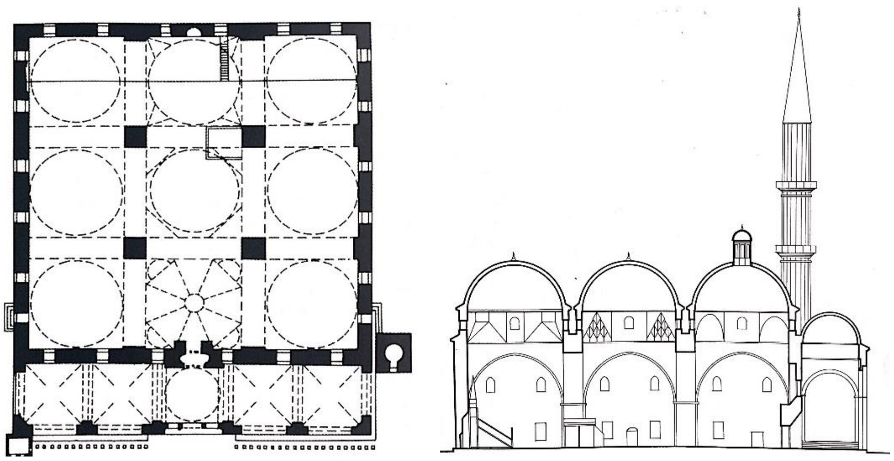
The multi-unit mosque, which is traditionally called as 'great mosque' (*ulucami*), has a more standardized and large interior space. The prayer-hall is defined by only one domed-square unit in the single-unit mosque while the domed-square unit is repeated transversally, longitudinally or both in the multi-unit mosque. Columns or piers are used to divide the interior into compartments, which are domed-square units, to provide shorter spans (Kuran, 1968). There are monumental examples in Bursa (Great Mosque), Edirne (Old Mosque and *Üç Şerefeli* Mosque), and Istanbul (*Zincirlikuyu* Mosque). In Great Mosque, which is the most monumental and traditional of the multi-domed mosques, twelve piers divide the vast interior into twenty domed compartments. Although the second dome on the main axis was originally open, the oculus was covered with glass in one of the modern remedial works. Below it, a large circular fountain is placed. There are two minarets on its north facade but there is no portico. (Figure 2.4) (Aslanapa, 1971; and Freely, 2011).



(a) (b)

Figure 2.4. (a) The plan of the mosque shows the twenty domed compartments, and two minarets on the north facade. (b) The oculus and the fountain are seen in the section of the mosque.
(Source. Kuran, 1968)

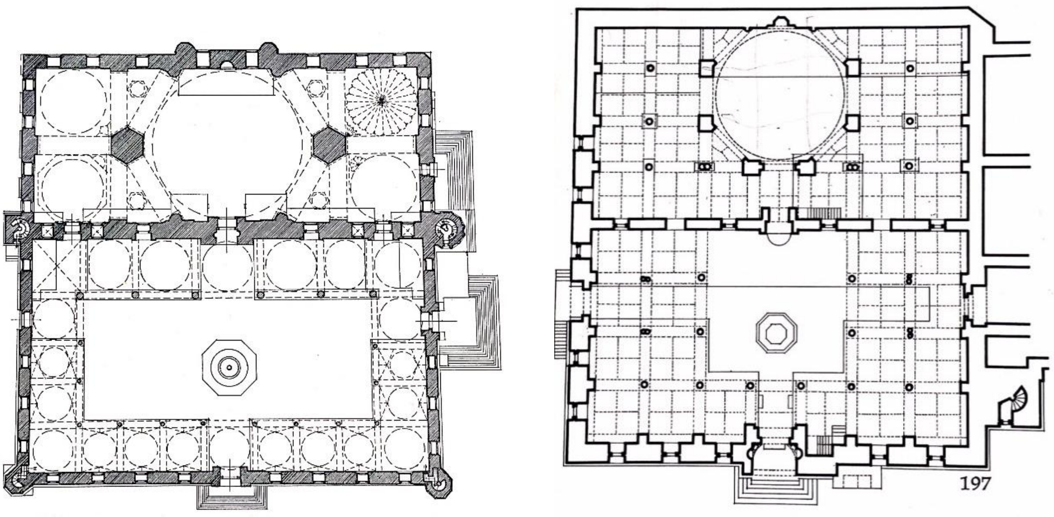
The Old Mosque, which is the earliest of the three imperial foundations in Edirne city center, is divided into nine equal sections in three rows. These sections are covered by nine domes, which are supported by four massive square masonry piers (Figure 2.5) (Freely, 2011).



(a) (b)

Figure 2.5. (a) In the plan of the Old Mosque, the domed nine compartments are seen; and (b) the section of the mosque shows the different arrangements for making the transition from the square base to the circular cornice.
[Source. (a) Goodwin, 1971; and (b) Kuran, 1968]

With the advent of more sophisticated building techniques, the multi-unit mosques with a larger central unit. The unit, which includes a *mihrab,* is constructed bigger than the other to emphasize the importance of the *mihrab.* The most important example is *Üç Şerefeli* Mosque (1437) in Edirne. This type can be also exemplified by Great Mosque (1376) and *Hatuniye* Mosque (1488) in Manisa, and *Atik Ali Paşa* Mosque (1497) in İstanbul (Figure 2.6) (Kuran, 1968).



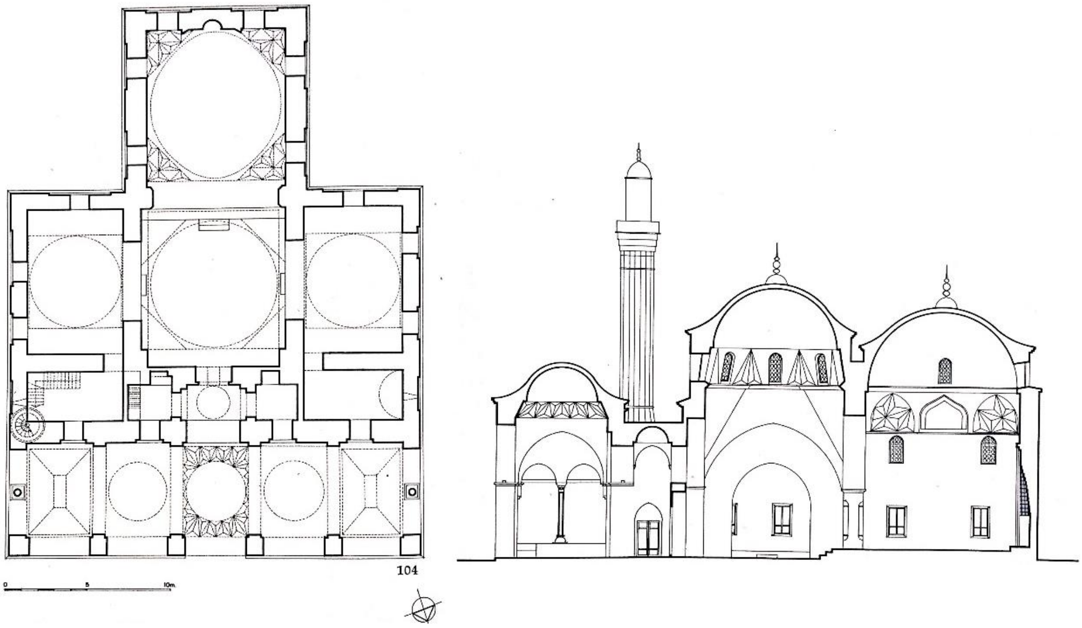
(a) (b)

Figure 2.6. The plans of (a) Üç Şerefeli Mosque in Edirne and (b) Great Mosque in Manisa.
[Source. (a) Aslanapa, 1971; and (b) Kuran, 1968]

The iwan mosque, which is the most original and interesting type of this period, is also known as "Bursa Type" and inverted 'T'. In this type, a mosque has an interior space developed with respect to longitudinal and transverse axes. There is a kinship between the iwan mosque and the madrasa in Seljuk period in terms of having a central hall and a prayer iwan in which the *mihrab*[2] and the *minbar*[3] are placed. The other domed spaces, in front of or next to it, are designed to meet different demands of public life,

[2] Niche of a mosque indicating the direction of mecca.
[3] A raised platform in the front area of a mosque from which sermon is given.

such as administration, court of law, kitchen, guestroom, classroom *etc*. The portico of this type has five bays; and it has one or two minarets. The mosques of Orhan Ghazi (1339), Murad the First (*Hüdavendigar*) (1366), which clearly illustrates the relationship between the Bursa Type mosque and the Seljuk madrasa, and Green Mosque (1424) in Bursa can be given as the examples of this type (Figures 2.7 and 2.8) (Kuran, 1968).



(a) (b)

Figure 2.7. (a) The plan of Orhan Ghazi Mosque becomes an inverted T by the addition of smaller domes on the sides and another larger one to the qible side; and (b) the section of the mosque.
(Source. Kuran, 1968)

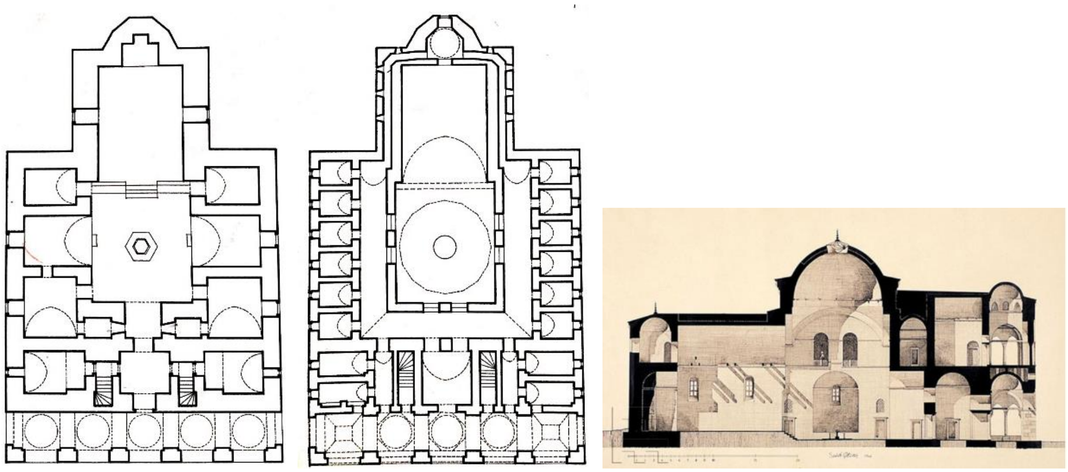
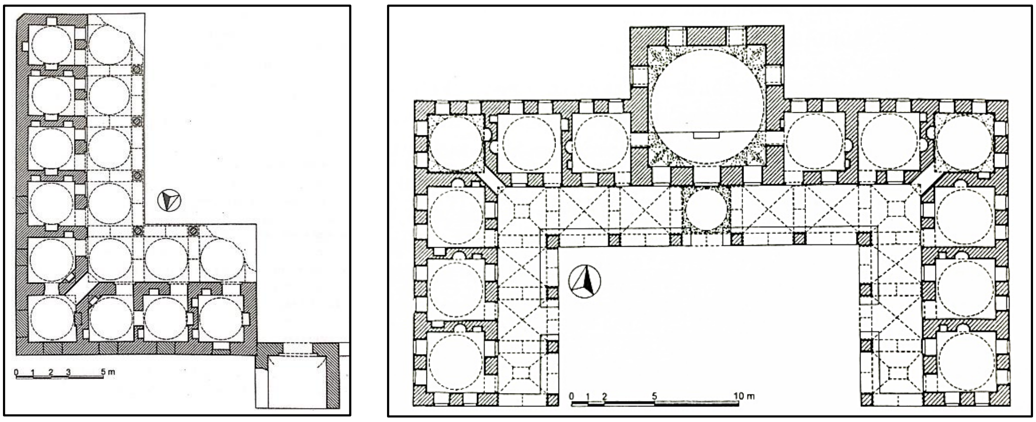

(a) (b) (c)

Figure 2.8. The two-story building including a mosque on the ground floor (a) and a madrasa on the upper floor (b). The section of the building is presented in (c). [Source. (a) and (b) Kuran, 1968; and (c) Sedat Çetintaş]

The development of the new style of Ottoman architecture can be clearly followed in madrasas, tombs, hans, and covered markets (*bedesten*), *etc.* as well as mosques.

Madrasa: During the early period, madrasas, which is the specialized institution of learning that was adopted by the Seljuks, were replaced by new plan schemes capable of meeting the practical necessities of the time, and adapted to new educational conditions (Aslanapa, 1971). All of the madrasas built in this period do not have a rectangular floor plan scheme. Apart from rectangular plans, polygon, square or L and U shape floor plan schemes are also seen (Figure 2.9). As an exception, Kapıağası Madrasa (1488) in Amasya has an unusual octagonal plan (Figure 2.10). It is used for the first time in this building and then repeated for Rüstem Pasha Madrasa (1550) in Istanbul during the classic period (Demiralp, 1999). Madrasas are almost always lined up around the sides of a domed and arcaded courtyard, with the large domed lecture hall which is in the center of one side (Freely, 2011). Lecture halls generally projects from the main building. The most remarkable change is observed on student cell. Each student cell, which has a dome on top, a fireplace and a window, opens into a courtyard with a fountain in the center. Although the madrasas were mostly designed as detached buildings, there are some examples that a mosque and a madrasa were designed together, and/or shared same courtyard for the first time in this period. Additionally, most of the madrasas surrounds less than four sides of the courtyard, i.e. one or two side(s) of the courtyard is/are left empty and open to outside or a surrounding wall is built (Demiralp, 1999; and Freely, 2011). Thus, having an internal courtyard that is a pre-Ottoman period feature disappeared gradually (Demiralp, 1999).



(a) (b)

Figure 2.9. (a) The plan of Hereke (Düzce) Village Madrasa is ‘L’ shape; and (b) the plan of İnegöl İshak Pasha Madrasa, which shares the courtyard with a mosque, is ‘U’ shape.
(Source. Demiralp, 1999)

(a) (b)

Figure 2.10. (a) The octagonal plan of Kapıağası Madrasa in Amasya consists of the student rooms and each is covered by a small dome, around an octagonal colonnaded courtyard; and (b) the aerial view of the madrasa.
[Source. (a) Demiralp, 1999; and (b) MoCT, 2012a]

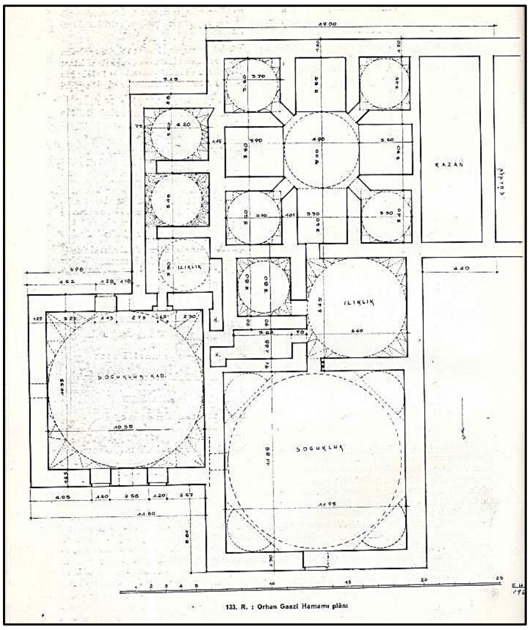
The monumental crown gate of the pre-Ottoman period, which is an impressive member, remains unobtrusive during this period. Although there are a few examples that have gates similar to ones belonging to the previous period, they do not have impressive ornamentation like previous examples (Demiralp, 1999).

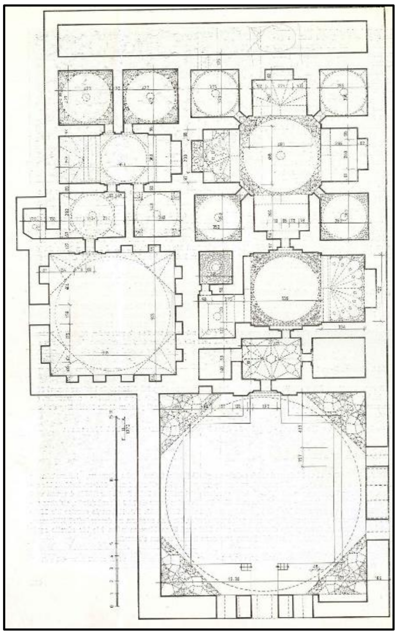
(a) (b)

Figure 2.11. (a) The crown gate of Bayezid II Madrasa in Edirne is very simple and not impressive according to previous period i.e. Seljuk; and (b) although the crown gate of the Kapıağası Madrasa in Amasya is similar with the ones in the previous period, it is not ornamented as much as them.
(Source. Demiralp, 1999)

Hamam: In the early Ottoman Architecture following the Seljuk period, hamams developed both architecturally and culturally reaching a mature state. The main two reasons that explain the construction of many hamams through the history of Ottomans are: (1) as hamams bring in money, they were devoted to the pious foundations; and (2) as a part of a social complex, they served to the congregation of the mosque in the complex. During the early period, two typologies based on differences in the plans of hot rooms were mainly preferred (Eyice, 1997)

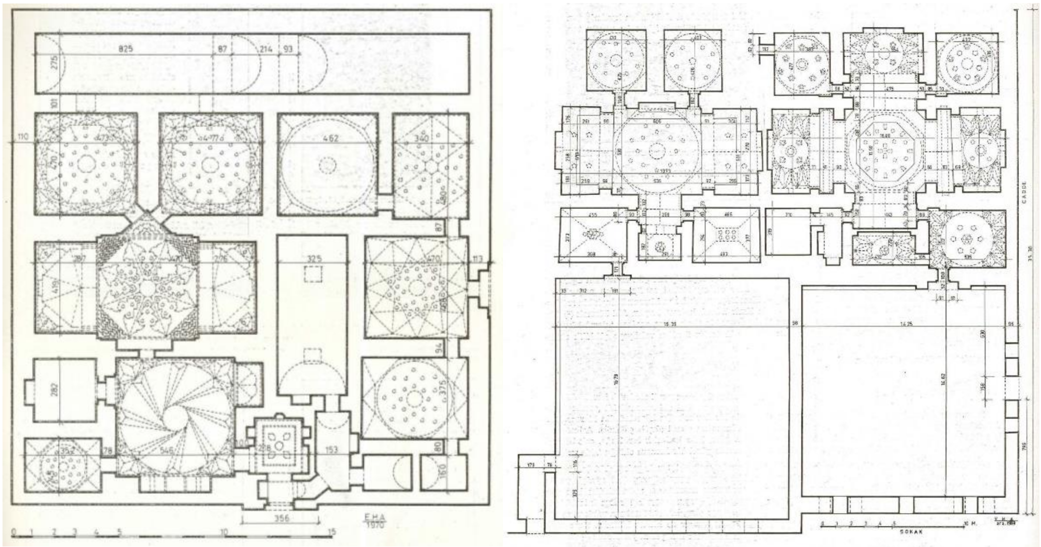
- This first type has a cross-axial plan with four iwans and four private bathing cubicles (*halvet*) units at corners. This is a very common typology, which is used in the oldest hamams in Anatolia. In this type, according to limitations of a site in which a hamam is built, variations can also be seen, such as decrease in the number of private bathing cubicles. Orhan Ghazi Hammam in Bursa (Figure 2.12a), Hacı Hekim Hamam in Bergama, the male's sections of Hacı Hamza Hammam in İznik, Saray and Tahtakale Hamams in Edirne (Figure 2.12b), can be given as examples.
- The second type has a domed hot room and double private bathing cubicles. The hot room, which is a narrow rectangular space, has three sections. The entrances of the private bathing cubicles, which are side by side, are opened to the section in the middle, which is covered by a dome on top. Ghazi Mihal Bey in Edirne (Figure 2.13a), Şengül, Yıldırım and Muradiye in Bursa; and women's section of Karacabey in Ankara are the hamams where this type is preferred (Figure 2.13b) (Eyice, 1997).





(a) (b)

Figure 2.12. (a) Orhan Ghazi Hamam; and (b) Tahtakale Hamam in Edirne (Source. Ayverdi, 1966)

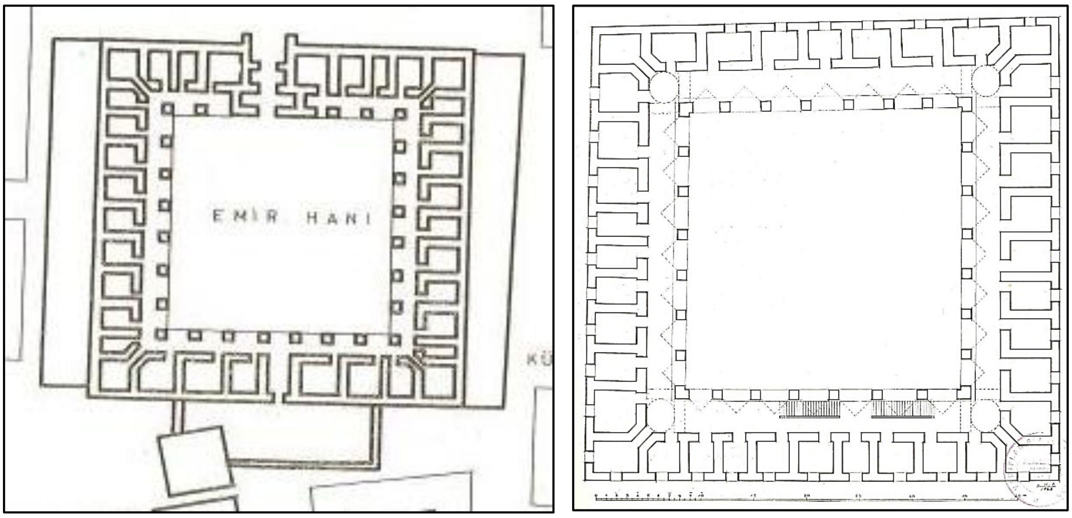


(a) (b)

Figure 2.13. The plans of (a) Ghazi Mihal Bey Hamam in Edirne; and (b) Karacabey Hamam in Ankara (left-hand side: women's section).
(Source. Ayverdi, 1966)

In this period, dressing area (*soyunmalık*) with great domes was built. The diameters of domes in the males section are between 10 to 15 m in Sarıca Paşa Hamam in Gelibolu, Atpazarı Hamam in Bursa and Tahtakale Hamam in Edirne. Yıldırım Bayezid Hamam in Mudurnu is known as the biggest domed hamam in Ottoman Architecture. The diameter of the male section's dome is 20 m (Eyice, 1997).

Hans: As with other building types, the Ottomans also inherited the han or caravanserai, which are designed to meet the needs of travelers on the road, engaging much of its functional and formal properties. The plan generally consists of a number of cells surrounding a courtyard which include a mosque, shops, stables, barn, and sleeping rooms. Since the expansion of commerce had necessitated the introduction of new types of buildings, which enable to accommodate various trade types, the caravanserais were incorporated into the urban environment. They were started to serve as commercial depots, such as wholesale centers selling particular goods (Kuran, 1968). Emir Han (1339) built by Orhan Ghazi became a model for hans built in the following years (Figures 2.14 and 2.15) (Kuban, 2009). In Bursa Ipek Han (first half of fifteenth century) was a center for silk merchants while Pirinc Han (1507), Fidan Han (fifteenth century), and Koza Han (1489) were mainly markets for grain (Kuran, 1968). Additionally, some hans were used to keep animals, as well as being a storage centers for merchandise (Eyice, 1955).



(a) (b)

Figure 2.14. (a) Ground floor plan and (b) first floor plan of Emir Han in Bursa. (Source. Ayverdi, 1966)

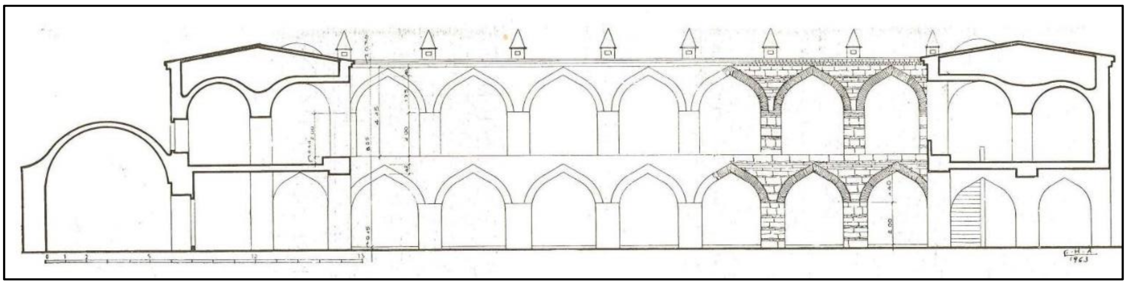


Figure 2.15. The section of Emir Han in Bursa (Source. Ayverdi, 1966)

Tomb: Tombs have conical or pyramidal roofs on a square or octagonal body during the Seljuks. Then, a polygonal or square body surmounted by a simple dome became the prevalent form in the early Ottoman period. This indicates the signals of forming a building typology for tombs. The Green Tomb (1421) built by Çelebi Sultan Mehmed in Bursa is one of the earliest examples of this period (Figures 2.16 -2.18) (Aslanapa, 1971).

Figure 2.16. A view from Green Tomb in Bursa
(Source. Cultural Inventory, 2012)

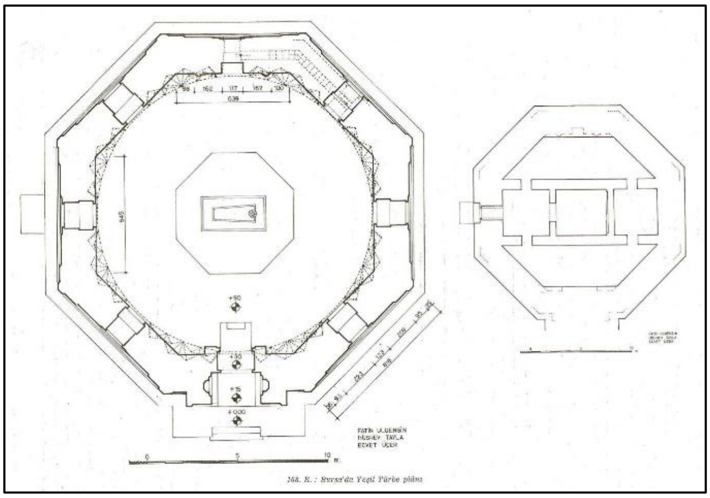


Figure 2.17. The plans of Green Tomb in Bursa
(Source. The archive of the General Directorate for Foundations)

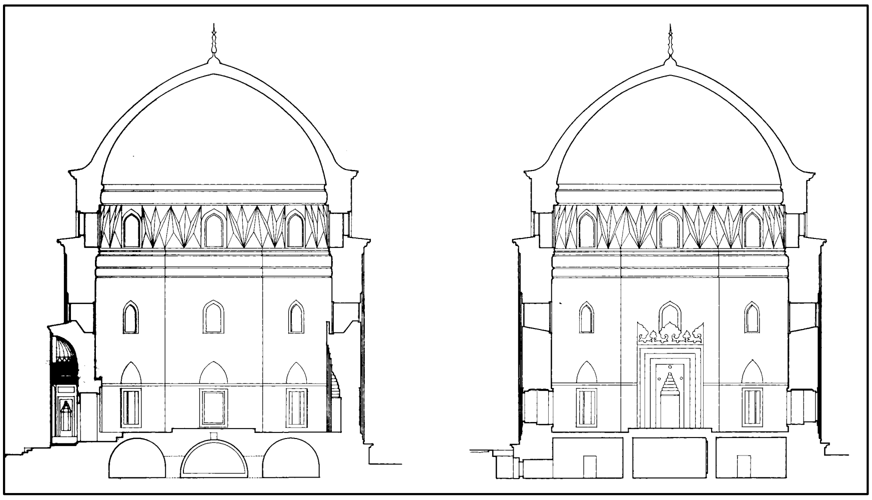


Figure 2.18. The sections of Green Tomb in Bursa
(Source. The archive of the General Directorate for Foundations)

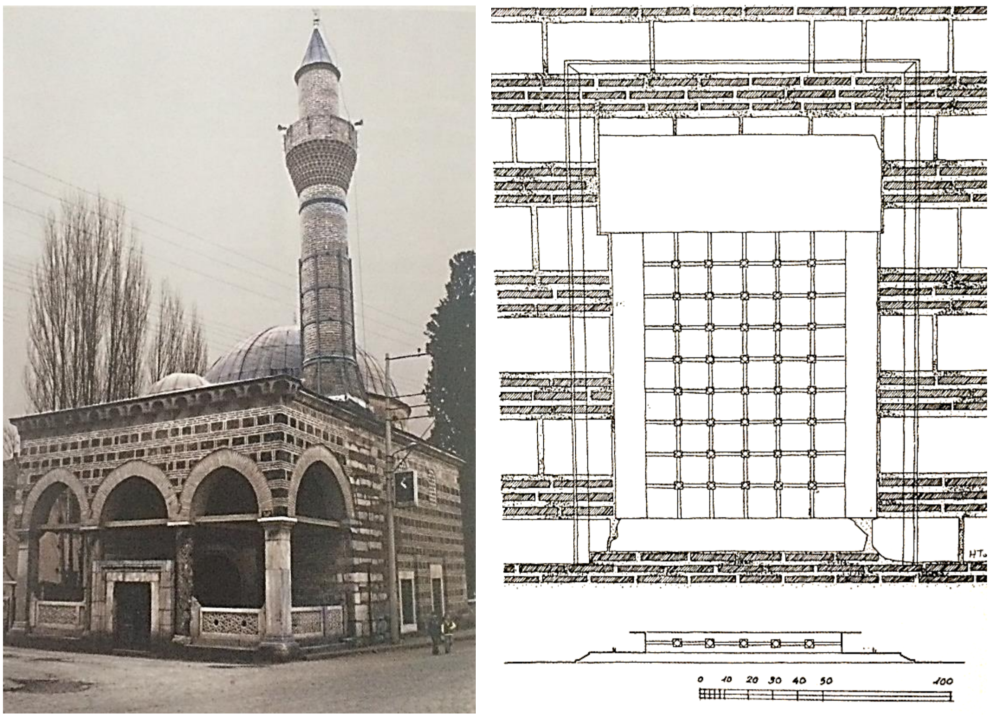
During the early period of Ottoman Architecture, many new aspects are also seen in selecting building materials and ornamentation which are given in the following section.

2.1.2. Traditional Materials of Construction

Monumental buildings were generally constructed by different combinations of the materials and techniques during different periods. The choice of materials of construction was influenced by neighboring nations and earlier local civilizations (local materials, techniques, traditions and masters) (Ünsal, 1959). The fourteenth century Ottoman architecture is also the combination of traditional Turco-Muslim forms, and local Byzantine structure and masonry technique (Kuran, 2012). As this study is delimited to the specific period in Anatolia, i.e. the Ottoman Empire, material choices for monumental architecture in the early Ottoman Architecture are presented in the following paragraphs.

Walls: During the early period of Ottoman Architecture, bordering with Byzantine and conquering its cities have affected the use of brick. With the influence of existing Byzantine buildings in these cities, brick was started to use in harmony with rubble stone, pitch-faced stone and cut-stone for exterior walls of buildings. The use of this technique was a characteristics feature not only of the fourteenth century, but also of the fifteenth. Brick courses are placed between regular stone courses. In Anatolian-Turkish architecture, it was the first time that the use of the middle and late Byzantine periods' wall technique of alternate stone and brick courses (*almaşık*) which replaced the ashlar faced walls of the Seljuk period in Central and Western Anatolia. This is one of the characteristic of the early period of Ottoman architecture (Demiralp, 1999 and Kuban, 2010).

The use of this technique sometimes shows variety in the orders of stones and bricks. In the same building, different orders can be seen in a facade as well as different facades have different orders (Figures 2.19 - 2.21). For instance, the cut-stone orders are used in the entrance facades whereas alternate of rubble stone and brick courses are preferred for the rear facades or the facades looking the inner courtyard. In several social complexes, the mosques are usually constructed from cut-stones whereas the technique of alternate stone and brick courses is used to build the other buildings in the complexes (Tayla, 2007).



(a) (b)

Figure 2.19. (a) The enterance facade of the Mahmut Çelebi Mosque in İznik (photo was taken in 1975); and (b) the order of a row of cut-stones and three rows of bricks in the side walls. This order is also used for the portico with adding vertical bricks in between the stones.
(Source. Tayla, 2007)

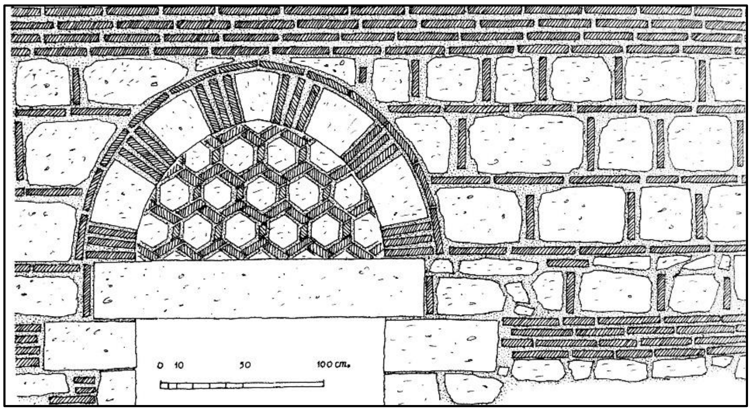


Figure 2.20. The Yıldırım Mosque in Edirne is built with alternating courses of rubble-stones and bricks.
(Source. Tayla, 2007)

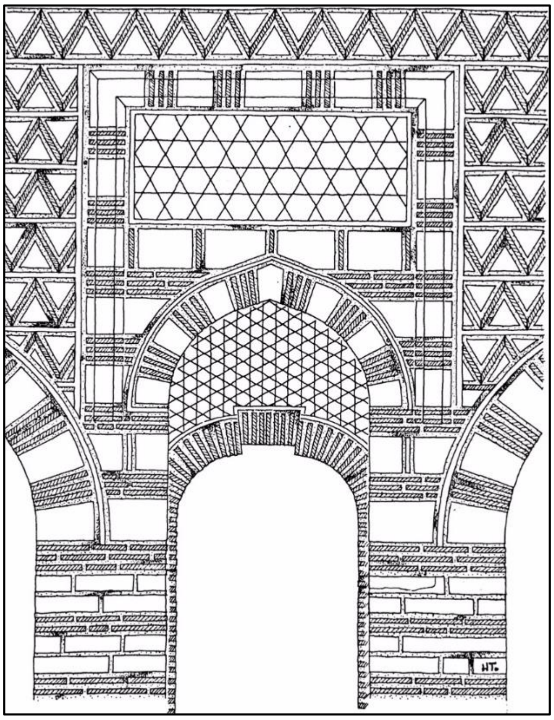
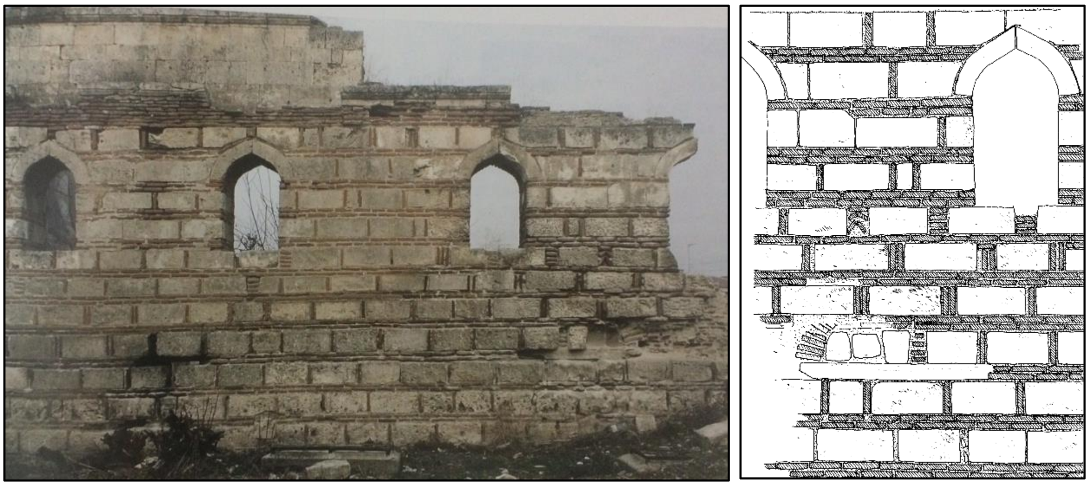


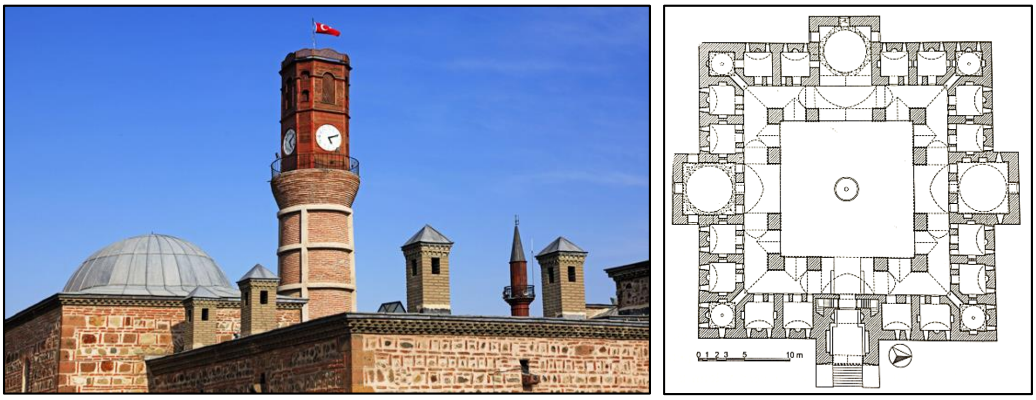
Figure 2.21. Different orders of alternating stones and bricks in the Selçuk Hatun Mosque in Bursa.
(Source. Tayla, 2007)

The technique of alternate stone and brick courses, like in other structure types, was used to build madrasahs in the early period. Brick was employed with stone for exterior walls in Ottoman madrasahs dated between the fourteenth and sixteenth centuries both as a horizontal course embedded in rubble stone or pitch-faced stonewall, and as a filling material, for example, Lala Şahin Pasha Madrasah (Bursa), Murad Hüdavendigar Madrasah (Bursa), Yıldırım Madrasah (Bursa), Subaşı Eyne Bey Madrasah (Bursa), Hacı Halil Paşa Madrasah (Gümüş – Amasya), Muradiye Madrasah (Bursa), Saatli Madrasah (Edirne) (Figure 2.22). The brick course(s) were also used in rubble stone walls of certain facades of buildings in order to avoid monotony, for instance, Çelebi Sultan Mehmed Madrasah (Merzifon), Yeşil Madrasah (Bursa), Koca Mustafa Pasha (Sümbül Efendi) Madrasah (Istanbul) (Figure 2.23) (Demiralp, 1999). In several buildings, building stones are supported by one or two bricks which were vertically placed (Demiralp, 1999) like in Alaaddin Bey Mosque (Bursa). Its exterior walls were built of rubble stone, and brick, which was inserted in both horizontal and vertical directions between stone courses (Kuran, 1964).



(a) (b)

Figure 2.22. (a) The photo showing the wall of Saatli Madrasah constructed by alternating stones and bricks in Edirne; (b) the drawing showing the order of a row of cut-stones and two rows of bricks, and a different order in between cut-stones, such as four horizontal bricks.
(Source. Tayla, 2007)



(a) (b)

Figure 2.23. (a) The technique of alternate rubble stone and brick courses in the walls of Çelebi Sultan Mehmed Madrasah built in 1414 in Merzifon-Amasya; and (b) the square shaped floor plan of the madrasa.
[Source. (a) Trekearth; and (b) Demiralp, 1999]

In the early Ottoman Architecture, usage of cut-stone is observed. Especially, in late 15th century, the number of madrasah whose exterior walls are covered by cut-stone has increased in parallel with increase in political and economic power of Ottoman Empire, for instance Great Mosque and Yeşil Mosque (Bursa), Fatih Madrasahs (8 buildings in Istanbul), Gedik Ahmed Pasha Madrasah (Afyon), Peykler Madrasah (Edirne), Bayezid II. Madrasah (Amasya) and Bayezid II. Madrasah (Edirne) (Demiralp, 1999). Especially, in the time of Beyazıt I and Mehmet I, in Bursa, the buildings were faced with marble and stone slabs (Figure 2.24) (Ünsal, 1959).

(a) (b)

Figure 2.24. The entrance (a) and side facades (b) of the Yeşil Mosque (1419) in Bursa. The entrance facade is constructed from marble and the side walls are cut-stones (travertine).
(Source. Photos taken by the author)

The use of spolia is frequently observed in the exterior walls of buildings in Anatolian Seljuk period whereas they are found occasionally in structures of Ottoman architecture. However, in several madrasahs, pillars and their capitals of porches are built of spolia in the early period of Ottoman Architecture. For instance, the materials of porches' pillars in Süleyman Pasha Madrasah (İznik), Koca Mustafa Pasha (Sümbül Efendi) Madrasah (Istanbul), Ayas Aga Madrasah (Amasya), Yavukluoğlu Madrasah

(Tire-Izmir) and Hereke (Düzce) Village Madrasah (Seferihisar-Izmir); and the materials of pillars and their capitals in Murad Hüdavendigar Madrasah (Bursa), Yeşil Madrasah (Bursa), Gedik Ahmed Pasha Madrasah (Afyon), Davud Pasha Madrasah (Istanbul) and Hacı Sinan Madrasah (Bayındır) are partially or totally spolia (Demiralp, 1999).

In hamam structures [Çifte Hamam (Hersekzade Ahmet Pasha Hamam), Rüstem Pasha Hamam, Kamanlı Hamam (Yahşi Bey Hamam), Özbek Village Hamam, Büyük Hamam, Küçük Hamam, Kaleiçi Hamam Ulamış Village Hamam and Düzce (Hereke) Village Hamam] dated between the fifteenth and sixteenth centuries in Izmir, the walls are built of rubble stone, pitch-faced stone, reused cut-stone, brick, timber, and lime mortar as a binder material. Bonding timber is used to compensate vertical loads to construct exterior walls. Exterior surfaces are bare whereas inner surfaces were plastered by *horasan*[4] (Reyhan and Ipekoğlu, 2004).

Minaret: The minarets, which are the integral parts of the mosques, were generally composed of nine sections: foundation, base, shoe, shaft, balcony, upper portion of the shaft, hood, finial and stairs (Tokay and Kuşüzümü, 2011). Some of these sections may not be seen in the early Ottoman period, such as base and shoe (Ödekan, 1988).

Although the Ottoman minarets generally have a stone base and a brick shaft and usually covered with lead, there are several minarets built from alternate stone and brick courses, such as the minaret of the Selçuk Hatun Mosque (1460) (Figure 2.25) (Uluengin, Uluengin and Uluengin, 2001, and Tayla 2007). Glazed brick, glazed tile faced [İznik Yeşil Mosque (1378-1391)] or plastered minarets are also seen as well as alternate courses of stones and bricks (Figure 2.26). Especially after the conquest of Istanbul, the brick lost its importance; and left its space to the stone. The construction of the monumental stone minarets starts with the Üç Şerefeli Mosque in Edirne, which is the first Ottoman mosque to have had not only multiple minarets but also multiple

[4] Horasan: Crushed or finely ground brick pieces, locally known as Horasan, have been used as aggregates in the manufacturing of lime mortars and plasters since ancient times (Akman, Güner and Aksoy, 1986). Horasan mortar and plaster have been used in the construction of aqueducts, bridges, wells, cisterns and public baths since Roman times due to their ability to set in the presence of water and their high mechanical strength (Lea, 1940; and Böke, Akkurt and İpekoğlu and Uğurlu, 2006)

balconies on a single minaret (Gündüz, 2005). It is the prototype of the minarets in the sixteenth century. Then, the Ottoman minaret is characterized by its extremely slender, pencil like structure with conical hood; and it became the exclusive form (Ödekan, 1988).

Apart from stones and bricks, the construction of a minaret required different specialized craftsman including masons, carpenters, lead casters, coppersmiths and blacksmiths due to the necessity of using different materials, such as timber, lead, copper, iron *etc*. (Uluengin *et al*., 2001).

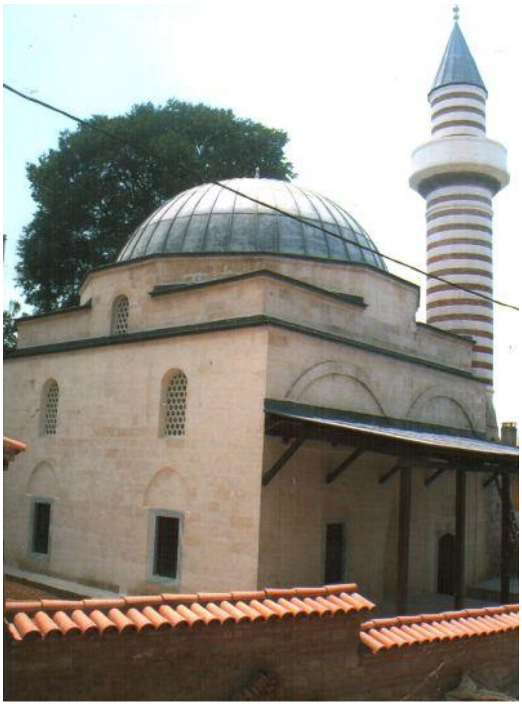


Figure 2.25. The minaret of the Selçuk Hatun Mosque in Edirne is constructed by alternating courses of stones and bricks.
(Source. Web page of Edirne İl Müftülüğü)

(a) (b)

Figure 2.26. The photos displaying (a) the general view of the İznik Yeşil Mosque; and (b) the single minaret of the mosque in the northwestern corner, which is decorated with glazed terra-cotta green, yellow, turqouise and dark purple colored tiles.
[Source. (a) MoCT, 2012; and (b) bursa.com.tr]

Doors: In Ottoman architecture, one of the major decorative elements is entry door. Geometric, floral and calligraphic patterns were used for embellishment, and ebony, mother of pearl, and ivory were preferred for inlay. These doors were made of oak to increase longevity (Uluengin *et al.*, 2001). Their metal fittings, such as lock, key, knocker and handle were of fine bronze (Ünsal, 1959). One of the door types is metal-clad doors which were used where the door is exposed to outdoor environmental conditions in monumental buildings, such as the entrances of courtyards. These doors were produced by using cladding materials, such as iron, copper or bronze on wood (Uluengin *et al.*, 2001).

Windows: Although there are many different types of windows with various functions, such as upper window, outer window, viewport window, false window, top window, lucarne, *etc.* in the Ottoman monumental architecture, a limited number of materials were used. Wood, plaster, lime - *tatlı kireç* - and glass were the basic materials (Uluengin *et al.*, 2001). Windows were usually arranged in a double horizontal row. The lower row had flat lintels with gratings of bronze or iron while the upper was filled with stained-glass panes. The outside of windows were divided into circular or oval shape plaster partitions (Ünsal, 1959).

Traceries: As regards traceries, various materials were used. Apart from marble, which was most extensively used, limestone, wood, metals, such as brass or bronze were generally preferred. As limestone (Küfeki stone) could not be carved as precisely as marble, traceries made of limestone were kept at distance above eye level, such as on minaret balconies (Uluengin *et al.*, 2001).

Roofs: The dome of monumental buildings is constructed of brick or stone. Interior surface of dome is plastered while its exterior surface is covered with lead, or in early times with tiles (Ünsal, 1959 and Uluengin *et al.*, 2001).

Ornamentation: The dried and baked brick wall-technique of Mesopotamia and Central Asia was improved by covering faces of walls with colored enamel, i.e. the glazed brick, to protect bricks from weathering during the Seljuk period. This technique, which was developed by Seljuks in Persia, brought to Anatolia and bequeathed to the Ottomans, was also observed during the early Ottoman architecture; for example in the minaret of the Green Mosque at İznik and in the Green Tomb at Bursa. It is even seen at Istanbul in the Çinili Köşk (Ünsal, 1959).

Simplicity in the ornamentation and a balance between blank and decorated surfaces were preferred. For instance, as regards madrasah, the simplified ornamentations are focused on crown gates, porticos surround the courtyard, lecture hall, student cells, and the pediments of doors and windows. Three types of ornamentations are preferred: stone embellishment; brick-stone wall embellishment; and glazed tile, glazed-mosaic and glazed brick embellishments. These embellishments are floral and geometric figures. Besides, inscriptions are also preferred for ornamentations (Figure 2.27) (Demiralp, 1999).

Figure 2.27. The photo showing the embellishments with inscriptions on the window pediment of the lecture hall; and with the composition of simplified palmette and rumi figures on the key stone of the arch in Hacı Halil Pasha Madrasa in Amasya. (Source. MoCT, 2012a)

To sum up, all of these buildings in Turkey represent the tangible heritage of the early Ottoman Architecture. However, their non-renewable and fragile character faces the risk of irreversible damages and losses. They are increasingly exposed to both natural and human-induced hazards, such as earthquakes, floods, fire, climate change, armed conflicts, unsustainable tourism, vandalism, false remedial activities or accelerating urbanization *etc.* in the course of time. Some of them destroy permanently and have deleterious effects on these irreplaceable heritage assets. Countering them effectively requires identifying and understanding these hazards and their root causes. Therefore, in the following sections the natural and human-induced hazards; and among these hazards, impacts of climate change, which is increasingly posing threats to the protection of tangible heritage, are given in brief.

2.2. Impacts of Hazards on Tangible Cultural Heritage

Hazard is "any phenomenon, substance or situation, which has the potential to cause disruption or damage to infrastructure and services, people, their property and their environment" (Abarquez and Murshed, 2004, 6). Hazards can be explained under two main title: natural and human-induced hazards. Although natural hazards are old as universe, human-induced hazards, which have led to considerable changes in the natural environment especially after the industrial revolution, are of recent origin (Table 2.3) (UNESCO/ ICCROM / ICOMOS / IUCN, 2010).

Table 2.3. Selected examples among the most common hazards that may cause disasters
(Source. WMO; ICSU, 2007 in UNESCO / ICCROM / ICOMOS / IUCN, 2010)

<table>
<tr><th colspan="2">TYPOLOGY OF HAZARDS</th></tr>
<tr><td>METEOROLOGICAL</td><td>a. storm [high precipitation; strong wind; cyclone/ hurricane/ typhoon; tornado/hail storm; ice storm; dust storm; wave action (at sea / lake)]
b. fire induced by lightning / static, spontaneous coal /peat combustion
c. drought
d. heatwave
e. high sea-surface temperature</td></tr>
<tr><td>HYDROLOGICAL</td><td>a. flood (precipitation flood – inadequate drainage or infiltration; flash flood; river or lake flood; mass movement dam; storm surge)
b. tsunami</td></tr>
<tr><td>BIOLOGICAL</td><td>a. epidemics (human, animal, or plant and human-animal transferable diseases)
b. pest infestations
c. algal blooms
d. rapidly spreading weeds or nuisance plants
e. coral bleaching event</td></tr>
<tr><td>HUMAN-INDUCED</td><td>a. fire (land clearance, arson, accident, drainage of peat soils)
b. pollution (health, e.g. food poisoning, disease)
i. nuclear/ radioactive accident
ii. waste mass movement (unstable spoil heap)
iii. air pollution toxic fire or explosion or leak
iv. water pollution failure or leak / spill → wildlife, plant mortality, disease
c. Violence- and conflict-induced human and wildlife mortality and ecosystem destruction
i. disease
ii. human wildlife / conflict
iii. large-scale population dislocation or relocation
iv. illegal activities and violence, e.g. illegal drug trade
v. warfare
d. Gas flaring
e. Infrastructure failure
i. water pollution (algal blooms, coral bleaching, pest infestation, disease epidemic)
ii. dam or levee failure, flood
iii. coastal protection (wall, artificial beach) failure flood and erosion
iv. mass movement (e.g. waste slumps)
f. Mining-induced
i. seismic activity and mass movement
ii. volcanic activity and mud volcano
iii. mass movement
iv. climate change and rainfall variation, e.g. mountain-top mining</td></tr>
<tr><td>CLIMATE CHANGE</td><td>a. sea-level rise
b. melting permafrost
c. rainfall pattern change
d. increased storm severity or frequency
e. desertification</td></tr>
</table>

The human-induced hazards have reached such a high level that their physical, chemical or biological effects have shown similar signs in a short term compared to the long term effects of natural hazards. Additionally, even if not enough power to cause natural disasters, some natural phenomena may give hazardous character to human-made activities or can give disastrous character to human-made hazards (Joyanoyic, 1988). For instance, when building in flood-prone areas, felling trees, or constructing non-engineered structures without taking into account safety norms, natural phenomena trigger the underlying dangers of human activities (Table 2.4) (UNESCO / ICCROM / ICOMOS / IUCN, 2010).

Table 2.4. The relationships between natural and human-made hazards and their possible combined effects (indirect / secondary).
(Source. UNESCO / ICCROM / ICOMOS / IUCN, 2010)

	NATURAL	**HUMAN-MADE**	**INDIRECT / SECONDARY**
Meteorological	Hurricane Lightning Heavy precipitation		Flooding (coastal / rivers) Fire Mass movement
Hydrological (caused by high rainfall)	Flash flood Landslide / volcanic ash / lava / ice damming of a river Tsunami	Hydrological infrastructure failure (dams, levees, reservoirs, drainage systems) Coastal protection failure (sea walls)	Disease epidemic Pollution
Volcanic	Lava flows Pyroclastic flows Ash and block falls Gases	Mining-induced (e.g. mud volcano)	Lahars (mudflows) Landslides Tsunami Fire
Seismic	Faulting Transient shaking Permanent deformation (e.g. folds) Induced movement (liquefaction and mass movement)	Dam- and reservoir induced mass movement Mining-induced Explosion / nuclear induced	Mass movement Fire Flood
Mass movement (of snow, ice, rock, soil mud, etc.) (induced by slow-acting erosion or one of the above)	Falls Slumps Slides Flows	Unstable mining / construction waste spoil heaps	

The threats pointed out above often affect human beings, flora and fauna, landscapes, infrastructures and superstructures including tangible heritage. Tangible heritage, such as historic cities, cultural landscapes, monuments, archaeological sites, museums, artistic handcrafts, and cultural activities have always been threatened by the ravages of time, natural disasters and our own interventions. These threats are affecting with rapid or slow onset but with an increasing trend (Figure 2.28) (Will and Meier, 2007; and UN World Conference on Disaster Risk Reduction, 2015).

Figure 2.28. The main risk factors and their speed of affecting cultural heritage (Source. Canuti, Margottini, Fanti, and Bromhead, 2009)

The progressive loss of tangible heritage because of floods, landslides, storms, fire, earthquakes, the effects of climate change, civil unrest and other hazards has become a significant concern (UN World Conference on Disaster Risk Reduction, 2015). For instance, major loss of cultural heritage can occur due to landslides and similar phenomena (e.g. avalanches, mud flows, debris flows, rock falls). They create mostly irreparable damage to cultural heritage by causing dislocation from its original position, distortion, and partly overturn in many cases. Landslides are triggered by heavy rains and frequently accompanied by floods, earthquakes, erosion and human activities such as excavations at the bottom of a slope or surcharge at the top of a slope. As well as landslide, floods, which are the most frequent natural disaster with an increasing adverse impact especially in urbanized areas, can damage or even destroy historic buildings, infrastructure, cultural landscapes and gardens. Moveable cultural heritage is also under threat in many flood events. Floods cause damage and failures, which is difficult to remediate due to wetting of building materials. Building materials, which are affected by salt transport, can suffer long-term damage. Possibility of repair and protection of them mostly decreases or repairing the consequences can take a very long time and require enormous efforts. Chemical pollutants and biological infection are also part of the problems caused by flooding (Drdacky et al., 2007).

2.2.1. Types of Natural Hazards in Turkey

The number of the most widely recognized types of hazards is thirty-one in Turkey. The most prevalent types of natural hazards including storms (strong wind), flood and hail except earthquakes. Heat wave, landslide, rock fall and avalanche have also been recorded as notable natural hazards (GDF, 2011). A number of disasters due to meteorological hazards such as storms and heavy rain have been increasing in Turkey since 1995 (Figure 2.29). Between 1940 and 2000, the Black Sea, Mediterranean and West Anatolia were the most impacted parts of the country especially in March-July due to the natural disasters (Gökçe, Özden and Demir, 2008).

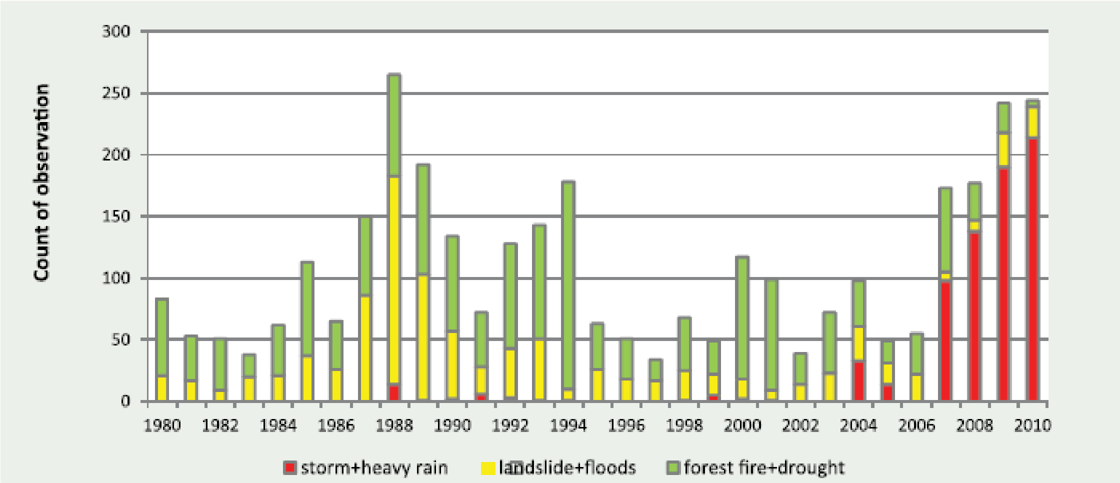


Figure 2.29. The graph shows the types and the number of disasters in Turkey between 1980 and 2010. A number of occurrence of storms associated by heavy rain has been increasing while a number of other types of disasters have been decreasing. [Source. Republic of Turkey Prime Ministry Disaster and Emergency Management Presidency (DEMP), 2011]

As knowledge about the characteristics and the impacts of hazards, which threat cultural heritage and present an added challenge for their conservation, is a prerequisite to prepare successful and appropriate risk management strategies, the following paragraphs focus on hazards (floods, landslides and sea level rise), which are multiplied and triggered by climate change, while recognizing the importance of the other hazards and their consequences.

Floods: In Turkey, a decrease trend in flooding in river basins has been observed due to an increase in the number of dams, stream improvement and rural to urban migration whereas an increasing number of flash floods in urban areas has been recorded due to incline trend in number of intense rainfalls induced by changing climate. The ratio of river flood events among all types of hydro-meteorological events is 33 % between 1967 and 1987 whereas this ratio falls to 14% between 1998 and 2008. Although there is a declining trend in the number of river flood events, the total number of events is 820 between 1975 and 2011 (Figure 2.30) [The Ministry of Environment and Urbanization (MoEU), 2013 and the Ministry of Forestry and Water Affairs (MoFWA), 2013].

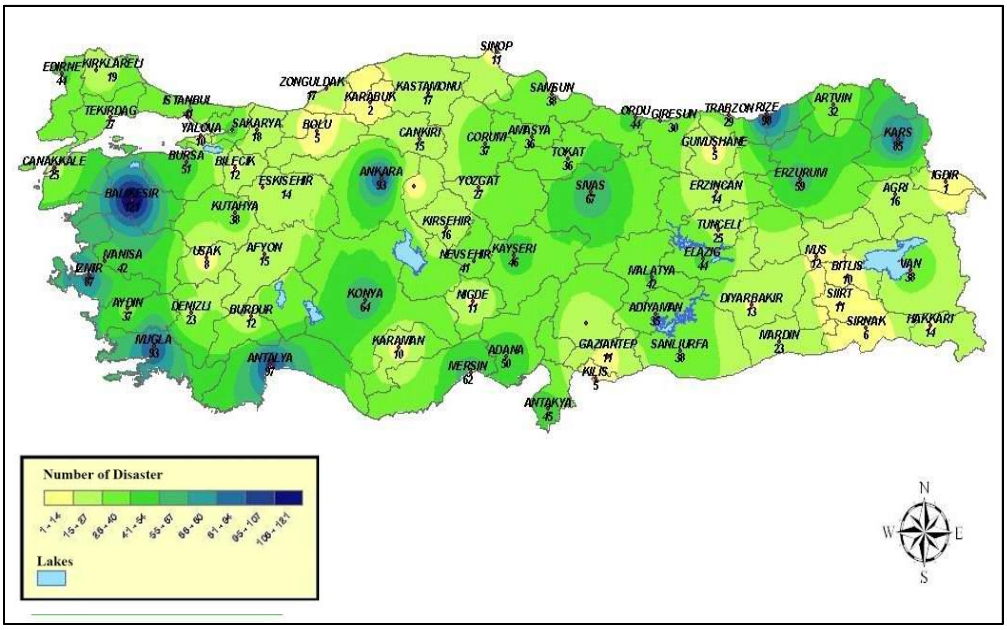


Figure 2.30. The map shows the number of disasters due to flooding, overflowing and heavy rain between 1940 and 2010
(Source. MoFWA, 2013)

As regards to flash flood, it is a very common and very hazardous phenomenon that associates with intense and prolonged rainstorms especially for coastal communities and major cities of Turkey (Kömüşcü and Çelik, 2012). Flash flood has been observed especially in March, April, June and July. Black Sea, Mediterranean and West Anatolia Regions have been severely affected by flash floods. Moreover, in recent decade, it has been observed that floods have occurred in areas that have rarely experienced or never had flash floods before. Therefore, although prevention programs have been successfully conducted since 1970 to reduce annual flood events, it is still necessary to implement new mitigation strategies in order to cope with combined effects of problems derived from urbanization and accelerated impacts of changing climate (MoFWA, 2013).

Landslide: Turkey is affected by a very large number of landslides widespread throughout its territory. It is one of the most destructive natural hazards. The disasters related with landslides in Turkey rank second following the earthquakes with respect to economic losses and casualties [General Directorate of Mineral Research and

Exploration (MTA), 2012]. One of the most landslide-prone regions is the West Black Sea Region in Turkey (Figure 2.31) (Gökçe *et al.* 2008).

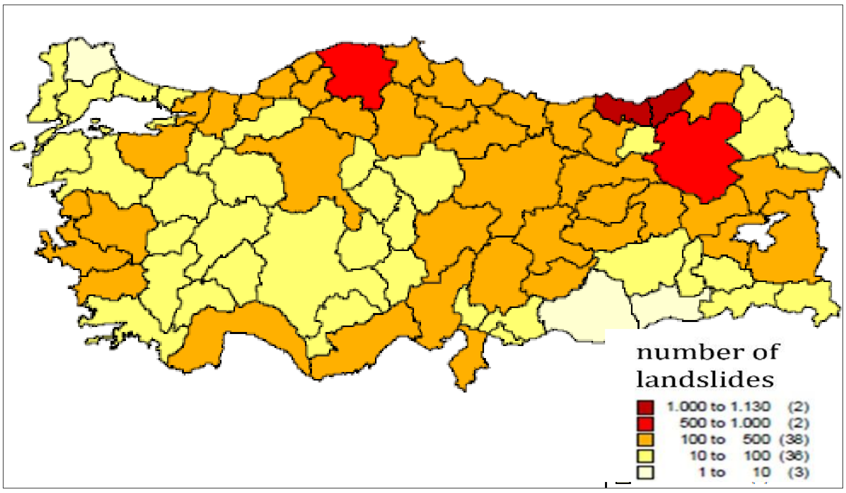


Figure 2.31. The map of the number of landslides sorted by cities between 1950 and 2008 indicating the cities in the West Black Sea Region as the most landslide-prone ones.
(Source. Gökçe *et al.* 2008)

Landslides are repetitive problems causing major disasters. The recovery efforts cannot eliminate disaster consequences even if they can be successful. Therefore, mechanical models and systems of monitoring of landslide processes should be elaborated for preservation of valuable historical monuments as well as reflecting the importance of preventive measures against natural disaster risks in the disaster protection policy and initiatives at both local and national level (Canuti, 2009). Within this context, in Turkey as the disasters arising from landslides are on the second rank, Landslide Inventory Mapping Project has been prepared to prevent or minimize natural disasters originated from mass movements. In the scope of this project, in order to present local, regional and national conditions, the maps on a 1:25.000 scale were digitized and integrated into Geological Database of Turkey. Inventory maps present geographic distributions, types and activities of mass movements (Figure 2.32).

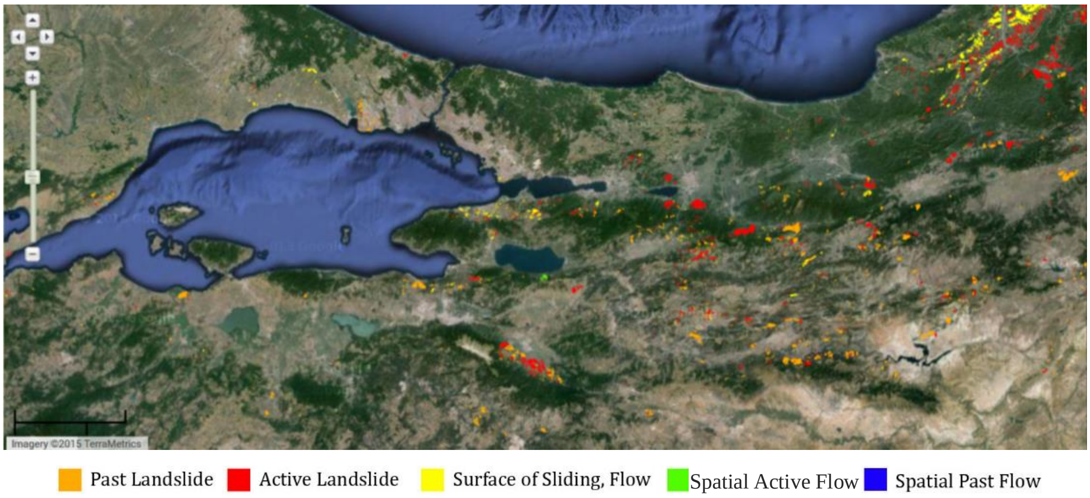


Figure 2.32. The inventory map including active and past landslides, active and past flow, and sliding in the southeastern of the Marmara Region.
(Source. MTA, 2012)

Sea Level Rise: The sea level rise (SLR) is a problem in many countries around the world, especially for those which have populated coastlines. As being a peninsula, SLR is also an issue for Turkey. Mediterranean Region is considered the most vulnerable coastal part of Europe with multiple potential impacts of SLR and low generic adaptive capacity. Among countries which have coastlines to Mediterranean Sea, Turkey is considered moderately vulnerable to SLR (MoFWA – former the Ministry of Environment and Forests, 2007; and Karaca and Nicholls, 2008). Several coastal areas, especially the low lying deltaic plains (Figure 2.33), are highly vulnerable according to recent international, national and local scale investigations. However, more detailed site specific studies of different coastal regions of Turkey are necessary to understand the impacts of SLR on the coastal environment induced by climate change (Karaca and Nicholls, 2008; Demirkesen *et al.* 2008; and Kuleli, 2010).

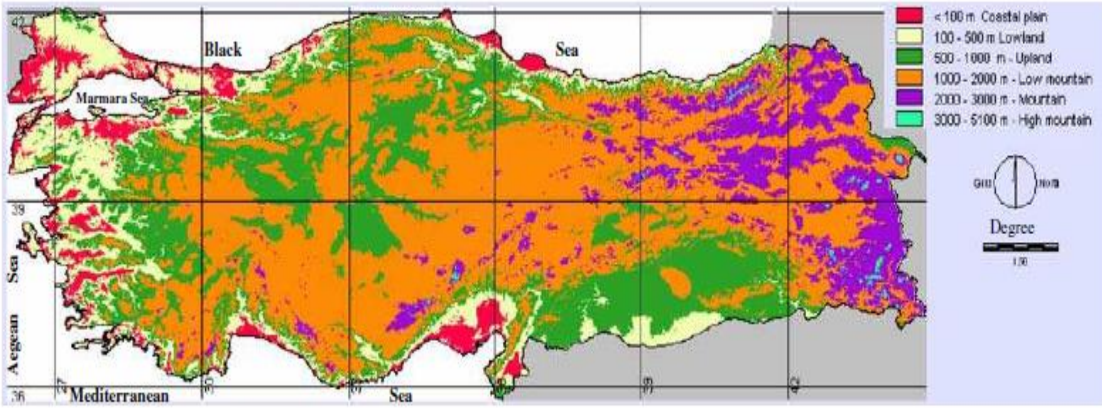


Figure 2.33. The digital elevation model presenting the elevation classes of Turkey (Source. Demirkesen *et al., 2*008)

According to a study by Bozkurt *et al.* (2011), the occurrence of flash floods and extreme precipitation events will probably increase due to warmer summers and sea surface temperatures of the seas surrounding Turkey in autumn (Bozkurt *et al.*, 2011). Besides erosion and inundation, upward and landward movements of the zones which are at risk of flooding are also the result of any rise in sea level (Nicholls *et al.*, 1999).

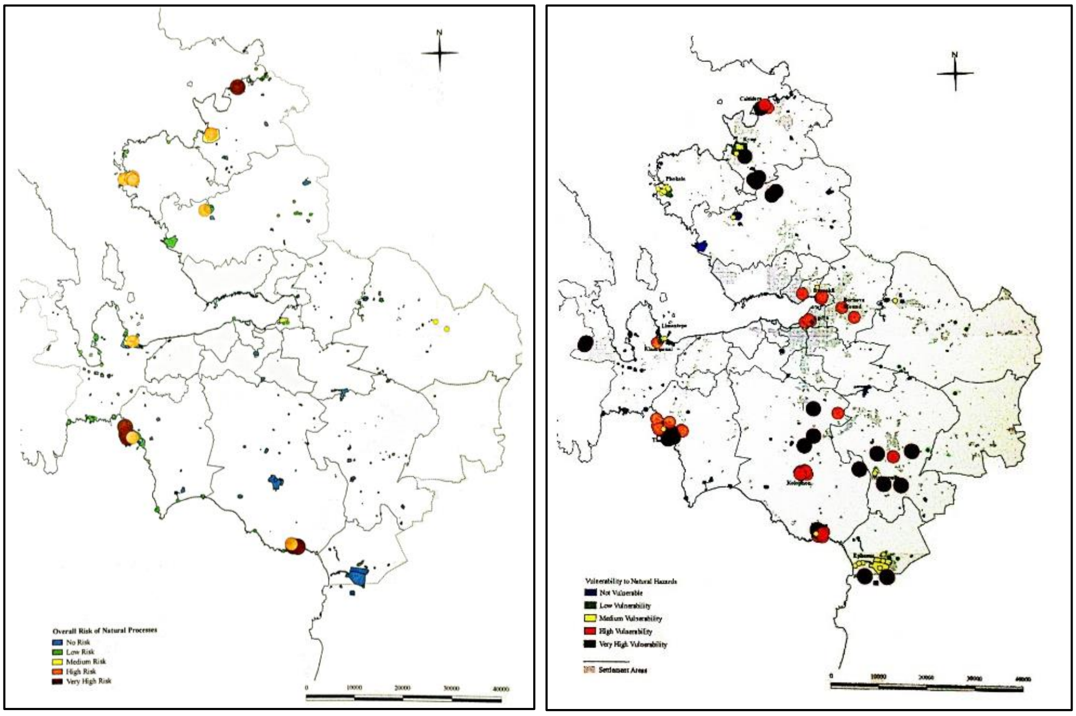
In this context, most of the studies indicate that no systematic research has been conducted for the long-lasting trends in sea level changes in Turkey. Therefore, local scenarios of SLR based on the long-term collection of tide-gauge data need improving. The vulnerability degree of cultural heritage in the coastlines of Turkey should be included and evaluated in further more detailed site specific studies.

To conclude, while preparing a disaster inventory, data on human and economic losses are taken into consideration. Disasters are included in the database according to several criteria of the Emergency Disasters Database (EM-DAT). They need to fulfill at least one of the criteria which are given below (Tschoegl *et al.,* 2006):

- the number of dead people is greater than or equal to 10
- affecting a hundred or more people
- declaring national aid
- declaring international aid

Therefore, the available maps of disasters presented above were prepared in accordance with hazards which have been recorded by taking into consideration the above mentioned criteria that differ from those related to the protection of cultural heritage. They mostly omit or do not explicitly include cultural heritage. They often result in a good coverage of the territory, but in a lack of relevant information in the context of cultural heritage. Maps obtained for different purposes often become unsuccessful to fulfill the specific data needed to develop management plans, recovery initiatives, *etc.* for cultural heritage. For instance, in the case of flood risk maps, water depth and flow velocity are of great value for protection of cultural heritage. However, these maps usually display only the areas affected by a given flood event and the predicted water depth which is approximately provided. Besides, there is usually no information about flow velocity. As a result, they have not been prepared to comply with conservation principles and requirements (Drdacky *et al.*, 2007).

Within this framework, in Turkey, in recent years several research initiatives have been conducted to develop methodologies for assessing risks deriving from not only natural hazards but also human induced hazards and understanding vulnerabilities of cultural heritage at territorial scale (Figure 2.34). The development of this kind of methodologies is necessary to help heritage managers and decision makers evaluate the whole picture because it is difficult to determine the percentage of loss of cultural heritage caused by any one type of disaster. Moreover, in the time of climate change, people who work in the heritage conservation sectors at national and local levels may face uncertainty about how to adapt changes. Therefore, it is important to develop methodologies and create databases, which become a main source of information to develop heritage management strategies and focus on reducing vulnerability instead of precise impact assessment.



(a) (b)

Figure 2.34. The maps showing (a) overall risk of natural processes affecting archeological heritage; and (b) vulnerability to natural hazards in İzmir-Turkey. (Source. Yıldırım Esen, 2014)

2.2.2. Climate Change as a Potential Hazard

Climate change[5] has been included in the main types of hazards that may cause disasters in the publications of UNESCO (2010), and it has also emerged as one of the most devastating threats to tangible heritage. In addition to being accepted as one of the main types of hazards, climate change may become the triggering mechanism and / or may have in multiplier effect on the frequency and intensity of several natural hazards; and on significant underlying risk factors. Hence, it affects vulnerability of cultural heritage against certain types of natural hazards. In other words, capacity and performance of a building to resist disasters may be severely reduced. For instance,

[5] Climate change refers to “a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and / or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity” (IPCC, 2007).

historic buildings may be affected by any increase in soil moisture that increases their vulnerability[6] to natural hazards, such as earthquakes and floods (UNESCO/ ICCROM / ICOMOS / IUCN, 2010).

Apart from sudden catastrophic impacts, climate change manifests itself via gradual, cumulative processes, such as deterioration processes of the fabric of heritage properties. The decay is mostly caused by a range of factors (physical, chemical and biological), which are determined by the site-specific (local) conditions, such as wind (erosion, vibration), relative humidity (RH), temperature, radiation / light, dust, water, erosion and siltation, micro-organisms. These factors have probably been affecting the property right from its creation. However, the local climatic conditions usually have low impact over a long duration and historical buildings have survived centuries under these specific climatic conditions. Even the smallest of changes in climatic conditions can magnify the impact of deterioration factors; for instance heritage properties may begin to deteriorate at an accelerated pace once these climatic conditions begin to fluctuate due to changing climate parameters. Climate change may worsen some factors and lessen others (UNESCO, 2012b). For instance, interaction between the changes in temperature and moisture over the century lead to changes in the distribution of pests (migration of pests in altitudes and latitudes or spread of existing and new species of pests) and may accelerate the activity of the organisms, such as bacteria, fungi, lichen, insects, *etc.* (English Heritage, 2008). Biological impact of the organisms on timber and other organic building materials is, therefore, a type of damage that will be affected by climate change (Colette, 2007b). Over the century, wooden buildings and building elements will be exposed to an increased risk of rot and pests, while all kinds of buildings will be under the risk of faster decomposition derived from biological growth (Kaslegard, 2011). Besides, changes in atmospheric moisture may lead to risks of flooding and soil instability (ground heave and subsidence); differentiation of rain-fall patterns, water-table levels, soil chemistry, groundwater, humidity cycles; and increases in the wetness time of materials and salt

[6] "Vulnerability is the susceptibility or exposure of cultural property to the hazard. Whereas a hazard is the external source of a disaster, vulnerability is the inherent weakness of the heritage property (due to its location or its specific characteristics). Disaster risk is a product of hazard and vulnerability. It is important to bear in mind that hazards such as earthquakes can trigger disasters although they are not disasters in themselves" (UNESCO *et al*, 2010, 8).

chlorides. Therefore, building materials which are not designed to withstand prolonged immersion are threatened by the invariably dirty water of flooding and the erosive character of rapid flowing water. Furthermore, as historic buildings are more porous and have a greater contact with the ground, they draw water from the ground into their structures. During the drying period, they lose water to the environment by surface evaporation, which causes corrosion or salt weathering as secondary effects (Colette, 2007a). The summary of changes in climate parameters and their consequences from the cultural heritage point of view are presented in Table 2.5.

Table 2.5. Principal climate change risks and related impacts on cultural heritage (Source. UNESCO, 2007)

CLIMATE INDICATOR	CLIMATE CHANGE RISK	PHYSICAL IMPACTS ON CULTURAL HERITAGE
Atmospheric moisture change	* Flooding (sea, river) * Intense rainfall * Changes in water table levels * Changes in soil chemistry * Ground water changes * Changes in humidity cycles * Increase in time of wetness Sea salt chlorides	* pH changes to buried archaeological evidence * Loss of stratigraphic integrity due to cracking and heaving from changes in sediment moisture * Data loss preserved in waterlogged / anaerobic / anoxic conditions *Eutrophication accelerating microbial decomposition of organics *Physical changes to porous building materials and finishes due to rising damp *Damage due to faulty or inadequate water disposal systems; historic rainwater goods not capable of handling heavy rain and often difficult to access, maintain, and adjust * Crystallization and dissolution of salts caused by wetting and drying affecting standing structures, archaeology, wall paintings, frescos and other decorated surfaces * Erosion of inorganic and organic materials due to flood waters * Biological attack of organic materials by insects, moulds, fungi, invasive species such as termites * Subsoil instability, ground heave and subsidence * Relative humidity cycles/shock causing splitting, cracking, flaking and dusting of materials and surfaces * Corrosion of metals * Other combined effects eg. increase in moisture combined with fertilizers and pesticides

Table 2.5 cont'd

Temperature change	* Diurnal, seasonal, extreme events (heat waves, snow loading) * Changes in freeze-thaw and ice storms, and increase in wet frost	* Deterioration of facades due to thermal stress * Freeze-thaw/frost damage * Damage inside brick, stone, ceramics that has got wet and frozen within material before drying * Biochemical deterioration *Changes in 'fitness for purpose' of some structures. For example overheating of the interior of buildings can lead to inappropriate alterations to the historic fabric due to the introduction of engineered solutions *Inappropriate adaptation to allow structures to remain in use
Sea level rises	* Coastal flooding * Sea water incursion	* Coastal erosion/loss *Intermittent introduction of large masses of 'strange' water to the site, which may disturb the metastable equilibrium between artefacts and soil * Permanent submersion of low lying areas
Wind	* Wind-driven rain * Wind-transported salt * Wind-driven sand * Winds, gusts and changes in direction	* Penetrative moisture into porous cultural heritage materials *Static and dynamic loading of historic or archaeological structures *Structural damage and collapse *Deterioration of surfaces due to erosion
Desertification	* Drought * Heat waves * Fall in water table	*Erosion *Salt weathering *Abandonment and collapse
Climate and pollution acting together	* pH precipitation * Changes in deposition of pollutants	*Stone recession by dissolution of carbonates *Blackening of materials *Corrosion of metals *Influence of bio-colonization
Climate and biological effects	* Proliferation of invasive species * Spread of existing and new species of insects (eg. termites) * Increase in mould growth * Changes to lichen colonies on buildings * Decline of original plant materials	*Collapse of structural timber and timber finishes *Reduction in availability of native species for repair and maintenance of buildings *Changes in the natural heritage values of cultural heritage sites *Changes in appearance of landscapes

In brief, having been designed to take into account the local climatic conditions; and having survived for centuries thanks to their compatibility with these conditions mean there is a connection between the stability of tangible heritage assets and their environment and surroundings. Therefore, interaction between the changes in temperature and moisture lead to changes in physical fabric of the assets, especially when phase transitions are under consideration. Although several impacts of climate change can be subtle and are predicted to occur over a long period of time, some climate change parameters, such as freeze-thaw, thermal shock temperature, humidity cycles, time of wetness and wind driven rain *etc.*, can cause changes by large amounts over a short period of time.

Within the light of these discussions, and addressing above-mentioned issues, the following part of this chapter introduces the scope of and current debate on climate change, and the anticipated changes in climate parameters that affect the deterioration mechanisms of physical fabric of the tangible heritage assets.

Climate Change is global in nature and has been variable over the past two decades. A credible body of scientific evidence shows that climate change is occurring, and it leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events (IPCC, 2012).

Climate change studies are based on: the physical understanding of the climate system, trends in observed climates, and projections from computer models of the climate. The computer models require inputs of future greenhouse gas emissions and global socio-economic scenarios to make analyses of the future risks and impacts of climate change. The models are mathematical formulation of the effects of all the key processes operating in the climate system; such as: atmosphere, ocean, land surface, cryosphere and biosphere; and factors that influence the system such as greenhouse gas emissions and future socio-economic patterns of land use (Sabbioni *et al*, 2006).

Long-term emission scenarios have been developed by the Intergovernmental Panel on Climate Change (IPCC) in order to assist climate change analysis, including climate modeling and the assessment of impacts, adaptation and mitigation by giving alternative description of how the future might unfold (IPCC, 2007). These scenarios are often based on various sets of storylines (B1, A1B, A2, etc.) which are explained in the Special Report on Emission Scenarios (SRES) of IPCC. Each storyline describes a different world evolving through the 21st century, with different key relationships and driving forces, such as population growth; social, economic and technological developments; environmental sustainability; settlement patterns; land-use and urbanization. Corresponding trajectories of greenhouse gas emissions may be deduced from these storylines. These scenarios extend to the year 2100 (IPCC, 2000 and The World Bank Group, 2015).

A wide range of future emissions and drivers' scenarios vary the degree of climate change considerably. This variety illustrates the uncertainties that are related to the process of climate change. As the climate system is inherently chaotic, its predictability is inherently limited. Although climate models cannot predict with certainty how quickly or to what extent the earth's climate will change in the next few decades, even now some climatic trends are emerging: "warming of the climate system is unequivocal" (IPCC, 2007b). Moreover, there are some robust patterns of change in precipitation, sea level, and frequency and magnitude of extreme events which take a toll on buildings and infrastructures, as well as ecological systems and human life. A broad range of human and natural systems are, therefore, facing with the hazardous results of the changes in climate as one of the most critical and the major environmental challenges of our time (Heymann, 2007).

The following section provides a snapshot of recent scientific literature on analyses of likely impacts and risks of climate change within this century by looking from both global and Turkey's perspective.

2.2.2.1. A Review of Global Climate Change

IPCC has concluded that the "scientific evidence for warming of the climate system is unequivocal" (IPCC, 2007a). "Since the 1950s, many of the observed changes are unprecedented over decades to millennia" (IPCC, 2013, 4). The atmosphere and ocean are warming. Four of the world's leading climate research centers have agreed that a warming trend over the last century with the 10 hottest years on record since 1998 [National Aeronautics and Space Administration (NASA), 2011; UK-Met Office, 2011; Japan Meteorological Agency (JMA), 2011; and National Oceanic and Atmospheric Administration (NOAA), 2013]. One of the dominant cause of the observed warming since the mid-20th century is the anthropogenic greenhouse gas emissions (GHGs) which have been steadily rising since the pre-industrial era.

Economic and population growth are the main drivers of increasing GHGs which are now higher than ever. The average annual concentration of carbon dioxide (CO2) in the atmosphere, which is the chief greenhouse gas that results from human activities, is 398.55 parts per million (ppm) based on data from Mauna Loa Observatory in Hawaii, at which measurements first began. The monthly average of CO2 is 403.26 ppm for April 2015. In 1959 the first year with a full year of instrument data, it was approximately 315 ppm. [IPCC, 2014; and NOAA-Earth System Research Laboratory (ESRL), 2014]. Current projections indicate an incline for the CO_2 concentration to rise to as much as 500–1000 ppm by the year 2100 (IPCC 2007).

As it is stated in the last report of the IPCC, "Climate change will amplify existing risks and create new risks for natural and human systems." Climate change-related risks have been observing on natural and human systems all over the world. More heat waves, floods (due to the heavier precipitation), droughts, more damaging hurricanes and tropical cyclones, rising sea level and coastal erosion *etc.* can be given as examples of these risks (IPCC, 2014).

In brief, according to the last Synthesis Report that was released in November 2014:

- "Human influence on the climate system is clear";
- "The more we disrupt our climate, the more we risk severe, pervasive and irreversible impacts"; and
- "We have the means to limit climate change and build a more prosperous, sustainable future" (IPCC, 2014).

a) Observations

In this section, the changes in climate systems and state of climate, especially climate extremes, in 2014 are given very briefly, as examining, finding and defining changes in climate systems lies beyond the scope of this study. Nevertheless, the outcomes of several datasets focusing on monitoring long-term changes in climate systems from the view point of heritage assets are given in the following sections in detail.

Although it is important to monitor and understand essential climate variables which are reflected as monthly and annual means, monitoring long term changes in extremes, which have a wide range of impacts on society, infrastructures and ecosystems, has come to the forefront during the recent decades (Blunden and Arndt, 2014). Several datasets have been developed to monitor these extremes, some of which right alongside climate anomalies and events for the year 2014 are given below very briefly according to the large range of available estimates.

- In terms of temperature extremes, both at the Earth's surface and through the troposphere, the year 2014 is globally ranked at top on records which were started to record in the mid to late 1800s.
- Due to being above the twentieth century annually-averaged temperature which is 13.9 °C across global land and ocean surfaces, the year 2014 has become the 38th consecutive year since 1977. The annually-averaged temperature was recorded 0.69 °C higher than the average of the last century.
- 9 of the 10 warmest years including 2014 have been recorded during the 21st century. Only the year 1998 (in 20th century) is the fourth warmest year in the 135-year period of record.
- The fourth highest annual value on record in terms of global average land surface temperature was 2014. It was recorded as 1 °C higher than the average during the 20th century average which is 8.5 °C.
- Global annually-averaged ocean temperature in 2014 is higher than the 20th century average.
- Since the early 20th century, the rate of global mean sea level has likely continued to rise. The rate of the rise has confidentially been above the mean rate during the previous two millennia. In early 2014, global mean sea level has reached a record high in line with the upward trend of 3.2 ± 0.4 mm/yr. over the past two decades (1993 to 2014).
- Due to being near average global precipitation, the year 2014 is the third consecutive year in terms of measurement of precipitation at land-based stations around the globe. It was also recorded 0.52 mm below the 1961–1990 average of 1.033 mm.
- 2014 has been marked by flooding around the world (e.g. more than two million people were affected by floods in May in Serbia, Bosnia-Herzegovina

and Croatia. Over 250% of the monthly average rainfall recorded in Southern parts of the Balkan Peninsula and over 500% of normal in parts of Turkey in September.)

- Droughts (e.g. a state of drought disaster was declared in the North-West Province of South Africa, which lasted from September to January. In November 2014, U.S. declared the category of drought as most severe, as large areas of the western U.S. were experienced exceptional drought with areas of California, Nevada and Texas received less than 40% of the 1961-1990 average rainfall.); heavy snow falls (e.g. two heavy snowfall events were experienced in the Pacific side of northern and eastern Japan in February. In mid-November U.S. experienced exceptional cold which triggered a lake-effect snow storm and more than 127 cm of snow fell in a 24-hour period.) and a below average number of tropical storms (e.g. although it was below average, the number of storms exceeded the 67 storms recorded in 2010 which is the lowest total in the modern satellite era.) were the other extreme events recorded globally in 2014.
- The other dramatic indicator of climate change is Arctic sea ice extent which has declined by over 4% per decade since 1979. It is the year when satellite measurements began. 2014 was below the long term mean that made the year the sixth lowest on record [IPCC, 2014; NASA, 2015; NOAA - National Climatic Data Center (NCDC), 2015; Met Office, 2015; World Meteorological Organization (WMO), 2014; and Kovats, 2014].

b) Projections

It is highlighted that although fluctuations in average temperatures from year to year will be expected, a long-term rise in global temperatures is being triggered by the continued increased in greenhouse gas levels in the atmosphere. This means that it is not expected that each successive year will be warmer than the year before. However, each successive decade is expected to be warmer than previous one due to continued emissions of greenhouse gases which will cause further changes in all components of the climate system (NASA, 2014 and IPCC, 2014). As the general conclusion of the recent studies indicates, the increase in global temperature is accelerating the hydrological cycle and altering marine systems, which lead changes in precipitation patterns. In other words, temperature and precipitation changes are closely associated with hydro-meteorological hazards, and exacerbate their states, for instance, increases in intense rainfall events; rising sea levels; decreases in the duration of snow season, snow cover, snow depth and sea ice; more frequent and intense heat waves, cold spells, drought; possible changes in floods, including flash floods, and landslides and soil erosion (IPCC, 2007 and IPCC, 2012). Individually and / or collectively, these changes pose risks for a wide range of human and environmental systems. The risks may vary by sub-regions and localities, but in general the followings are the most remarkable projected changes which are based on a range of emissions scenarios:

- By the end of the 21st century, substantial warming in temperature extremes is projected. An additional warming of 1.1ºC to 6.4ºC is anticipated. It is virtually certain that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur at the global scale. Warming is and will be greatest over land areas and higher latitudes.
- It is likely that there will be an increase in the frequency of heavy precipitation or the proportion of total rainfall from heavy falls over many areas of the globe such as particularly in the high latitudes and tropical regions, and in winter in the northern mid-latitudes. On the other hand, due to reduced precipitation and/or increased evapotranspiration, it is expected with medium confidence that droughts will intensify and be prolonged in some seasons and areas, such as southern Europe and the Mediterranean region.
- Severe drought will lead to an increase in forest fires.
- It is likely that the frequency of heavy precipitation, heavy rainfalls associated with tropical cyclones, and average tropical cyclone maximum wind speed will increase during this century in many regions of the world.
- More and stronger hurricanes, as well as commensurate flooding in the aftermath are generated by increasingly warm ocean surface temperature.
- Changes in heat waves, glacial retreat, and/or permafrost degradation will affect high mountain phenomena such as slope instabilities, movements of mass and glacial lake outburst floods.

- Possible changes in floods and landslides are also expected due to greater intensity of wind and rain (Westphal, 2008; Pollner, Kryspin-Watson and Nieuwejaar, 2010; and IPCC, 2012).
- Increase in global mean sea level will continue during the 21st century. Increase in ocean warming and loss of mass from glaciers and ice sheets will very likely lead to accelerate the rate of sea level rise in comparison the rate during 1971 to 2010 (IPCC, 2014).

2.2.2.2. A Review of Climate Change in Turkey

Turkey lies between latitudes 36-42°N and adjacent to the Mediterranean Sea. It may be expected to have a Mediterranean climate; however, apart from the southern and western coastal areas, the rest of the country has varied climate due to a number of factors make the climate more complex. Diverse nature of the landscape, extremely varied topography, an inland sea (the Black Sea) to the north, the existence of the mountains that run parallel to the north coast, and the vast Russian plain which acts as a close source of very cold air in winter affect the climate of Turkey. Moreover, in contrast with the north part, the east of Turkey is next to Syria and the Middle East where summers are very hot, and the southern coastline is just 500 km far away from the hot continent of Africa. Most of Turkey located on high plateau. While the coastal areas enjoy milder climates, the inland Anatolian plateau experiences extremes of hot summers and cold winters with limited rainfall. Towards to the east, the terrain becomes increasingly mountainous. The terrain is mostly hilly even in the lower-lying west. All these factors result in significant differences in climatic conditions from one region to the other (Met Office, 2011, and Sensoy, Demircan, Ulupınar and Balta, 2008).

Climate change models predict that due to locating in the Mediterranean basin, Turkey is one of most vulnerable countries to climate change and experiencing a range of climate changes. Climate change has already turned the heat on forest, water and land resources of Turkey by leading to changes in the frequency and intension of droughts, floods and extreme weather conditions [Turkish Ministry of Development (MoD), 2012].

According to the Climate Change Performance Index (CCPI) (2014) which demonstrates the main regional differences in climate protection performance within 58 countries, Turkey's national climate experts accept that Turkey does not have a national strategic planning policy to directly address climate change. It has difficulties while implementing most policies that are in place. Its fossil fuel industry is increasing rapidly in the energy sector which is the most carbon intensive sector. Therefore, it ranks 51st in the overall countries, i.e. in the 'very poor' grade group (Burck, Marten and Bals, 2014). It is understood that Turkey has a long way to examine the impacts of climate change and adapt itself to the changing situations. There is still a gap in publishing updated results of research on climate change in Turkey. Therefore, the following sections include the recent observations of and projected changes in climate of Turkey until the year 2013.

a) Observations

Turkey has already been vulnerable to current climate variability. The last century has been characterized by overall warming with altered precipitation patterns leading to wetter winters, drier summers and increased frequency of extreme and unpredictable weather including heavy rain and storm events. Observations and highlights in climate system are summarized in the following paragraphs.

Temperature: According to results of the Turkish State Meteorological Service's study, which covers the period from 1971 to 2004 and 100 measurement stations, at most stations, maximum of maximum, minimum of maximum, maximum of minimum and minimum of minimum temperatures have increased. There is an increasing trend on the numbers of summer days and tropical nights all over Turkey whereas a decreasing trend is observed on the number of ice days and frost days. Summer days have increased 59 days in 100 years. The number of warm days, whose average increasing is 26 days in 100 years, has been increasing all over Turkey. Warm nights have been also in increasing trends all over Turkey except Euphrates Basin. Thus, cool days and cool nights have been decreasing in most of the station. Warm spells have increased while cold spells have decreased. In most inland stations, diurnal temperature range has increased whereas it has decreased along coastal areas (Sensoy, Demircan and Alan, 2008).

In 2012, Turkey's average temperature, which is 14.2 °C, is higher than the average temperature of near past (1971-2000 / Reference Period) which is 13.2 °C (Figure 2.35). In general, in coastal parts of Turkey, Marmara Region, east part of Eastern Region, Niğde, Aksaray, Nevşehir and Karaman average annual temperature was increased by 2.0 °C. Throughout 2012, heat waves in 66 centers and cold waves in 33 centers were recorded. As regards seasons:

- A general decreasing trend in winter temperatures have been observed in the last five decades. Winter temperatures of 2012 are significantly below normal. Anomalies were sometimes down to -3 °C because a cold snap in early February followed a cold January with frequent outbreaks of arctic air. The lowest degree, which was -35 °C, was recorded in February in Erzurum.
- Except some areas in the western and eastern areas of Turkey, spring was warmer than normal.
- Summer was unusually warm. Conspicuous increase in summer temperature was observed across the country, particularly in the west and southwest. Maximum temperature above 40 °C was recorded at 40 measurement stations and the highest was 47 °C in July, in Ceylanpınarı. 31 stations broke their own record on maximum temperature. Tropical days (max. temperature > 30 °C) were experienced at 122 stations.
- Fall was warmer than normal. Anomalies in western Turkey exceeded +4°C [Mühr, *et al*., 2013; MoFWA - General Directorate of Meteorology (GDM), Department of Research, 2013 and Organization for Economic Co-operation and Development (OECD), 2013].

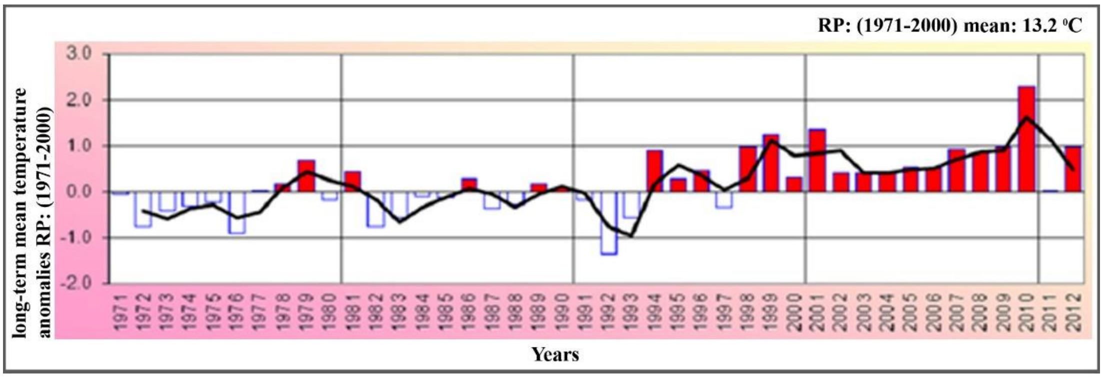


Figure 2.35. Annually mean temperature anomalies in Turkey (Source. T.R. Ministry of Forestry and Water Affairs - General Directorate of Meteorology, Department of Research, 2013)

Precipitation: According to results of the Turkish State Meteorological Service's study, which covers the period from 1971 to 2004 and 100 measurement stations, although there is a declining trend in mean annual precipitation at 30 stations which are located in the Aegean and inland Anatolia, simple daily intensity index has been increasing in most of the stations. As the number of days with heavy precipitations have been in an increasing trend especially in the Black Sea and Mediterranean Regions, actualization of extreme flood events has been also increasing. In most of the station except Eastern Marmara and South Anatolia Region, the maximum one-day and 5 days precipitation have increased. Consecutive dry days have decreased in some stations, Konya, Karapınar, Ceylanpınar and Iğdır which are suffering drought problem, whereas in Marmara, Aegean and the Black Sea Region, they are in the increase trend. On the other hand, the increase trend of consecutive wet days have been experienced especially in eastern parts of the Marmara and around Afyon, Burdur, Niğde, Sinop, Sivas, Rize, Kilis and Muş, whereas the decrease trend have been in the Aegean and Konya (Sensoy, Demircan and Alan, 2008).

Annual average precipitation is 642.8 mm in Turkey. Arid periods were experienced in 2006, 2007 and 2008 whereas positive trend was observed in rainfall anomalies from 2009 to 2012. The year 2009 was recorded as the wettest year with 804 mm rainfall while 2008 was the driest year with 506 mm rainfall. The uninterrupted order of the wettest and the driest years are noticeable.

In 2012, average precipitation, which is 643 mm, has increased by 16%. January, February, May, August and December were characterized by above-average rainfall, whereas March, April, June, July, September, October and November were below-average rainfall. Along the Mediterranean coast of Turkey, where rainfall in some places was almost twice the long-term average, were wetter than normal whereas most of the Eastern Region and east part of Black Sea Region got lesser precipitation than normal. As regards seasons:

- In winter, Eastern and Southern Regions of Turkey were wetter than normal.
- In spring, southeastern Turkey was slightly drier than normal. Upper lows in April and May led to a slight wet anomaly around the Bosporus.
- Summer was quite dry in Turkey.
- Among three fall months, in September and November, western Turkey was mostly dry and got well-below average rainfall. Precipitation was only 10% and 45% of normal, respectively (Mühr, *et al*., 2013 and MoFWA - GDM, Department of Research, 2013).

Highlight events observed in 2012 in Turkey are in below:

- An extreme cold spell which occurred in late January and early February ends with heavy snowfalls. The dust-darkened snow fell in February in Şırnak.
- The Aegean Sea and western Turkey were affected by a strong gale in mid-April.
- Heavy damage occurred and four people died due to gusty storm. Istanbul was particularly affected with gusts of 29 m/s. Six road construction workers in Elazığ died in a tornado on 9 April.
- In western and central Turkey, Saharan dust was observed on 18 April. Dust storms affected eastern Turkey on 30 May, 30 July, and 1 August.
- Mud rain fell on 1 August in Kars. Heavy rain caused flooding in several places in Turkey on 22–23 October (Mühr, *et al*., 2013).

In summary, as Turkey's Fifth National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) declares that present climate change effects include rising summer temperatures, reduced winter precipitation in the western provinces, greater frequency of droughts, land degradation, coastal erosion, and flooding. Large coherent pattern of changes are observed in warming across the country including maximum and minimum temperatures whereas much more mixed pattern of changes are observed in precipitation. Hydro-meteorological hazards, especially storms and floods, occur quite frequently and lead to serious loss of life and property in various regions in Turkey. It is expected that due to irregular, sudden and heavy precipitations and floods whose pattern are affected by changing climate, the landslide, erosion and long term drought rates will increase. Increased storms cause disasters such as hail, lightning, flash floods and urban flooding more influential (MoEU, 2013).

b) Projections

Turkey is highly vulnerable to possible climate change impacts as being a part of the southern belt of Mediterranean Europe. It is predicted that changes in climate systems continue and intensify over 21st century. These changes accelerate damaging impacts on Turkey's environment and infrastructure, with significant consequences for economy and society (MDG-F 1680 Project, 2012). In spite of several differences in magnitude of these changes, there is consistently good agreement over several issues within three different general circulation models called ECHAM5 (European Center-Hamburg, Version 5), CCSM3 (Community Climate System Model, Version 3) and HadCM3 (Hadley Centre Coupled Model, Version 3) over Turkey (MoEU, 2013) .The IPCC reports, and other national and international scientific modeling studies declare these changes as increasing summer temperatures, decreasing winter precipitation in western provinces, loss of surface water, increased frequency of droughts, land degradation, coastal erosion and floods. Turkey will get hotter, more arid and unstable in terms of precipitation patterns in near future. Among Europe and Central Asia (ECA) countries, Turkey is one of the countries which are the most exposed to increased climate extremes relative to today's natural variability. It is the third country in terms of having frangible and vulnerable socio-economic and ecological structures (Figure 2.36) (Baettig *et al.*, 2007; the World Bank, 2009; Kadıoğlu, 2012; MoEU, 2012; and IPCC, 2012).

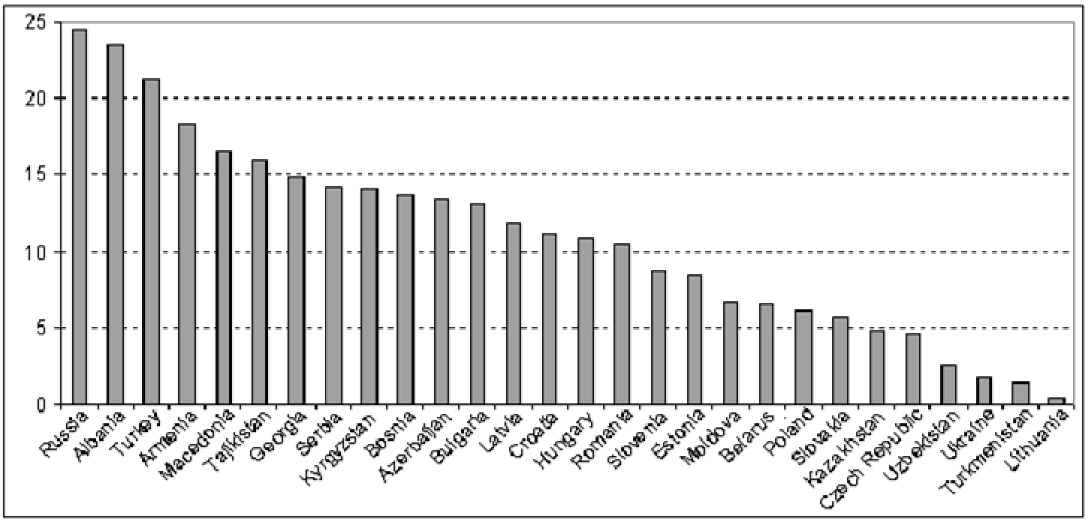


Figure 2.36. Turkey is together with Russia and Albania among ECA countries likely to experience the greatest increases in climate extremes by the end of the 21st century. The figure was prepared by combining the number of hot, dry and wet years; hot, dry and wet summers; and hot, dry and wet winters projected over the 2070-2100 period relative to the 1961-1990 period.
[Source. Baettig *et al*., 2007 (obtained from the World Bank, 2009)]

The following paragraphs summarize research on a range of projected changes in climate from the latest IPCC reports, and the literature with focus on projections for Turkey.

Summary of Temperature Change: According to the Coupled Model Intercomparison Project[7] (CMIP3) models, which have a good agreement over Turkey and the surrounding region in general, projected temperature increases are around 2.5-3^{0}C in the north, 3-3.5^{0}C over central and south-western regions, and 3.5-4.0^{0}C in the east of Turkey for 2100 compared with 1960-1990, based on a large number of climate models and the A1B emission scenario (Figure 2.37) (MET Office, 2011).

[7] Climate model output from simulations of the past, present and future climate was collected by the Program for Climate Model Diagnosis and Intercomparison (PCMDI); and this archived data constitutes phase 3 of the Coupled Model Intercomparison Project (CMIP3). This unprecedented collection of recent model output is commonly known as the CMIP3 multi-model dataset (MET Office, 2011). In recent years, the program provided leadership in managing the Coupled Model Intercomparison Project, Phase 5 (CMIP5) which was the basis for IPCC's Fifth Assessment Report on Climate Change (http://www-pcmdi.llnl.gov/).

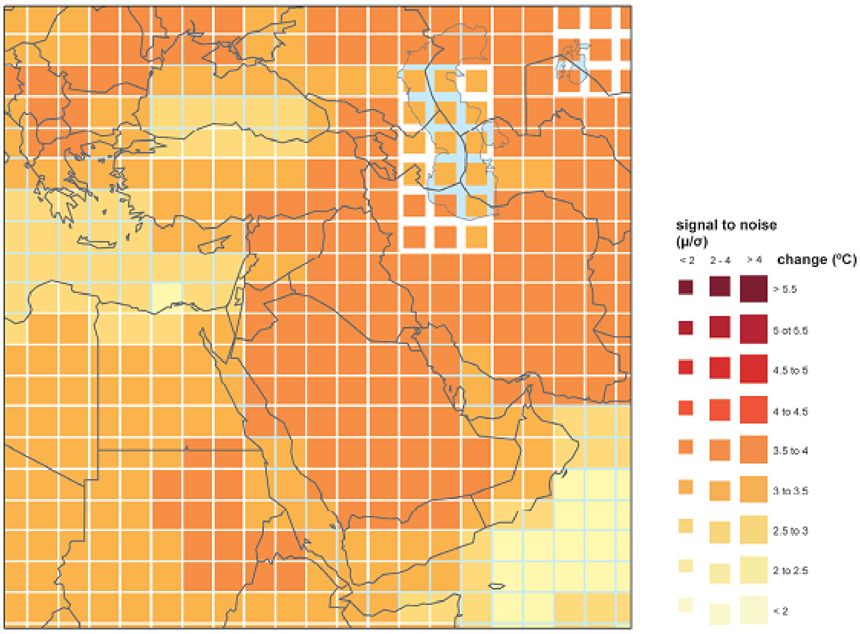


Figure 2.37. The map shows the percentage change in mean annual temperature by 2100 relative to baseline climate (1960-1990). Increase in temperatures in the future is projected by all of the models in the CMIP3 ensemble. (The size of each pixel shows the agreement level of the models over the magnitude of the increase) (Source. MET Office, 2011)

According the study of Önol and Unal (2012), a temperature increase of 2-5°C for the projected climate (2071- 2100; A2) compared with the reference climate (1961-1990; RF) was found by using the International Centre for Theoretical Physics (ICTP) Regional Climate Model Version 3 (RegCM3) with the A2 emission scenario (Önal and Unal, 2012). As regards to seasons (Figure 2.38):

- Summer: In the period RF with respect to A2, one of the most striking results is the highest temperature change which is 5 °C over the Marmara (MAR) and Aegean (AEG) regions in comparison with the other regions in summer. The highest estimated temperature increase is especially in the AEG Region with up to 6 °C.
- Winter: Winter temperature change which is just over 2 °C in the MAR and AEG Regions is smaller than all the other regions at the end of this century. The highest estimated temperature change in winter is in the eastern half of Turkey in the period RF with respect to A2 (Önal and Unal, 2012).

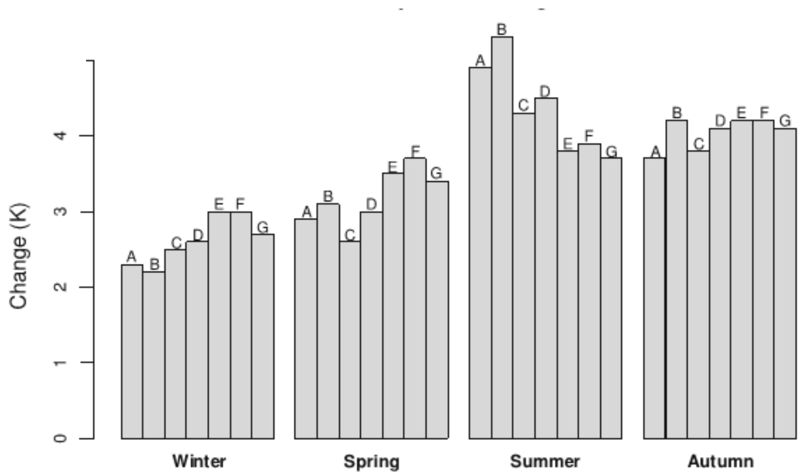


Figure 2.38. The graph shows a real mean temperature change (A2 minus RF) by seasons for the seven climatic regions of Turkey [A: MAR (the Marmara Region); B: AEG (the Aegean Region); C: BLS (the Black Sea Region); D: CEA (the Central Anatolia Region); E: ESA (the Eastern Anatolia Region); F: SEA (the Southeastern Anatolia region); G: MED (the Mediterranean Region)]
(Source. Önal and Unal, 2012)

According to the projections obtained using the ECHAM5 model with A2 scenario simulation, the increase in projected surface temperatures is less than 0.5 °C in winter and 1.0 °C in summer for the 2011-2040 period all over Turkey. In the second period (2041-2070), surface temperatures start to increase by about 1.5 °C in winter and about 2.4 °C in summer. By the end of the 21st century, significant increases in surface temperature are around 3.5 °C in winter and 6 °C in summer (Figure 2.39) (MoEU, 2013).

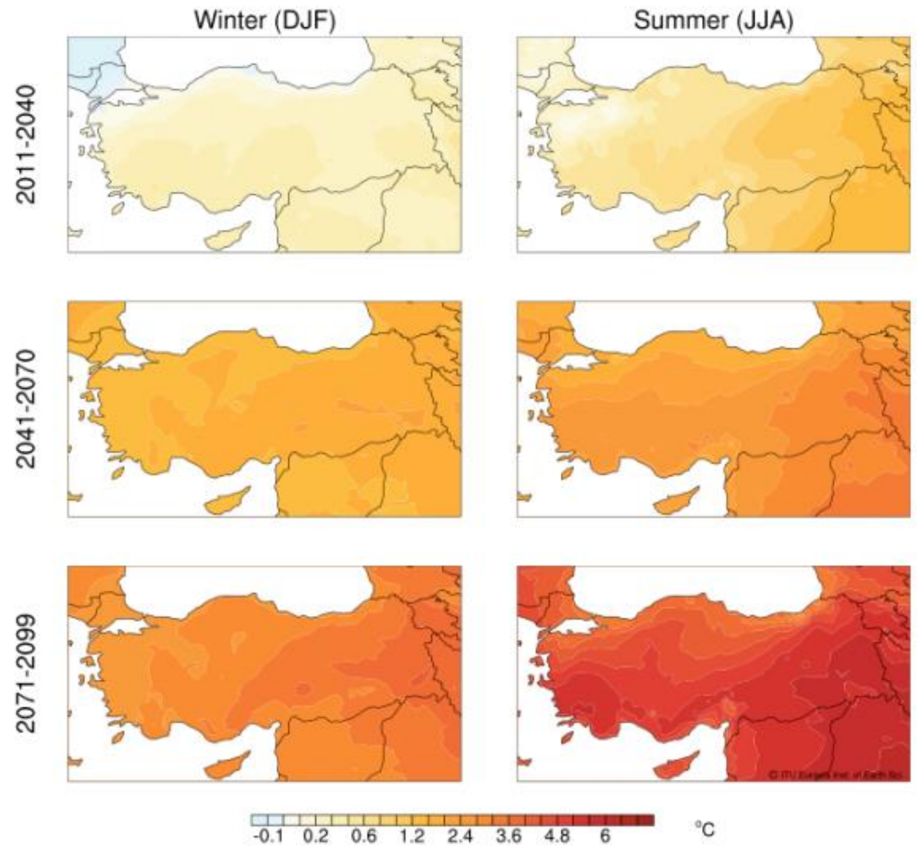


Figure 2.39. The maps show projected changes in surface temperature during winter (left) and summer (right) seasons in 30-year periods of the twenty first century relative to baseline climate (1961-1990)
(Source. MoEU, 2012)

In summary, as it is mentioned in previous sections, there are different climate models and scenarios to project climate change globally. For Turkey, five downscaled simulations are available for the period 2071-2099. These are based on the A2 simulations of ECHAM5, HadCM3 and CCSM3, the A1FI simulation of CCSM3 and the B1 simulation of CCSM3 (Table 2.6). In the context of model estimations, there are magnitude differences between different scenario simulations of the same GCM or between different GCM simulations of the same scenario. In spite of differences, all models declare that the increase in surface temperature in Turkey will not be uniform. Especially for the last period, the summer temperature increases reach to around 6 °C in the south-eastern and south-western parts of Turkey whereas it rises to around 3 °C in much of the Black Sea and Marmara regions. The models also highlight that in winter the changes are relatively small whereas in transition seasons they increase and make peak in summer (Güven, 2007; MoEU - GDEM - Department of Climate Change, 2012; MoEU, 2013 and OECD, 2013).

Table 2.6. Projected seasonal surface changes (°C) in the last 30-year period (2071-2099) relative to baseline climate (1961-1990) according to different scenario simulations.
(Source. MoEU, 2013)

Scenario	GCM	Winter		Spring		Summer		Fall	
		W	E	W	E	W	E	W	E
A2	ECHAM5	2.9	3.4	3.1	4.1	4.7	5.2	4.0	4.4
	HadCM3	3.4	3.8	3.7	4.1	6.9	6.1	4.0	4.3
	CCSM3	2.5	2.9	3.6	3.5	6.4	6.8	4.9	5.9
A1FI	CCSM3	3.5	4.0	4.8	4.9	6.9	7.3	5.5	6.8
B1	CCSM3	1.3	1.5	1.7	1.7	3.3	3.4	2.5	3.0

* W indicates the western half of Turkey and E indicates eastern half of Turkey.
* ECHAM5: European Center-Hamburg, Version 5
* HadCM3: Hadley Centre Coupled Model, Version 3
* CCSM3: Community Climate System Model, Version 3
*A2, A1FI, B1[8]

According to latest outputs of Turkish State Meteorological Service (SMS)'s project called 'Climate Projections for Turkey' with different global models and scenarios [one of them: Hadley Centre Global Environment Model Version 2- Earth System

[8] A2 Scenarios: Relatively slow demographic transition and relatively slow convergence in regional fertility patterns. Relatively slow convergence in inter-regional GDP per capita differences. Relatively slow end-use and supply-side energy efficiency improvements (compared to other storylines). Delayed development of renewable energy. No barriers to the use of nuclear energy.
A1FI: A future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality.
B1 Scenarios: Rapid demographic transition driven by rapid social development, including education. High economic growth in all regions, with significant catch-up in the presently less-developed regions that leads to a substantial reduction in present income disparities. Comparatively small increase in energy demand because of dematerialization of economic activities, saturation of material- and energy-intensive activities (e.g. car ownership), and effective innovation and implementation of measures to improve energy efficiency. Timely and effective development of non-fossil energy supply options in response to the desire for a clean local and regional environment and to the gradual depletion of conventional oil and gas supplies (IPCC, 2000).

(HadGEM2-ES) GCM with Representative Concentration Pathways **(**RCP) 4.5[9] and RCP8.5[10]] for a period between the years 2013-2099, temperature difference values tend to increase from now to until the end of the century in both scenarios. According to RCP4.5 scenario, in the first period (2013-2040), annual mean temperatures increase about 1.5-2 °C whereas summer temperatures increase about 2-3 °C especially in Marmara and west of Black Sea Region. In second period (2041-2070), in spring and autumn, temperatures increase about 2-3 °C while up to 4 °C incline is in summer. In last period (2071-2099), temperatures increase about 2 °C in winter and about 3 °C in spring and autumn. Temperatures increase up to 5 °C in summers in the Southeast Anatolia Region and coastal part of the Aegean Region. According to RCP8.5 scenario, in the first period (2013-2040), spring and summer temperatures increase about 3 °C. In the second period (2041-2070), about 2-3 °C increase is in the winter temperature, about 3-4 °C in autumn and spring temperatures and about 5 °C in summer temperature. In the last period (2071-2099), about 3-4 °C increase is in west of Trabzon and Mersin line and about 4-5 °C in east of Trabzon and Mersin line in winter temperature. In South East Anatolia Region, an increase is about 6 °C in spring and autumn temperature while an increase exceeding 6 °C in summer temperature throughout the country (Table 2.7) (Demircan *et al.*, 2014).

Table 2.7. Comparison projected temperatures between RCP4.5 and RCP8.5 scenarios by seasons in three different periods
(Source. Demircan *et al.*, 2014)

	RCP45	**RCP85**	**RCP45**	**RCP85**	**RCP45**	**RCP85**	**RCP45**	**RCP85**
Period	**Winter**		**Spring**		**Summer**		**Autumn**	
2013-2040	1.5-2	1-2	1.5-2	2-3	2-3	1.5-3	1.5-2	1.5-3
2041-2071	1.5-2	2-3	2-3	3-5	2-4	4-5	2-4	3-5
2071-2099	2-3	3-5	2-4	4-6	3-5	5-6	3-5	4-6

[9] RCP4.5: Global annual GHG emissions (measured in CO2-equivalents) peak around 2040, then decline.
[10] RCP8.5: Emissions continue to rise throughout the 21st century.

Summary of Change in Precipitation Patterns: Mean annual rainfall is predicted to show a significant decline trend by as much as 15% in the southern ECA countries (Figure 2.40). As it is understood from the Figure 2.34, Turkey is one of the countries which will experience drastic decrease in the ECA region. Besides, in southeast Europe countries, precipitation intensity will differ drastically in annual runoff (a measure of water availability). They will have an average decrease of 25%.

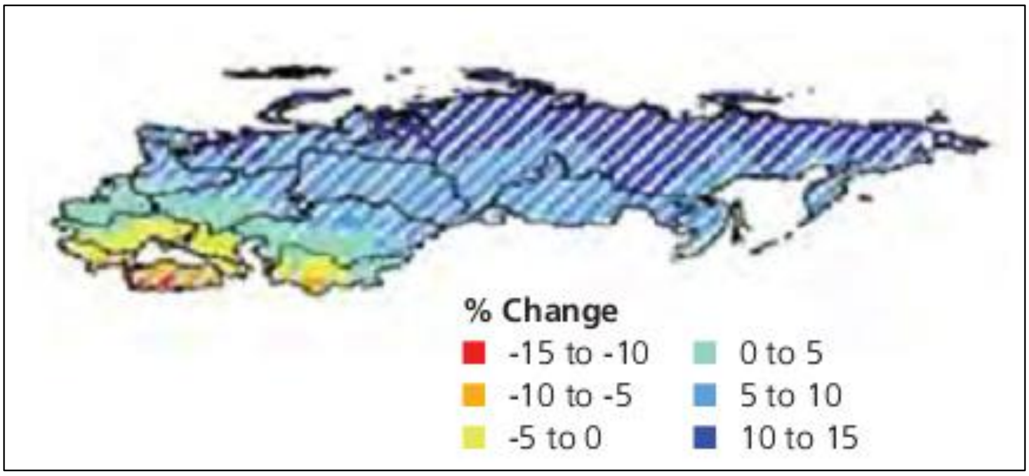


Figure 2.40. The map shows the precipitation change in mean annual rainfall for the years 2030-2049 relative to baseline climate (1980-1999) by using 20 GCMs. [Source.Westphal, 2008 (obtained from the World Bank, 2009)]

According to results of the ECHAM5 A2 simulation which was used to prepare Turkey's National Climate Change Adaptation Strategy and Action Plan, for the first 30-year period (2011-2040) winter and spring precipitation increases up 30% for much of Turkey whereas for the second 30-year period (2041-2070) winter precipitation will decrease up to 20% in the southern and western parts of Turkey. A decrease is also projected for spring precipitation in the southern and central parts of Turkey. On the other hand, in both seasons, an increase is simulated in the northern parts. Although changes in the pattern of the winter precipitation in the last period (2071-2099) are similar to that of second period, the strength of changes is different. It is projected that the areas with the decline pattern in precipitation will become much dryer while the areas with incline pattern in precipitation become much wetter in the last period. A decline trend is also simulated for spring precipitation during the last period over Turkey except Black Sea Region where the precipitation is estimated to increase. As a consequence, the ECHAM5 simulation highlights the areas as hot spots in terms of the strength of changes in precipitation: Mediterranean and Southeastern Anatolia Regions with significant reductions and Black Sea Region with significant increases. In the rest of Turkey, the changes will be relatively small (Figure 2.41) (MoEU, 2013).

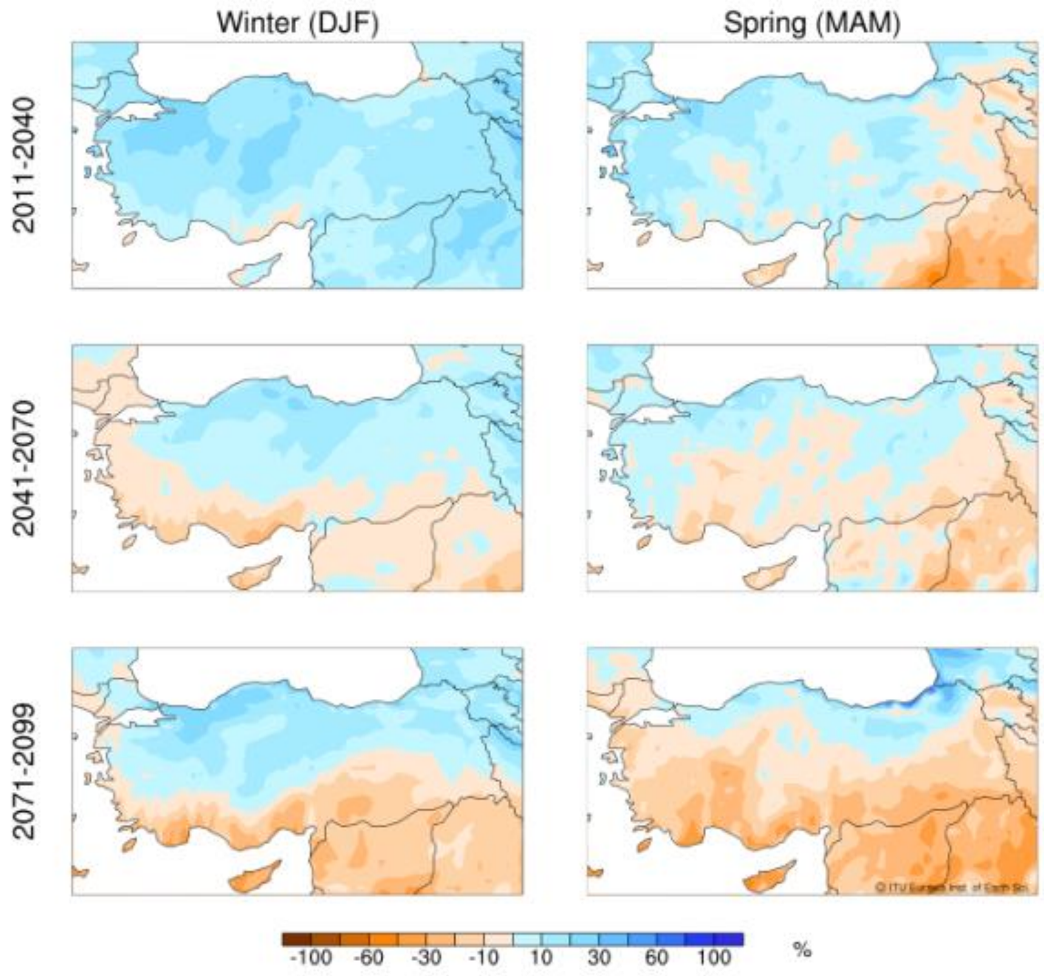


Figure 2.41. The maps, which are based on the A2 scenario simulation of the ECHAM5 GCM, display the simulated changes in precipitation (%) for winter (left column) and spring (right column) relative to baseline climate (1961-1990). (Source. MoEU, 2013)

As there are different climate models and scenarios to project climate change globally, in Table 2.8 the comparison of ECHAM5 based on A2 scenario with the other GCMs such as HadCM3 based on A2 scenario and CCSM3 based on A2, A1FI and B1 scenarios in the context of precipitation projections in Turkey is presented.

Table 2.8. Projected seasonal precipitation changes (%) in 2071-2099 period over 1961-1990 period based on different scenario simulations. (Source. MoEU, 2013)

Scenario	GCM	Winter		Spring		Summer		Fall	
		N[11]	S[12]	N	S	N	S	N	S
A2	ECHAM5[13]	+13	-17	+1.5	-23	-23	-30	-4	+4
	HadCM3[14]	-2.5	-26	-1	-28	-48	-61	+3	+21
	CCSM3[15]	-6	-32	-21	-36	-33	-62	-6	-23
A1FI	CCSM3	-0.6	-35	-30	-47	-57	-70	-1.5	-10
B1	CCSM3	-0.6	-14	-10	-28	-19	-40	-7	-16

According to Climate Projections for Turkey Project prepared with HadGEM2-ES GCM that is simulated by RCP 4.5 scenario for a period between the years 2013-2099, in first period (2013-2040), an increase in precipitation during the winter months in the coast part of the Aegean, middle part of the Black Sea and East Anatolia Regions whereas a decrease about 20% is in the spring in many regions. In second period (2041-2070), decrease about 20% in winter precipitation is in East Anatolia, Southeast Anatolia and central and eastern parts of Mediterranean region. It is a decrease around 30% in summer season in Eastern Anatolia. Apart from coastal part of the Aegean Region and a small part of Central Anatolia Region, a decrease in precipitation is in the autumn all over Turkey. In last period (2071-2099), especially along coastal line

[11] N indicates the northern half of Turkey
[12] S indicates southern half of Turkey
[13] European Center-Hamburg, Version 5
[14] Hadley Centre Coupled Model, Version 3
[15] Community Climate System Model, Version 3

except South East Anatolia Region, it is an increase about 10%. It is a decrease about 20% in spring precipitation except coastal part of the Aegean Region, west and east part of Black Sea Region and northern part of East Anatolia Region. Apart from coastal part of the Aegean, the Marmara and the Black Sea Regions, it is a decrease up to 40% in summer precipitation. In autumn, a decrease is in precipitation over Turkey (Demircan *et al.,* 2014). In the study, outputs also include the results of the RCP 8.5 scenario. The comparison table which shows both scenario's precipitation projections is presented in Table 2.9.

Table 2.9. Comparison projected precipitation between RCP4.5 and RCP8.5 scenarios by seasons in three different periods (%) (Source. Demircan *et al.*, 2014)

	RCP45	**RCP85**	**RCP45**	**RCP85**	**RCP45**	**RCP85**	**RCP45**	**RCP85**
Period	**Winter**		**Spring**		**Summer**		**Autumn**	
2013-2040	-10/+20	-10/+30	-20/+20	-20/+30	-30/+40	-40/+40	-30/+10	-30/+10
2041-2071	-30/+30	-30/+40	-40/+20	-40/+30	-50/+60	-50/+60	-40/+10	-40/+10
2071-2099	-20/+30	-30/+50	-50/+20	-50/+30	-50/+50	-50/+60	-50/+10	-50/+10

Summary of the Rising Risk of Extreme Weather Events: Extreme events that might affect the daily life in a negative way are calculated using daily values of climate variables such as daily maximum and minimum temperatures and daily precipitation. The annual changes in two of such variables – hot spell and heavy rainy days – are presented in Figure 2.42 for three different periods (First Period: 2011-2040; Second Period: 2041-2070; and Third Period: 2071-2099). These changes are based on the ECHAM5 A2 simulation's estimations. They are extreme in their duration and spatial extent. The hot spell is defined as a period of consecutive days in which the maximum temperature exceeds 30 °C. The heavy rainy days are defined as the number of days with precipitation greater than 10 kg/m^2. Although the number of hot spell periods change relatively small in the first period, it increases substantially up to 10 days in the South-eastern Anatolia Region and coastal areas of the Mediterranean Region in the third period. In the first period, the number of heavy rainy days increase all over

Turkey, while an increase up to 10 days is in the north-western parts of the Anatolian Peninsula. In the second and the third periods, a decrease up to 10 days is projected in the Mediterranean and South-eastern Anatolia Regions while an increase is projected in the Black Sea, Central and Eastern Anatolia regions (MoEU, 2013).

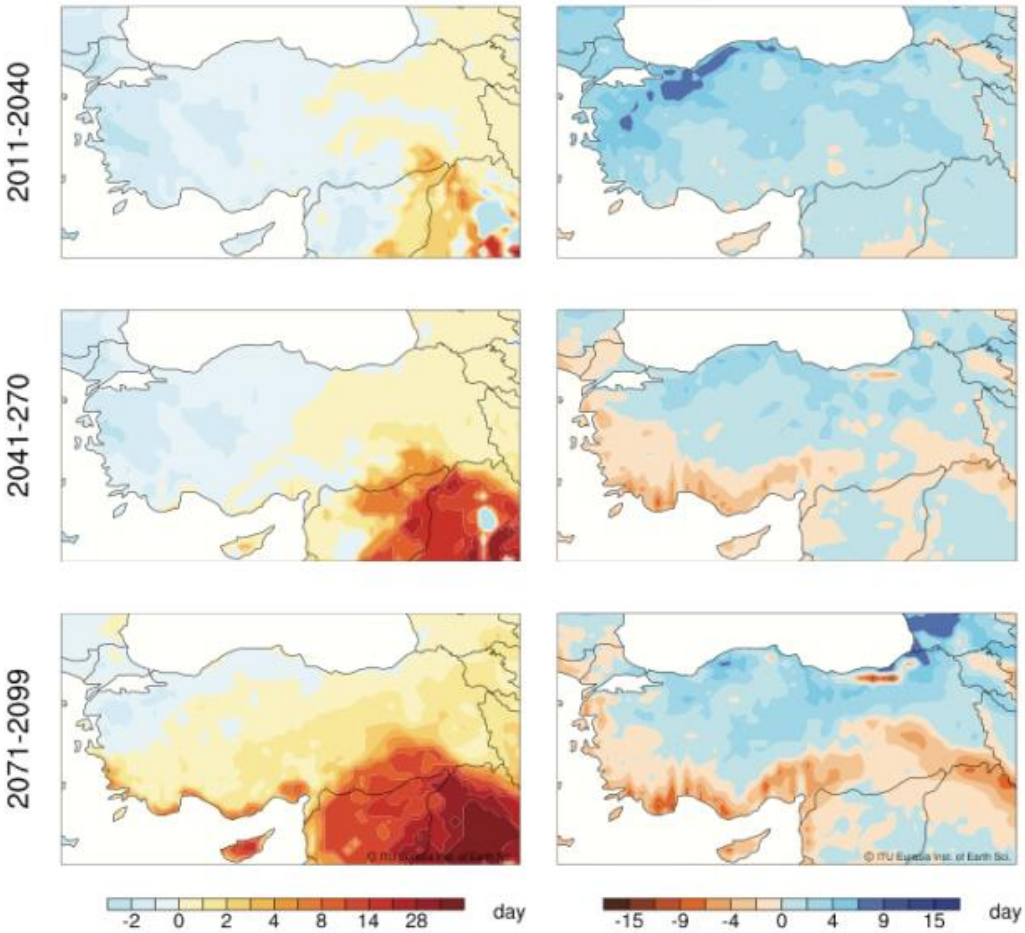


Figure 2.42. Projections of Annual Changes which are based on the A2 scenario simulation of the ECHAM5 GCM compare to 1961-1990 in hot spell (left column) and heavy rainy days (right column) (based on).
(Source. MoEU, 2013)

In summary, it is understood that GCMs have been developed by different research groups and organizations over the years. In the context of model estimations, there are magnitude differences between different scenario simulations of the same GCM or between different GCM simulations of the same scenario. Though some differences in magnitudes, there are consistent trends in all the model simulations focusing on Turkey. All simulations agree on a temperature increase, and a precipitation increase and decrease by regions in Turkey in the 21st century. An increase of a few degrees in weather conditions means extreme temperatures and a significant increase in heavy precipitations. Hence, Climate Change may manifest itself in the following forms in Turkey:

- Increase in summer temperatures, reduce in winter precipitation (especially in the western provinces), warmer winters with less snow;
- Increase in the frequency and severity of drought (especially in in the South, Southeast and West Regions) and heat waves;
- Severe drought will lead to an increase in forest fires;
- Increasing irregularity in rainfall patterns;
- Increase in short term sudden heavy rainfall and thundery showers resulting in flash floods;
- Gradual shifting of the seasons;
- Loss of surface waters, more frequent arid seasons, degradation of soil, erosion in coastal regions resulting in direct threats to water resources;
- Increase in intensity of wind and rain causing severe floods and landslides (especially in the Western Black Sea Region);
- Continued sea level rise (especially Istanbul and Izmir is under threat) with possibility of saltwater intrusion;
- Eutrophication and salination of shallow lakes (Kadıoğlu, 2012; OECD, 2013; and MoEU, 2013).

To conclude, climate change is a kind of triggering mechanism and / or has multiplier effect on the extent of several natural hazards, i.e. the number and intensity of hazards are likely to be expected to rise due to changing climate. Therefore, it is important to include climate change into a risk preparedness framework in order to create a better understanding of the impacts of climate change; find ways to measure; and develop effective strategies to react in a timely manner. However, as it is highlighted in the Turkey's Fifth National Communication under UNFCCC, although there are positive achievements in applied climate science in Turkey, only a few set of variables and statistics have been produced due to very limited demand for climate projection products. Moreover, the climate research community has not been encouraged to grow; and there is a lack of strategic road map to establish a national climate research program and / or define a national research agenda (MoEU, 2013).

2.3. Anticipated Impacts of Climate Change on Tangible Cultural Heritage

The impacts of climate change are usually analyzed for several sectors such as energy, agriculture, water, food security, forestry, transportation, *etc*. but few studies have specifically quantified the effects of changes on tangible cultural heritage. As the world comes to grip with the potential scope of climate change, it is becoming clear that the actual and projected impacts of climatic change pose a key threat to many tangible cultural heritage properties. Indeed, the conservation of the tangible cultural heritage and its economic, social, and cultural contribution to society is being challenged by the changes in temperature, rainfall patterns, frequency and intensity of flooding, and a potential increase in storminess, sea level and coastal erosion. Despite the fact that projected climate changes associated will cause changes in the magnitude and the seasonal variations of temperature and precipitation patterns in many parts of the globe, it is still less known the magnitude and consequences of the effects of climate change on tangible cultural heritage.

The stock of buildings of historic and cultural significance is likely to be hit hard by climate related impacts because of their fragility and age. Changes in climate systems will, therefore, influence the conservation conditions for tangible cultural heritage, and make the sustainability of tangible cultural heritage more difficult. However, not just climate change itself but also society's coping strategies to overcome the stress derived from the climate change issue, such as some policies for adaptation and mitigation will affect the heritage in various ways. Many historic buildings, sites, landscapes and World Heritage Properties have already experienced significant changes in the past and unfortunately, many more historic assets are potentially at risk due to future changes in the climate (UNESCO, 2005). The unfavorable impacts of climate change on the tangible cultural heritage over the century have, therefore, newly become a subject of growing concern. Several scientific studies in recent years addressing the predictions of future climate trends, its anticipated effects, the vulnerability of tangible cultural heritage in the face of these effects, and the future management recommendations have been conducted. The estimations of the studies are based on climate models, such as Regional Climate Models (RCMs) which are generally used for limited areas and shorter time periods [recent past (1961-1990), near future (2010-2039) and far future (2070-2099)] (Cassar and Pender, 2005). While conducting the models, climate parameters (temperature derived parameters – range, freeze-thaw, thermal shock; water derived parameters – precipitation, humidity cycles, time of wetness; wind derived parameters-wind, wind driven rain, sand and salt) which are most likely to be critical to tangible cultural heritage properties, and their interaction are a matter of concern. Besides, the pollution derived parameters [Sulfur dioxide (SO_2), nitrogen oxides (NO_x), elemental carbon and pH] are also taken into account. The daily, monthly, seasonal, and yearly outputs of the models have been used to elaborate critical impacts on the tangible cultural heritage (Sabbioni *et al*., 2006b).

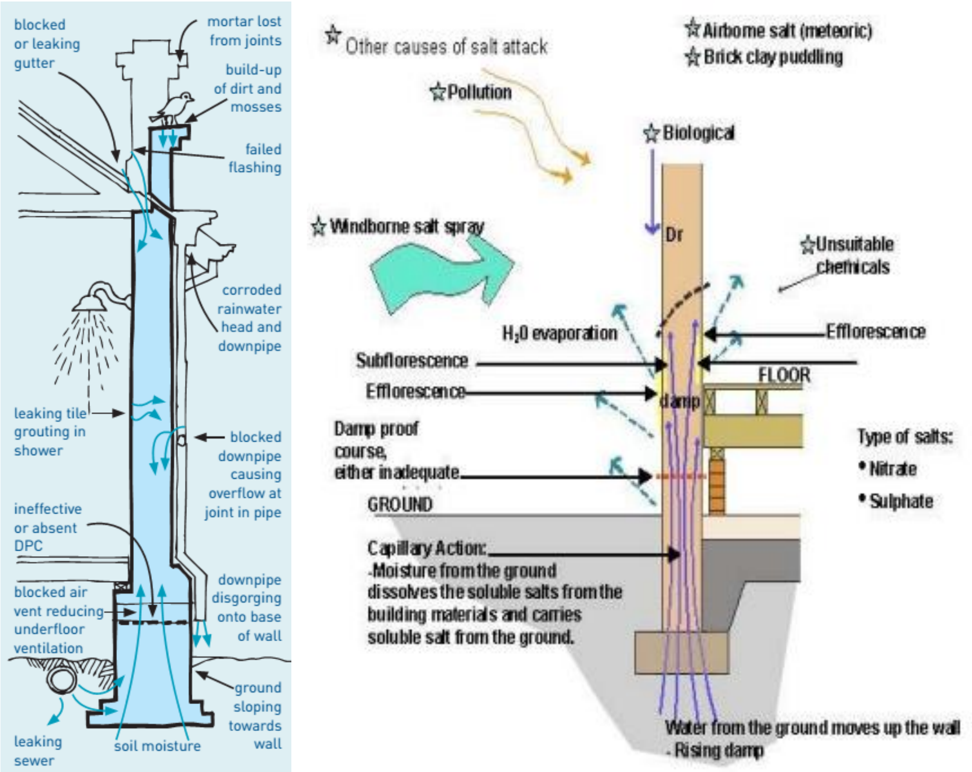
Europe has already been experienced the consequences of changing climate over recent decades. It sets to continue and intensify over this century; hence, it is a very real threat facing Europe's cultural heritage. In the following subsections, these treats are presented within the framework of traditional materials and deterioration processes.

2.3.1. Stone and Brick Deterioration

Salt weathering, frost, thermoclastism, surface recession, biodeterioration and blackening are the most important damage processes that act synergistically on the built heritage made of stone. Porous stones, both natural and man-made, bricks and mortars are affected by salt crystallization and frost. Particularly in urban environments, carbonate stones mostly undergo surface recession (chemical dissolution) and blackening while marble and granite are particularly susceptible to thermoclastism (thermal cracking). As they are initiated and controlled by the interaction between stone and exogenic factors such as climate and / or pollution, some processes will be accelerated or worsened by future changes in climate, whilst others will be retarded. The overall mean temperatures for the next century are predicted to rise in a range of three to five degrees in Europe. The potential impacts of shocks (extreme and sudden variations) or changes in the amplitude of the diurnal or seasonal variation of temperature will be amplified in a number of ways, such as phase changes (salt crystallizing or water freezing) (Sabbioni *et al.*, 2010).

(i) Salt crystallization: It is one of the most recurrent and severe decay processes, which has damage to European tangible cultural heritage. It has long been know that masonries are susceptible to deterioration when salts crystals grow within the pores. Salts are passed through and transported into buildings in many ways, such as in saline content of the rainfall and driving rain, by capillary rise from groundwater and soil water, by splashing from run-off water on impermeable surfaces, in fog and dew, by sea floods and as sea spray, *etc*. (Figure 2.43). When the dampness evaporates from the walls, the salts are left behind. They slowly accumulate to the point where there are sufficient to cause damage. Then, the materials are disrupted; and after a repeated number of weathering cycles, progressive decay of masonry often occurs by fretting that results in loss of surface skins. As it affects the durability of porous materials, it poses a problem to masonry (Figure 2.44) (Young, 2008; McAllister, McCabe, Srinivasan, Smith and Warke, 2011; and Viles, 2012).

In order to assess the durability of the stone, the cyclic crystallization of salts within a porous building stone has often been used. The Building Research Establishment, which has long been a source and provided an outline guidance on durability testing, describes the procedure of the salt crystallization test, which is mainly intended for use on limestones or sandstones. In the test, stone samples are subjected to at least 15 test cycles to assess durability of porous building stones (Moh'd, Howarth and Bland, 1996).



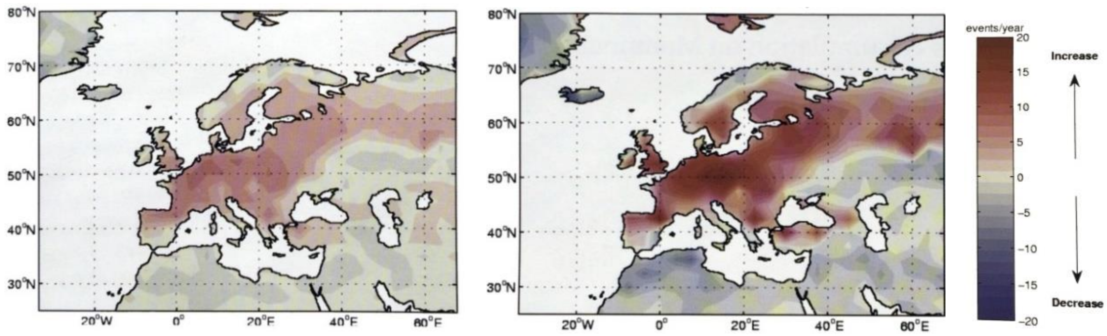
(a) (b)

Figure 2.43. (a) Many sources of damp in walls; (b) causes of salt attack in buildings [Source. (a) Young, 2008; and (b) Ahmad and Rahman, 2010]

(a) (b)

Figure 2.44. (a) Salt attack in bricks cause extensive fretting, crumbling and loss of kiln-hardened outer fire-skin of the brick; and (b) loss of the sandstone's natural case-hardened surface occurs due to moisture and salts which are trapped into the stone by the inappropriate use of water repellent coating.
(Source. Young, 2008)

As dissolution, recrystallization and the growth of salt crystals link to the climate that a building is exposed, salt damage risk is sensitive to fluctuations in temperature and moisture content (McAllister *et al*., 2011; and Viles, 2012). The recent results show that the number of transitions between crystalline solids to electrolyte solutions increases substantially over the period 1961-2099 due to lower relative humidity in summers; for instance, sodium chloride crystallizes when relative humidity falls below 75.5 % (Figure 2.45). This means that stresses within the pores of building materials will increase. Moreover, the predicted changes in atmospheric moisture may lead greater salt mobilization and subsequent damaging crystallization on carved surfaces (Brimblecombe, Grossi and Harris, 2006; and Colette, 2007).

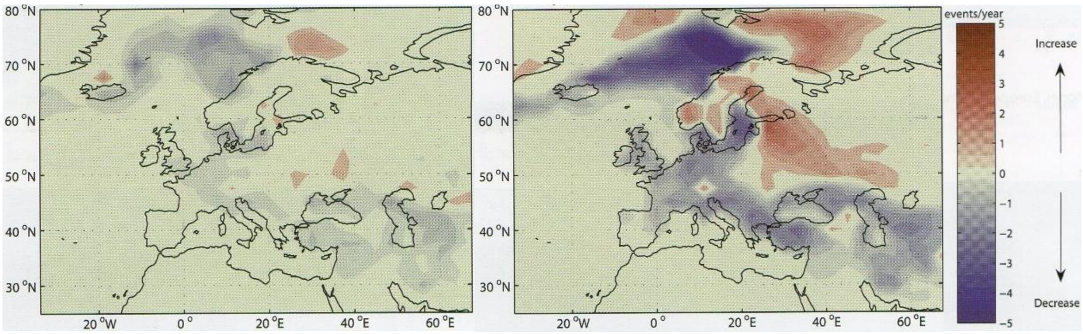


(a) (b)

Figure 2.45. The maps of changes in relative humidity cycles (events / year) show the changes in the phase transition (dissolution and crystallization events): (a) change from recent past to near future; and (b) change from recent past to far future. (Source. Sabbioni *et al.,* 2010)

(ii) Frost damage: It is the result of an increase in water volume when freezing within pores or fissures. The severity of the effect is related to the intensity, rate and duration of freezing, the cyclic action, and interstitial moisture (Hall, 2004). The greatest number of fluctuations often around 0 °C can amplify the risk of frost damage as a result of the anticipated climate change. As overall mean temperatures for the next century are predicted to increase up to 5 °C in Europe, phase changes, which happen at a very precise temperature and are very sensitive to small changes, the pattern may change. The changing pattern of the frequency of freeze–thaw cycles and wet-frost over the next century can be used as an indicator for the risk of frost damage (Kaslegard, 2011; and Grossi, Brimblecombe and Harris, 2007).

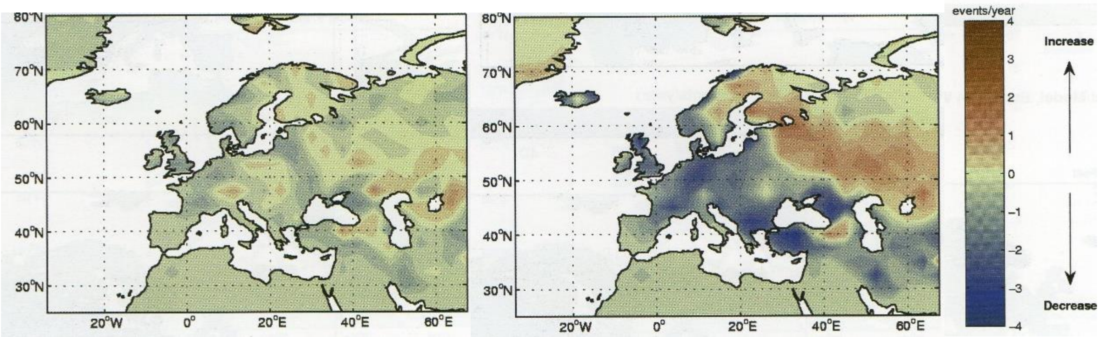
Freeze–thaw processes will change over the next century; and different parts of Europe will experience changes in the climate parameters, which affect heritage in many different ways (Figure 2.46). For instance, although freezing events will decrease in temperate Europe, at latitudes that are more northern (or potentially high altitudes) increase in temperature will lead to raise the number of freeze–thaw events. As the temperature effects are likely to increase in the future in temperate Europe, porous stone, which is typically used in the monuments of temperate areas, may be less vulnerable to freeze-thaw processes in the future; and management strategies may be directed to other damage factors. However, this situation is different in the far north Europe. Warmer temperature will affect archeological sites, foundation of structures and induce landslides; therefore, in this part of Europe it will be wise to support strategic decision makers in heritage sector (Grossi *et al.*, 2007).



(a) (b)

Figure 2.46. The maps of changes in freeze-thaw cycle (events / year) show: (a) change from recent past to near future; and (b) change from recent past to far future. (Source. Sabbioni *et al.*, 2010)

Another indicator of frost damage danger is wet-frost, which occurs when freezing takes place immediately after rain. Since an expansion in volume of water within pores and cracks, frost resistance can become a problem. In the project called Noah's Ark, wet-frost index is calculated by the number of days in the course of the year in which temperatures over 0 °C with rain and immediately followed by days with average temperatures below -1 °C (Figure 2.47). It will make a great difference if it has recently rained and moisture content is over certain critical values when it freezes (Noah's Ark, 2007; Sabbioni *et al.*, 2010; and Kaslegard, 2011). Poor drainage, cracked pointing or damaged plaster pave the way for penetrating moisture into a masonry. Flaking plaster or cracking and fragmentation of pointing, stones and bricks are the main effects on tangible cultural heritage (Kaslegard, 2011).



(a) (b)

Figure 2.47. The maps of changes in wet-frost index (events / year) show: (a) change from recent past to near future; and (b) change from recent past to far future. (Source. Sabbioni *et al.*, 2010)

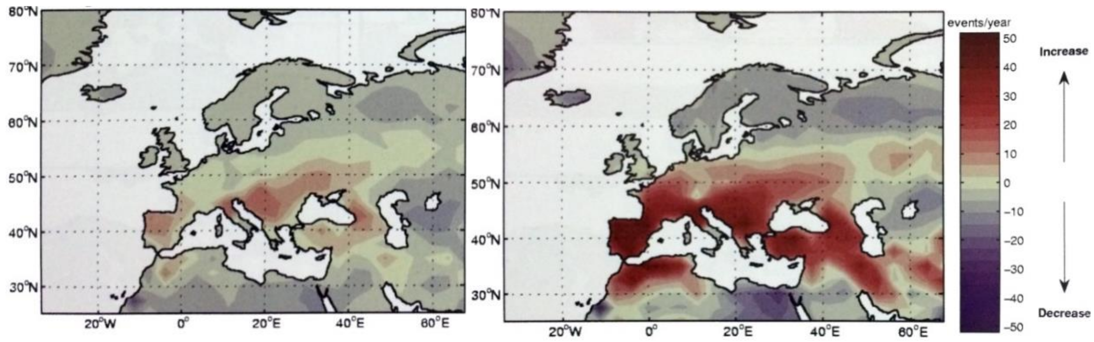
Risk mapping for wet-frost is slightly different from the one for freeze-thaw cycles. In southern and coastal parts of the Nordic region towards the end of the century will experience somewhat less often the risk of frost damage, while the risk will increase in higher altitudes, and areas that are more northern remain the same. If both freeze-thaw cycles and wet-frost are taken into account, the inner and northern part of the Scandinavian Peninsula, most regions of Finland, the Arctic regions, and some areas of the European landmass, such as Russia are most likely to experience a greater risk of damage. Although, changes from the recent past (1961-1990) to the near future (2010-2039) are insignificant, changes from near future to far future (2070-2099) appear to be significant (Sabbioni *et al.*, 2010; and Kaslegard, 2011).

(iii) Thermal stress: It is the result of changes in temperature, i.e. thermal shocks, which occur when the sun appears or disappears. In sunny days, as a result of overheating due to the solar radiation, differential expansions in materials and internal stress between a surface and subsurface layers are induced (Camuffo, 1981; and Jenkins and Smith, 1990). A system of internal tension is determined by "the thermal anisotropy of the crystalline lattice", "the size of the granules" and "their spatial association" (Veniale, 1995). Thermal cycles may cause weathering and mechanical damage to the outer layers of stones. If duration of the cycle is short, a thin layer may be affected. As the key part of the artistic value of monuments constitute the surface layer, daily or shorter temperature cycles might be more important than the seasonal ones in some cases (Camuffo, Vincenzi and Pilan, 1984; and Camuffo, 2014). The damage begins at the discontinuities embodied into a stone, and common boundaries between different minerals of which the stone is composed. Moreover, significant short-term (3-15 min) temperature fluctuations are also generated by variations in wind speed and cloud cover (Camuffo, 1981; and Jenkins and Smith, 1990).

In the long run, crystalline lattice of stones is slightly displaced from their original position by temperature fluctuations. That forms a less regular weaker structure leading to the granular disaggregation, which is frequently found on stones with granular or crystalline texture, such as granite and marble. Fatigue failure is accelerated along grain or crystal interfaces when stresses generated between grains or large crystals with differently oriented crystallographic directions, or having different expansion coefficients (Camuffo, 2014). Opening cracks along grain or crystal boundaries which lead to an increase in porosity not only makes marble liable to penetration of moisture but also causes enlarge that may induce to warp of a thin plate of stone. Therefore, as the damage is irreversible, structural stability of monuments or buildings may be under the risk (Scherer, 2006).

According to studies that project the pattern of future risks on cultural heritage, the highest level of risk for the thermal stress will be experienced in the Mediterranean Basin, especially Spain, France, Italy, the Balkan Peninsula, and Turkey; and in some cases, more than 300 events per year, meaning almost one event per day will occur.

The results also indicate that the monuments which made from marble will be under increasing risk of thermal stress in the future especially in several countries, such as Italy, Greece and Turkey where the density of monuments (number of monuments / area) built in marble is the highest (Figure 2.48) (Bonazza, Sabbioni, Messina, Guaraldi, and Nuntiis, 2009).



(a) (b)

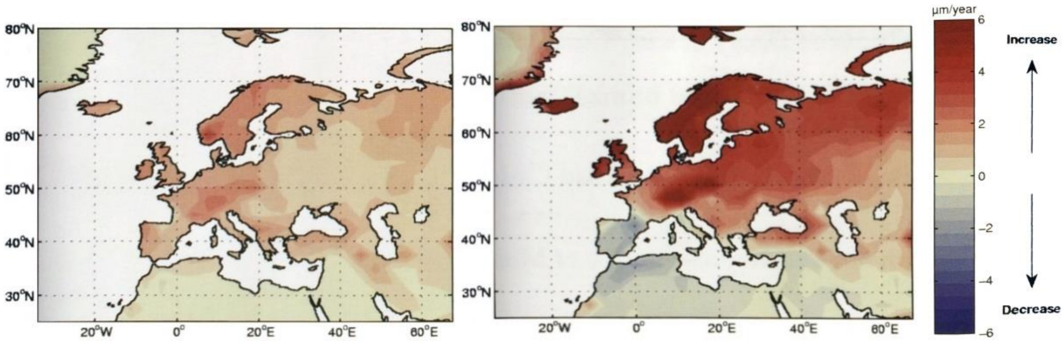
Figure 2.48. The maps of changes in thermal stress (events / year) show: (a) change from recent past to near future; and (b) change from recent past to far future. (Source. Sabbioni *et al.*, 2010)

(iv) Surface recession: Precipitation has an important role in surface recession of stones, such as marble and limestone that contain carbon, among the climate parameters which are critical to heritage conservation and are expected to change in the future. The chemical decomposition related to surface recession of carbonate stones is caused by rainwater in three different processes : (1) a clean rain effect due to rain at pH~5.6 in equilibrium with atmospheric CO_2 (karst effect), (2) an acid rain effect, caused by rain with additional acidity due to the presence of sulfuric and nitric acid, and (3) the dry deposition of gaseous pollutants, especially sulfur dioxide (SO_2) and NOx, occurring between precipitation events (Bonazza, Messinaa, Sabbioni, Grossi, and Brimblecombe, 2008). In other words, chemical decomposition is related to concentration of pollutants and the combined effects of them, which are accumulated on facades with the triggering impact of climatic factors.

During the chemical processes, rainfall is important not only having a role to transport acid substance from the atmosphere to facades but also its purely meteorological nature. For instance, during summer seasons in the Mediterranean climate, as rainfall events does not frequently occur, deposition of pollutants in dry phase generally happens, especially in urban sites. After accumulation of pollutants in the dry phase, when heavy shower occurs, they are washed away. Therefore, it may be useful to measure the intensity of the rainfall per day (amount/day) instead of monthly precipitation. In other words, knowing the intensity and frequency of rainfall leads to indicate the possible dominance of wet or dry deposition (Camuffo, 1995).

When the contribution of karst and acid rain effects are significant, white areas form usually on surfaces of calcareous stones (e.g. limestone and marble), which are exposed to wind and rain. Chemical reactions lead to produce gypsum, which is dissolved and removed by runoff rainwater. Material loss due to accumulation of acidic pollutions and dissolution of calcite, and the karst effect are direct indications of measuring surface recession in such exposed areas (Siegesmund and Snethlage, 2014).

It has been found in the project of the Noah's Ark that the average surface recession rate of carbonate stone is likely to increase in Europe due to climate change. The recessions are calculated as a European average for three periods (1961-1990; 2010-2039; 2070-2099). For all periods, the recession arises especially from the karst effect. The addition of dry and wet depositions increases the rate by approximately 0.6 μm per year. This means that their contribution to total surface recession is around 4%. It is also observed that the effects of air pollution get smaller over time, while the karst effect remains almost constant and dominant in the future. This points the declining trend in acidified European background conditions (rural/remote areas receiving only atmospheric deposition). On the other hand, many monuments and buildings are situated in cities; and it is expected that the concentration of SO_2 and other pollutants in cities is higher than the European background. Therefore, in order to understand the role of urban context, carbonate stones in Prague were studied. The results show that although the contribution of dry deposition is greater than in rural areas, it will not have significant effect on recession rates in comparison with the karst effect alone. As a result, it is predicted that karst recession of carbonate stone, which results from the rise in CO_2 concentrations, will increase. The rate of increase is most marked in high precipitation mountain areas, where carbonate buildings will undergo the highest risk of damage due to rainfall (Figure 2.49). The effect of acidic air pollutants and acid rain is quite small because of the effect of more stringent pollution regulation policies in Europe (Bonazza *et al*., 2008; and Sabbioni *et al*., 2010).



(a) (b)

Figure 2.49. The maps of changes in surface recession rates of low porosity carbonate stone show: (a) change from recent past to near future; and (b) change from recent past to far future.
(Source. Sabbioni *et al*., 2010)

(v) Biodeterioration: Biodeterioration is defined as "any undesirable change in the properties of a material caused by the vital activities of organisms" (Hueck, 1968, 8). As biological colonizers (macro and microorganisms) of stones cause aesthetic (colored patches or patinas and crusts), physical (abrasion, mechanical stress) and chemical (solubilisation, new-reaction products) damages, biodeterioration is one of the main problems related to monuments and buildings conservation (Herrera and Videla, 2009). However, macro and microorganisms, such as bacteria, fungi, algae, lichens, and higher plants, can bring about and/or intensify deterioration mechanisms when particular conditions and necessary factors occur. It is not enough to consider the mere presence of them as cause of decay (Urzì and De Leo, 2001). Influencing factors of colonization of diverse groups of organisms on the stone surfaces of monuments and artworks are as in the following:

- the material-specific parameters [pH, mineral constituents, salinity, moisture content (derived from rising dampness, damaged water drainage, condensational moisture, *etc*.), relative percentage of various minerals, texture, porosity and permeability];

- certain environmental conditions of the site [relative humidity, temperature, wind, light and rainfall, and anthropogenic pollutants (nitrogen compounds, hydrocarbons, *etc.*) from agricultural and industrial sources] (Kumar and Kumar, 1999; and Allsopp, Kenneth, and Gaylarde, 2004).

In other words, accumulation of macro and microorganisms depends on stones' structure and chemical composition, while the climatic conditions and cultural eutrophication of the atmosphere influence the intensity of living organisms, and the type and degree of deterioration (Prieto and Silva, 2005).

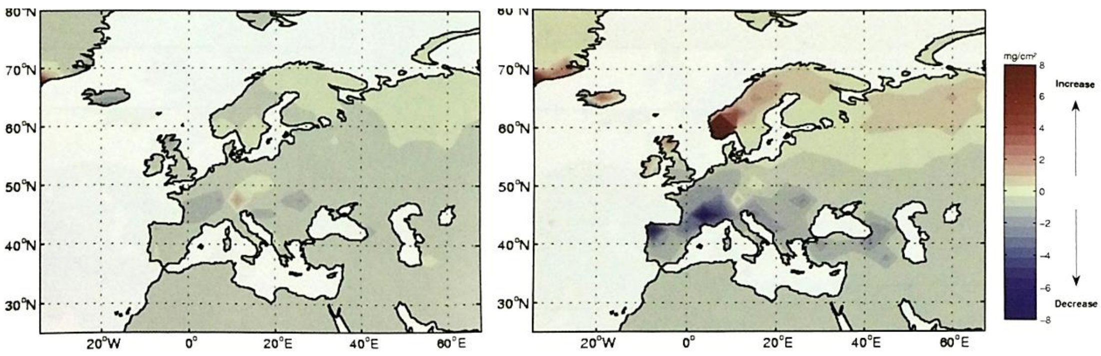
Microorganisms, among biological colonizers, play a critical role in stone deterioration through formation of biofilm, chemical reactions with substrate on which enzymes act, physical penetration into the substrate, and production of pigments (Warscheid and Braams, 2000). The deteriorating effects of colonizers include a discoloration leading to aesthetically unacceptable appearance of stains on the often richly sculptured outer surfaces; bounding to crystals particles, i.e. stone surfaces and pore spaces via secreting of extracellular polymeric substances[16] (EPS) which causes mechanical damage in deeper layers due to shrinking and swelling cycles inside a pore system. When distribution of pore size is changed by mechanical stress, the response of a stone to moisture and temperature fluctuations changes; accelerating the rate of accumulation of atmospheric pollutants that lead to formation of harmful crusts on surfaces (Blaschke, 1987; Steiger, Wolf and Dannecker, 1993; Urzi, Criseo, Krumbein, Wollenzien and Gorbushina, 1993; Morton and Surman, 1994; Dornieden, Gorbushina and Krumbein, 2000; Warscheid, 1996; Urzì and De Leo, 2001)

Among macro organisms, plants with roots and aerial vegetative apparatus like climbing and adhering parts of leaves have potentials to create irreparable damage to buildings and monuments. Apart from leading to aesthetic damage, they cause

[16] The function of "Extracellular polymeric substances" (EPS), which is secreted by microorganisms into their environment, is to reinforce the attachment on a surface (Morton and Surman, 1994).

alterations to stone as a result of mechanical actions of the roots and fixing parts (e.g. growth and shrinking / swelling, *etc.*) inducing physical stresses and mechanical breaks; chemical action through the production of acidity and exudates from their rootlets; and vegetation shading that slows down water evaporation (Urzì and De Leo, 2001).

As it is mentioned above the activity of the organisms, such as bacteria, fungi, lichen, insects, *etc.* is greatly dependent on climatic conditions especially temperature and humidity. The composition and distribution of communities accumulated on monuments can be explained by understanding a correlation between biological colonizers and climatic parameters. Biological impact of them on building materials is, therefore, a type of damage that will be affected by climate change (UNESCO, 2007). In order to predict the biomass of biofilms accumulation on stone monuments and its species richness based on the climate forecast in the near and far future was researched by taking account of horizontal and flat surfaces of acid stones (e.g. granite and schist) and general climate of a specific area (e.g. non-urban environments) within the scope of the Noah's Ark Project (Sabbioni *et al.*, 2010). According to results of the Project, over the century, biomass stock on monuments may not be affected excessively by the changes in climate in the near future whereas in the far future, several regions, such as North of Russia, Scandinavia and Scotland may be under the risk of great increase in biomass stock. This means that building materials will be exposed to an increased risk of faster decomposition derived from biological growth (Figure 2.50). Apart from increases in biomass accumulation, some regions, such as Western and South Europe, except for the Alps, a greater decrease is predicted (Sabbioni *et al.*, 2010; and Kaslegard, 2011).



(a) (b)

Figure 2.50. The maps of changes in total biomass accumulation (mg/cm^2) show: (a) change from recent past to near future; and (b) change from recent past to far future. (Source. Sabbioni *et al.,* 2010)

The results of the Noah’s Ark Project show the patterns of lichen species richness in Europe which correlate significantly negative to the yearly average temperature, i.e. increase in temperature causes decrease in the richness of lichen species and vice versa. Lichen species richness will decrease in the near future while a great decrease will be expected in the far future in almost all Europe (Figure 2.51) (Sabbioni *et al.,* 2010). When the period from 1850 to 1980 is evaluated in terms of the microclimate of the city of Rome, a decrease in precipitation, 10 % decrease in relative humidity, accompanied by an increase in temperature of 0.5 °C to 1.5 °C as well as increasing air pollution, a decrease in micro flora diversity (especially lichens) is obvious whereas decrease in the total biomass on stone is not significant (Caneva, Gori, and Montefinale, 1995).

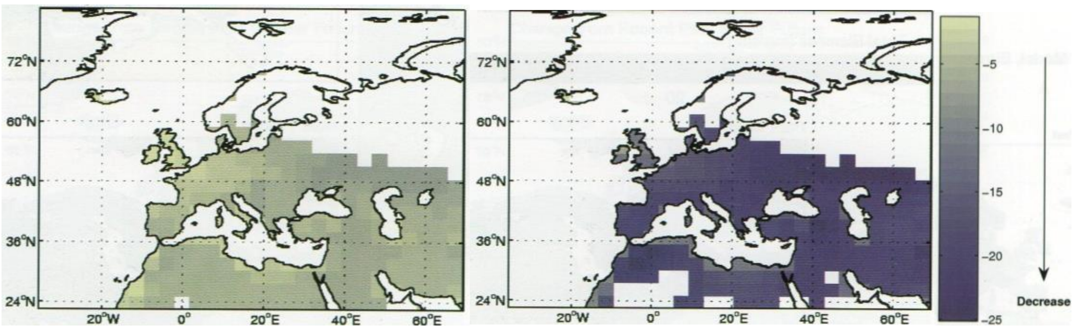


Figure 2.51. The maps of changes in lichen species richness show: (a) change from recent past to near future; and (b) change from recent past to far future. (Source. Sabbioni *et al.*, 2010)

(vi) Blackening: Although acidic pollutant levels have considerably been in decline trend since the early 1990s, buildings and monuments in an urban environment are exposed to air pollution are still in danger of deterioration (Doehne and Price, 2010). The danger comes from two main sources: gaseous pollution that increase the corrosivity of the atmosphere leading to chemical deterioration, i.e. corrosion (material damage) and particulate pollution that is the source of the black matter dirtying light colored surfaces leading to blackening / soiling (aesthetic damage). The latter matter is much more complicated due to surface deposition of complex mixtures of carbonaceous particles rather than a single substance (Haynie, 1986; Pesava, Aksu, Toprak, Horvath, Seidl, 1999; Grossi and Brimblecombe, 2002; Hamilton and Crabbe, 2009; and Watt, Hamilton, Lefèvre, and Ionescu, 2009). The mixture includes dust, soot (expressed as particulate elemental carbon, PEC or EC) and other tiny bits of solid materials derived from many sources such as combustion of diesel fuel by trucks and buses, burning of garbage, industrial processes, construction, and domestic use of fireplaces and woodstoves (Pesava *et al*., 1999; Hamilton and Crabbe, 2009).

Since the beginning of the twentieth century, there has been a shift from high levels of sulphate deposition from coal burning to a blackening process dominated by diesel soot and nitrogen deposition from vehicular sources in cities. As the significance of the blackening has increased, the importance of aesthetic considerations has come to the forefront (Grossi and Brimblecombe, 2007). Blackening is related to the surface covered by the carbonaceous deposits which have high optical absorptivity. In addition to its potential for damage, the blackened surfaces cause a visual nuisance. The deposits reduce the amount of light reflected from the surface that can be used to set limit values to air pollution (Haynie, 1986; Yocom and Kawecki, 1986; and Pesava *et al*., 1999). When 0.2% of the area of a white surface is covered by dark particulate matter, darkness can be perceived against a clean background by the human eye (Hancock, Esmen and Furber, 1976). Besides, the acceptable interval of blackening level is when EC concentrations is around 2-3 μgm^{-3} (Sabbioni *et al.*, 2010). As blackening is not a homogeneous layer covering an entire facade, distribution patterns are also taken into account, apart from levels of blackening. Some patterns which obscure architectural forms, such as vertical streaking and lumpy features, get a strong negative reaction, while others which cause shadowing effects are more acceptable (Grossi and Brimblecombe, 2004).

Over the 21st century of urban environment, the potential for dramatic changes in the blackening patterns may occur due to new climate regimes, especially changes in wind-driven rain (Figure 2.52). Therefore, as partial self-cleaning of urban historic buildings may occur, the adverse public response to changes in blackening patterns may be the focusing issue of cultural heritage professionals. The future blackening patterns will be formed by a balance between accumulation and redistribution. The accumulation will be mostly influenced by atmospheric elemental carbon concentrations, surface roughness and time of wetness while the redistribution will be dominated by wind-driven rain, precipitation amount and wind direction (Viles, 2002; Davidson, Tang, Finger, Etyemezian, Striegel and Sherwood, 2000; and Grossi and Brimblecombe, 2007). Moreover, today and in the near future cleaner atmospheres, deposits which are richer in oily organics and poorer in elemental carbon may result in brownish-yellowish coatings on urban building stones (Grossi, Brimblecombe, Esbert, and Alonso, 2007).

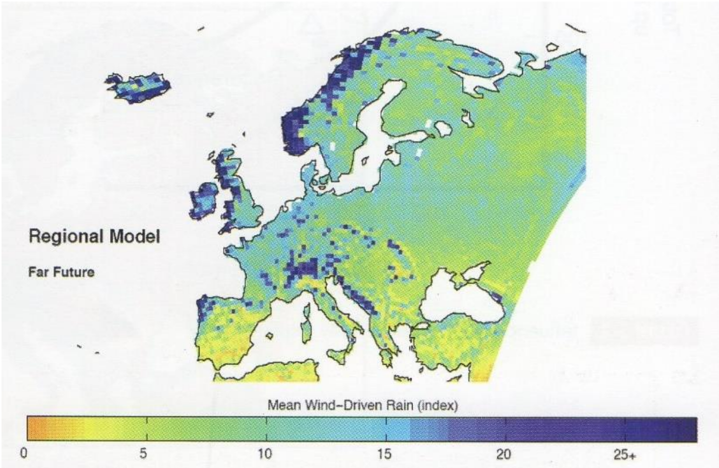


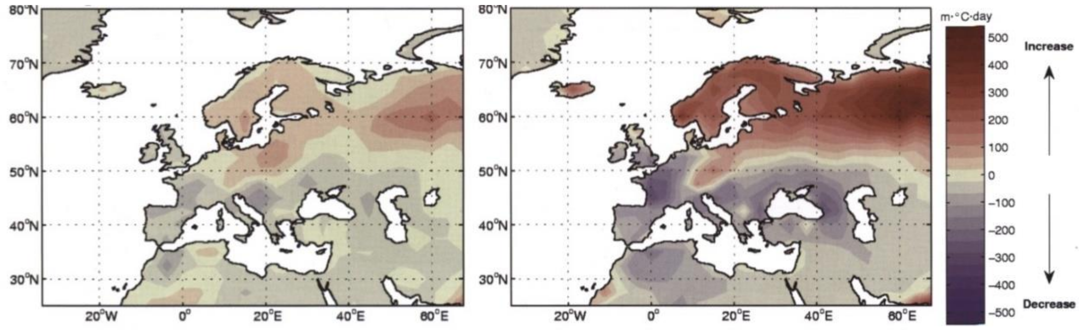
Figure 2.52. Regional model output of the wind-driven rain index shows the projected rain washing experienced by buildings in the far future.
(Source. Sabbioni *et al.*, 2010)

2.3.2. Timber Deterioration

Timber, which is rich in cellulose and lignin, is susceptible to the attack of different kinds of bacteria, fungi and insects. Timber construction is under similar threat from these organisms. If it is not properly constructed and maintained, its structural integrity will deteriorate over time because of the loss of timber mass due to decaying activities of these organisms; which is greatly dependent on the natural durability of wood, the local climatic conditions, such as temperature and humidity which are more or less favorable for decay organisms, and the likely climatic change (Gobakken, Mattson and Alfredsen, 2008; Kaslegard, 2010; and Wang and Wang, 2012).

The growth conditions of these organisms vary from species to species under a specific temperature. As a rough generalization, among these organisms, wood-degrading fungi can survive in a hibernating state below 5 °C whereas above 65 °C, it dies within a very short time (Zabel and Morrell, 1992; and Wang and Wang, 2012). Additionally, the biological decomposition of timber requires a certain amount of humidity. Timber-decay is minimal when the fibre saturation moisture content is below or about 30% due to lack of enough suction strength of fungi to access the absorbed moisture whereas timber is rapidly decayed when the moisture is above this value because it is in the form of free water and is easily accessed by the decay fungi (Wang and Wang, 2012).

Changes in temperature, and amount and intensity of precipitation due to climate change may put wooden buildings at risk in terms of their durability and integrity. The research project Noah's Ark (2007) has dealt with one of the principal damage mechanisms by which historic wooden structures deteriorate, i.e. attack by wood-degrading fungi (Noah's Ark Project, 2007). Also, climate risk index, which takes into account the real moisture penetration depth, has been developed to understand how the decomposition of wooden structures, exposed to the outdoor weather, due to wood-degrading fungi will be affected in the future by projected changes in climate parameters (e.g. temperature and precipitation). Spruce, a popular construction material in Europe, is the type of wood that is used within the Noah's Ark Project model as an example. The model assumes a moisture content of 20% and 48 hours after water penetration as threshold levels for the wood-degrading fungi to grow. The results clearly illustrate that increasing rainfall and mean temperature will result in increasing risk of deterioration of timber structures and building parts due to wood degrading fungi. The risk of outdoor fungi attack is expected to increase up to 50% in Northern and Eastern Europe in the course of the century (Figure 2.53) (Sabbioni *et al.*, 2010). Norway, Sweden, Finland and to some extent Iceland and the Faeroe Islands will experience the greatest increase in risk whereas Southern and Western Europe such as France, Italy, *etc.* will experience decreasing risks. Increased risk means an increase in the presence of conditions that allow the fungi to grow, i.e. a warmer and more humid climate (Kaslegard, 2010 and Sabbioni *et al.*, 2010).



(a) (b)

Figure 2.53. The maps of climate induced decay of outdoor wooden structures by fungal growth show: (a) change from recent past to near future; (b) change from recent past to far future.
(Source. Sabbioni *et al.*, 2010)

Timber is also exposed to chemical decomposition due to a slow process of oxygen with the help of temperature and light, in particular ultraviolet radiation. Besides, salt contributes to the chemical decomposition of timber materials. When high concentrations of salt come into contact with damp timber damage can occur; for instance in Greenland and Svalbard, increased concentrations of salt particles from the sea due to less sea ice and more wind reach wooden buildings in coastal areas, and cause decomposition (Kaslegard, 2011).

2.3.3. Metals Deterioration

A number of metals are particularly prone to chemical decomposition. Chemical process often together with physical and biological processes causes metals such as iron, copper and zinc to slowly corrode away. Corrosion is defined in International Organization for Standardization (ISO) 8044 Standard (1999) as “Physicochemical interaction between a metal and its environment that results in changes in the properties of the metal, and which may lead to significant impairment of the function of the metal, the environment, or the technical system, of which these form a part” (ISO, 1999). In the case of artistic or historic artefacts, the corrosion effects can be seen as acceptable whereas in most cases, it is considered as deterioration. For instance, producing a patina is considered aesthetically pleasant in the case of heritage artefacts but creating rust, which has a greater volume than the iron, damages surrounding stone or masonry due to splitting (Noah's Ark, 2007; and Cano and Lafuente, 2013).

Corrosion in metal structures is influenced by two significant environmental factors, chloride deposition and acid pollution, particularly SO_2 (Noah's Ark, 2007). These environmental factors work together with climatic factors such as humidity and temperature, which are important players for the processes (Kaslegard, 2011). Climate and pollution act together in a complex way: the corrosion stress is increased by air pollution – gaseous and/or solid. Therefore, dependence between climate and pollution should be taken into account (UN- Economic Commission for Europe, 2008; and Kreislova and Knotkova, 2011). In other words, important causes of the atmospheric corrosion of metal structures and building elements can be grouped into the following categories: climatic parameters, gaseous air pollutants, particulate air pollutants and acid rain. Among them, two significant effects, which are the combination of environmental and climatic factors, have been investigated within the Noah's Ark Project taking into account the impacts of climate change:

> * "the combined effect of temperature and SO_2 pollution, illustrated for carbon steel but indicative also of bronze corrosion;
> * the combined effect of temperature and chloride deposition, including information on windborne sea salt aerosol, illustrated for zinc but indicative also of lead and steady state copper corrosion" (Sabbioni *et al*, 2010, 83).

These two effects were also combined in a multiple-risk map. Although these effects have been presented in terms of certain metals, it is highlighted that these two main effects are both important for all metals at varying degrees (Sabbioni *et al*, 2010).

(i) The combined effect of temperature and SO_2 pollution: Sulfur dioxide (SO_2), along with nitrogen oxides (NO_x), is considered the main precursor of acid rain and an indicator of air quality. Increases in sulfur dioxide concentrations accelerate the corrosion of metals, through the formation of acids, such as sulphuric acid (H_2SO_4). It is formed primarily from the combustion of sulphur-containing fuels (Wahab and Alawi, 2008).

Corrosion of the historical metals, such as iron and bronze, caused by SO_2 pollution were investigated in a range of experimental programs by taking into account temperature and humidity dependence. Temperature and relative humidity act in combination to determine the wetness conditions on a metal surface. When the surface is sufficiently wet, pollutants may dissolve on the surface layer and then penetrate it by acting as corrosive agents (UN- Economic Commission for Europe, 2008).

The temperature dependence of carbon steel corrosion was exemplified through the cities of Riga, London, and Rome within the Noah's Ark Project by assuming an unchanged level of SO_2 of 10 $\mu g/m^3$. The results indicate that if pollution concentration is not reduced, the effect of global climate change will be significant. In the London grid, since the temperature changes from about 8 °C to about 12 °C, corrosion remains high. In the Rome grid, an increasing temperature from about 11 °C to 17 °C highlights the effect of drying surface on the reduction of the corrosion rate. In the Riga grid, although the temperature also increases from 2 °C to 9 °C, the corrosion rate increases (Figure 2.54) (Sabbioni *et al*, 2010). In the Nordic Region, corrosion is expected to increase with a constant level of SO_2. However, if the model takes into account the reduction in SO_2 level in the future, after the reference period of 1961-1990, the negative effects of climate change are counterbalanced and the further decrease of SO_2 level will result in a decrease in carbon steel corrosion (Figure 2.55) (Sabbioni *et al*, 2010; and Kaslegard, 2011).

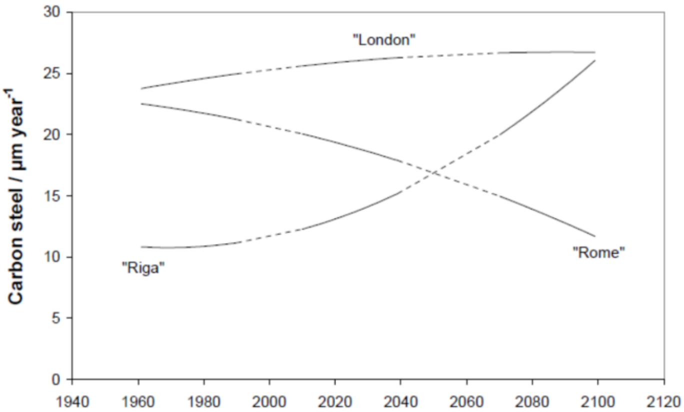
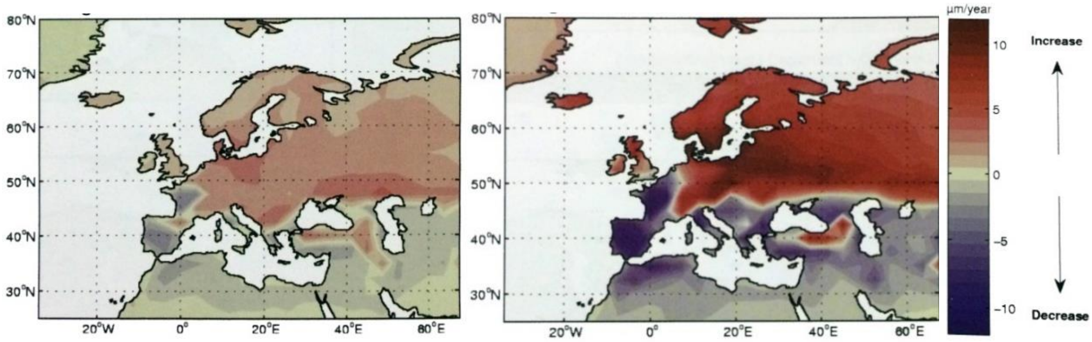


Figure 2.54. The graph demonstrates the calculated corrosion of carbon steel for three grid cells (London, Rome, and Riga) due to SO_2, which is assumed at a constant level of 10 μg/m^3. [Solid lines show the periods with available data (1961-1990, 2010-2030, and 2070-2099)] (Source. Sabbioni *et al*, 2010).



(a) (b)

Figure 2.55. The maps of corrosion of steel-iron and bronze caused by acidifying pollutants in urban areas show: (a) change from recent past to near future; (b) change from recent past to far future (Source: Sabbioni *et al*., 2010).

(ii) The Combined Effect of Temperature and Chloride Deposition: Chlorides have hygroscopic property, which contribute to the creation of an electrolytic layer that extends the periods of a surface wetness, even at high temperatures. Therefore, the concentration of chlorides affects strongly the corrosion rate of most metals. For example, when chlorides are present and temperature increases above 10°C, corrosion continues to increase (Sabbioni *et al.,* 2010).

The dependence for chloride deposition was identified for zinc (Zn) by selecting the same three grid cells representing Riga, London, and Rome, as was mentioned above. The deposition level was chosen as 300 mg/m^2*day^1. Although this level is relatively high, it can occur within hundreds of meters from the seashore or in areas where roads are salted. Relative humidity is an important parameter in this process, and it is expected to decrease when temperature increases. The results indicate that temperature is the dominant factor in increasing the corrosive effect of chlorides on Zn everywhere, as shown in Figure 2.56, whereas the effect of relative humidity and temperature have equal importance for carbon steel. The decreasing relative humidity tends to balance the increasing temperature (Figure 2.57) (UN- Economic Commission for Europe, 2008; and Sabbioni *et al.*, 2010).

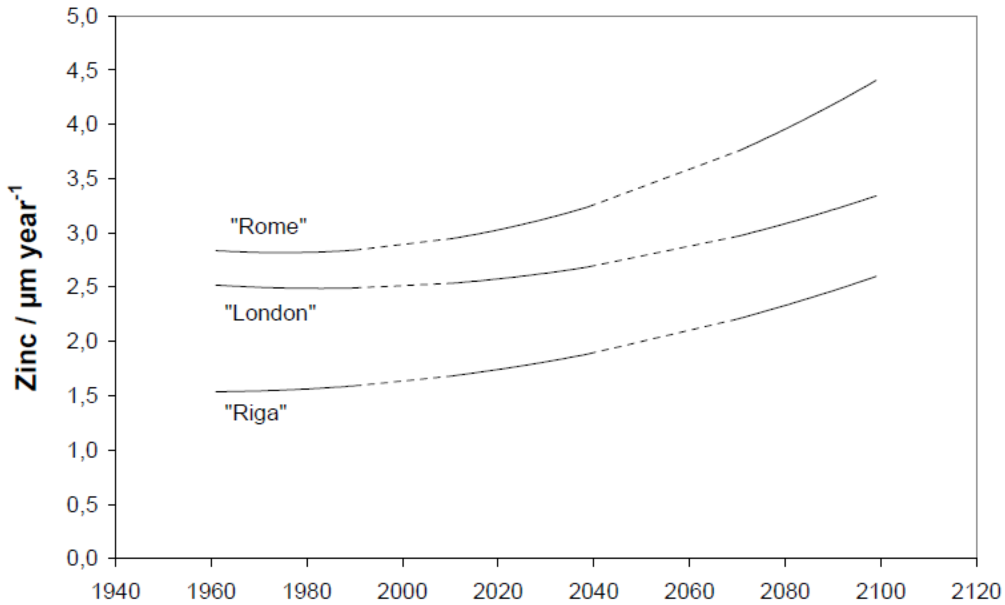
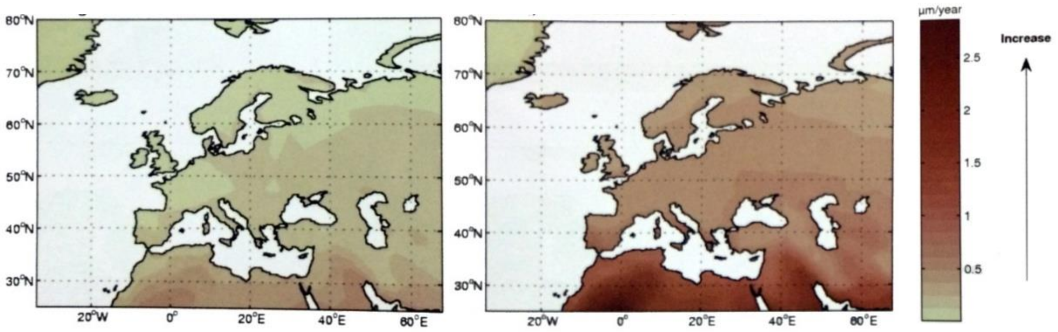


Figure 2.56. The graph demonstrates the calculated corrosion of Zn due to Cl deposition for three grid cells (London, Rome and Riga). Cl deposition is assumed at a constant level of 300 mg/m^2*day^1 (Source. Sabbioni *et al.*, 2010).



(a) (b)

Figure 2.57. The maps of corrosion of zinc copper and lead caused by high chloride deposition show: (a) change from recent past to near future; (b) change from recent past to far future
(Source. Sabbioni *et al.*, 2010)

(iii) Multiple Risk Map for Metals: The individual synthesis maps for carbon steel and Zn was used to prepare a multiple risk map for metals in general within the Noah's Ark Project. The combined effect of temperature and SO_2 pollution was examined by using carbon steel, which is also a very good indicator of iron and bronze corrosion in environments dominated by acidifying pollutants. The combined effect of temperature and chloride deposition was examined by using Zn. As SO_2 pollution and chloride deposition are the two most important factors governing corrosion, the map will be valid for metals in general (UN-Economic Commission for Europe, 2008; and Sabbioni *et al.,* 2010).

The ISO 9223[17] standard, which establishes a classification system for the corrosivity of atmospheric environments; and specifies the key factors in the atmospheric corrosion of metals and alloys (e.g. carbon steel, zinc, copper and aluminum) (ISO 9223, 2012), was used to prepare the combination of maps. The corrosivity category is labelled from C1 (very low) to C5 (very high) and the following approach was adopted to combine two maps:

- "use the corrosivity category (C1-C5) for zinc in coastal areas;

[17] ISO 9223 (Corrosion of metals and alloys - Corrosivity of atmospheres – Classification) specifies the key factors in the atmospheric corrosion of metals and alloys. These are the temperature-humidity complex, pollution by sulfur dioxide and airborne salinity. Corrosion effects of other pollutants (ozone, nitrogen oxides, and particulates) are not considered decisive in the assessment of corrosivity (ISO 9223, 2012).

- use the corrosivity category (C1-C5) for zinc in near-coastal areas, but calculated based on a lower chloride deposition rate than for the original zinc map;

- use the corrosivity category (C1-C5) for carbon steel for inland areas." (UN-Economic Commission for Europe, 2008, 10).

It is stated that the corrosion threshold value that should not be exceeded for carbon steel is 20 μm per year, while the value that should not be exceeded for zinc is 1.1 μm per year (Sabbioni *et al.*, 2010).

As the environmental factors work together with climatic factors, the changes in these factors due to climate change will cause variation of the risk pattern of atmospheric corrosion of metals. Depending on the area, climate change can either increase or decrease the risk of corrosion. In inland areas, the corrosion is expected to increase in Northern Europe and to decrease in Southern Europe. In some regions, the risk of corrosion will decrease due to the effect of stringent legislations lessening acid rain. In coastal areas all over Europe, increasing temperatures will lead to increase in corrosion due to the higher effect of chloride deposition (Figure 2.58). The magnitude of the risk depends on the chosen scenario (Brimblecombe *et al.*, 2006; and Sabbioni *et al.*, 2010).

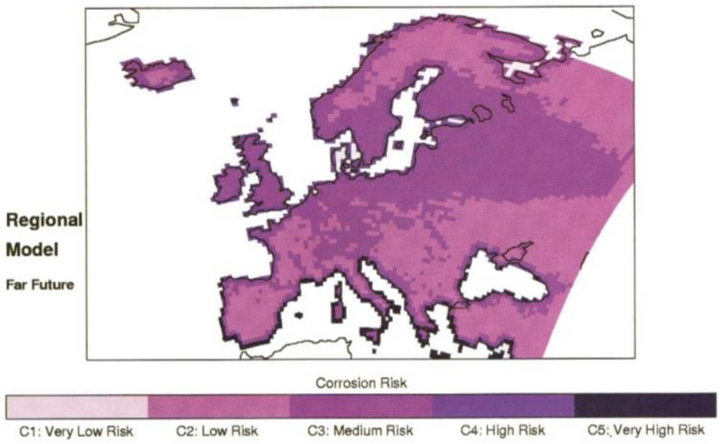


Figure 2.58. The purpose of the map is to show areas where corrosion of metals can increase or decrease due to future climate changes. It is based on the ISO 9223 corrosivity categories C1 (very low), C2 (low), C3 (medium), C4 (high) and C5 (very high) (Source. Sabbioni *et al.*, 2010).

2.3.4. Conclusion

It is obvious that during the transition and adaptation period, the additional sources of stress derived from climate change on tangible heritage assets should be taken into account. There will be losses and these losses will be magnified if appropriate adaptation strategies are not put in places in the immediate future. Although these scientific studies are not sufficient yet, the outcomes of these risk and vulnerability analyses form the basis of an initial assessment of opportunities for adaptation; and inform decision makers of the type of risk most prevalent in a particular region to provide a sustainable management of the future threats to tangible heritage. For instance, although recession rates will increase to some extent, they will remain under the significant rates of attack which was experienced during the first half of the twentieth century. It is likely that the removal of old black crusts due to rainwater will occur; and white areas due to washout will be more noticeable on monuments. Besides, especially if the deposition of pollutants is reduced through legislation, surfaces may become cleaner. Under such a future scenario, black and white areas on whitened buildings could present greater contrasts, which alter both appearance and physio-chemical properties; and trigger changes in management strategies (Bonazza *et al.*, 2008; and Sabbioni *et al.*, 2010). Furthermore, porous stone, which is typically used in the monuments of temperate areas in Europe, may be less vulnerable to freeze-thaw processes in the future; and management strategies may be directed to other damage factors. However, this situation is different in the far north Europe. Warmer temperature will affect archeological sites, foundation of structures and induce landslides; therefore, in this part of Europe it will be wise to support strategic decision makers in heritage sector (Grossi *et al*., 2007).

Consequently, deterioration processes involve a complex mixture of chemical, physical and biological processes; and it is necessary to analyze the impacts of climate change on the links of these interacting processes. Besides, a key task is to provide a balanced assessment of the different levels of competing risks provided by the various aspects of climate change on tangible heritage assets, such as air pollution, natural hazards, and management practices for comprehensive analyses and streamlining current management practices (Figure 2.59) (Viles, 2002).

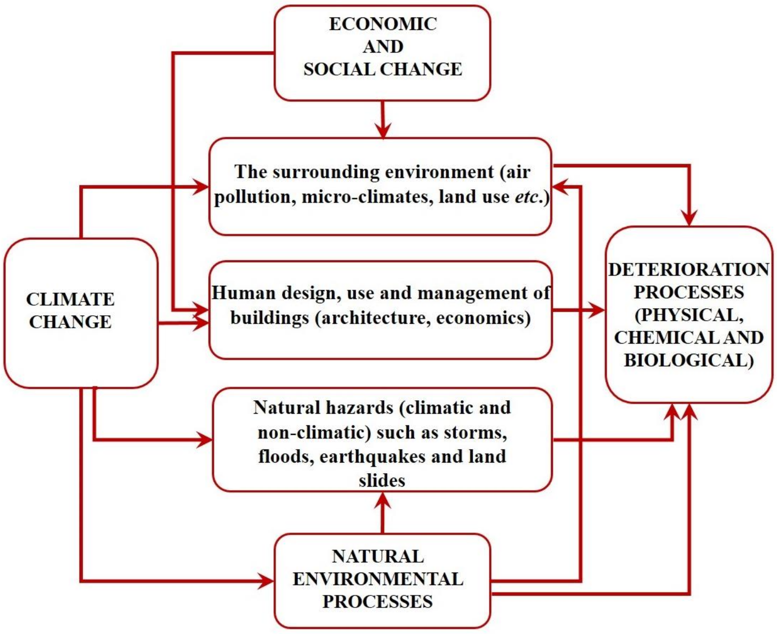


Figure 2.59. A conceptual diagram of climate change and other factors affecting future deteriorations.
(Source. Viles, 2002)

2.4. Case Study Area: Bursa - Its Tangible Heritage and Climate

Bursa is located on the slopes of Uludağ Mountain in the north-western part of Anatolia and in the south of the Marmara Region (Figure 2.60). Bursa is positioned in a junction that connects Marmara Region with West and Central Anatolia. The latitude and the longitude of Bursa are 40°12′ N and 29°04′ E, respectively (Bursa Metropolitan Municipality - Bursa Site Management Unit, 2013).

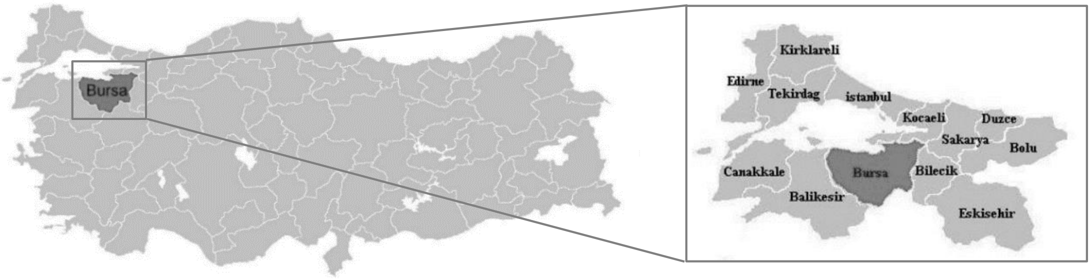


Figure 2.60. Location of Bursa and Marmara Region in Turkey.
(Source. Bursa Metropolitan Municipality - Bursa Site Management Unit, 2013)

Bursa has been an important Anatolian city with a history dating back to 5000 B.C and the home of many civilizations from Bithynians to Romans, from Byzantines to the Ottomans. It offers a unique architectural pattern by preserving the authenticity of its historical properties (Bursa Metropolitan Municipality - Bursa Site Management Unit, 2013). Since the scope of this study is limited to the early period of Ottoman State, brief information about Bursa at that period has been given in the following paragraphs and sections.

Bursa was conquered by the Ottoman Principality in 1326, on its way to 'becoming an empire'. It represents both the starting point of a course of transition from principality to empire by gaining the political entity and it has a task of serving as a melting pot of different cultures (Tanman, 1996). In other words, the Ottoman State, which started at the end of the thirteenth century as a small principality, became a multicultural and multi-ethnic empire by the second half of the fifteenth century (Bursa Metropolitan Municipality - Bursa Site Management Unit, 2013).

When Bursa is considered from the perspective of the architectural history, it gained a new appearance with building activities following the conquest. The city was decorated with many architectural works of art. It became the first capital where the elements of the early Ottoman architectural style were explored; the uncertainties were experienced; the new arrangements were discovered; and a variety of influences from different cultural identities were accepted. Ottoman architecture produced its first important examples in Bursa and its surrounding until Edirne acquired the title of capital city during the reign of Sultan Murad the Second. The *Üç Şerefeli* Mosque was built in Edirne, which opened the doors to the age of the classical Ottoman Architectural style (Tanman, 1996).

During the fourteenth and fifteenth centuries, as a settlement policy of the Ottomans, the foundation and the growth pattern of new neighborhoods were developed to promote community spirit for newly settled nomadics. New neighborhoods were founded by the erection of a social complex. Starting with Orhan Ghazi, the first five Sultans, named as Murad the First, Yıldırım Bayezid, Chelebi Mehmed (Mehmed the First), and Murad the Second erected at least one building complex in different corners of Bursa which shaped the urban form of the city. The complexes, which were centers of social, cultural, religious and educational functions, consist of public buildings such as mosques, *madrasas*, *hammams*, public kitchens and tombs (Kuran, 1968). These complexes were included in the UNESCO World Heritage List in 2014.

In this context, material preferences during the early period of Ottoman Architecture, monumental buildings included in the World Heritage Sites, and the changing trends of climatic parameters in Bursa have been investigated and presented in the following sections.

2.4.1. Traditional Materials of Construction in Bursa

The stone masonry tradition of the Seljuk and Principalities Period had been replaced with the alternating stone-brick masonry, which is found especially in the centers of the Early Ottoman Period. The close source of the alternating stone-brick technique is found in the late Byzantine architecture. As this technique was economic and completed quickly, it was used for both modest buildings and the buildings, which were built on the order of the sultans due to being in financial difficulties, such as Orhan Mosque, Hüdavendigar Mosque and Muradiye Mosque. However, regular-coursed dressed stone masonry was used when the state was in finacial wellbeing such as during the reigns of Yıldırım Bayezit and Chelebi Sultan Mehmet (Gabriel, 1958).

The main material of the alternate courses walls is silica-based stone generally collected from rivers and used as unhewn, such as the walls of Orhan Mosque, Emir Han, Orhan Hamam, İznik Süleyman Paşa and Lala Şahin Madrasas, *etc.* or as hewn with hammer like in Bursa Alaaddin Mosque and İznik Hacı Özbek Mosque. As a second surface treatment method, pitch-faced stone was used like in Hüdavendigar Mosque and Yıldırım Madrasah. Although the use of the cut stone was very limited, it was used to construct piers and facades of porticos, main door frames. *Küfeki* stone and marble were prefered and dressed skillfully like in Ulu Mosque and Yıldırım Mosque (Gabriel, 1958 and Ayverdi, 1966). Marble and limestone were supplied from both the nearest quaries and the nearby ancient cities, such as Cyzique (Gabriel, 1958).

Brick could be easily made in Bursa where the main material clay, and wood fuel were found (Gabriel, 1958). Brick was used for the certain parts of the structures such as domes, vaults, the transition elements from the corners of a square-based wall structure to the circular base of a dome, pillars, minarets, arches, mouldings, saw-tooth courses. In other words, in the early period of Ottoman architecture, in Bursa, brick was prefered to built upper parts of structures whereas rubble stone, stone and brick, cut-stone were preferred for main walls. However, brick was never used as the main material of the main walls (Gabriel, 1958; Ayverdi, 1966 and Batur, 1980).

Mortar was prepared by mixing sand and lime, and adding broken brick pieces. Since the sources of lime was abundant, it was used to prepare mortar and plaster (Gabriel, 1958 and Ayverdi, 1966). Niches and fireplaces were also constructed by using a type of plaster composed of lime like in Yıldırım Bayezit Mosque and Green Mosque (Gabriel, 1958).

The covering material of roof systems was slightly curved tiles. Although it has been still observed on the roofs of the buildings in İznik, the tiles were replaced with lead sheets, especially after conquering Istanbul. Many ore deposits were operated and the roofs of many buildings in Anatolia such as mosques, tombs, hans, hamams *etc.* were covered with lead sheets mined from these deposits (Gabriel, 1958 and Ayverdi, 1966).

Window shutters, window frames and doors were made of timber especially oak (Ayverdi, 1966).

The studies focusing on the material of construction preferences during the early period of Ottoman Architecture indicate that the most of the tombs, which were built in between 1450 and 1500, in Bursa, were constructed by using cut-stone. The percentage of cut-stone preference is 87% of 31 tombs whereas the percentage of rubble stone is 0% among the investigated tombs (Table 2.10). As the size of the tombs was smaller than the mosque, the preference of cut-stone in tombs was higher than in mosques (Daş, 2003).

In Bursa, marble finishing were observed in only two tombs. First one is the tomb of Devlet Hatun, which was constructed by the order of Çelebi Mehmet in the memory of his mother. The latter one is the Green Tomb, which was constructed for Çelebi Mehmet. The preference of marble is the sign of prosperity and power of the reign of Çelebi Mehmet after the Ottoman Interregnum (Daş, 2003).

Except the tomb of Umur Bey in Bursa, which is the only example that was completely built with brick, the alternating pattern of brick and stone courses was usually employed to build tombs (Daş, 2003).

Table 2.10. The tombs having alternating pattern of courses of brick and stone (Source. Adapted from Daş, 2003)

Name of the Tomb	Place	Date	Cut-stone-brick	Pitch-faced stone-brick	Rubble stone - brick	Stone (S) Brick (B) Courses			vertically laid bricks
						1	2	3	
Ertuğrul Gazi Tomb	Söğüt	end of 13th cc	X			S		B	
Kırkkızlar Tomb	İznik	1330-1362	X				B	T	
Süleyman Paşa Tomb	Yenişehir	1337-1338		X		S	B		
Sarı Saltuk Tomb	İznik	mid 14th cc	X			S	B		X
Lala Şahin Paşa Tomb	M.Kemalpaşa	1376	X			S		B	

Table 2.10 cont'd

Malkoçoğlu Mehmet Bey Tomb	Gebze	1385	X			S		B	
Gülçiçek Hatun Tomb	Bursa	1399-1400	X			S		B	
Yakup Çelebi Tomb	İznik	end of 14th cc	X			S	B		X
Yıldırım Bayezid Tomb	Bursa	1406	X			S	B		
Ebe Hatun Tomb	Bursa	1432-1481	X			S	B		
Ayaz Köyü Tomb	M.Kemalpaşa	1442		X		S	B		
Hatuniye Tomb	Bursa	1449	X			S	B		X
Abdal Mehmet Tomb	Bursa	1450	X			S		B	X
Azeb Bey Tomb	Bursa	1450-1451	X			S	B		X
Şeyh Kudbeddin Tomb	İznik	early 15th cc	X			S		B	
Hanım Kızlar Tomb	Bursa	mid 15th cc	X			S		B	
Okçu Baba Tomb	Bursa	mid 15th cc	X			S	B		X
Murad the Second Tomb	Bursa	1451	X			S	B		
Abdüllatif-i Kudsi Tomb	Bursa	1452		X			T, B		
Hamza Bey Tomb	Bursa	1461	X			S	B		X
Bülbül Hatun Tomb	Karacabey	1472-1473		X		S		B	X
Wives of Hamza Bey Tomb	Bursa	third quarter of 15th cc	X			S	B		X
Karamustafa Paşa Tomb	Bursa	1477	X			S	B		X
Cem Sultan Tomb	Bursa	1479	X			S	B		X
İshak Paşa Tomb	İnegöl	1486	X			S	B		X
Şair Ahmed Paşa Tomb	Bursa	1496	X			S	B		X
Alaaddin Tomb	Bursa	Second half of 15th cc	X			S	B		
Karışdıran Süleyman Tomb	Bursa	Second half of 15th cc	X			S	B		X
Saraylılar Tomb	Bursa	Second half of 15th cc	X			S		B	X
Gülşah Hatun Tomb	Bursa	end of 15th-first quarter of 16th cc	X			S	B		X
Hamza Baba Tomb	Kemalpaşa	end of 15th-first quarter of 16th cc	X			S	B		
	SUM		**27**	**4**	**0**	**29**	**1** **22**	**1** **9**	**16**

In the study of Bağbancı and Bağbancı (2005), 13 masonry buildings (Emir Han, Bedesten, İpek Han, Geyve Han, Gelincik, Sipahi, Hacı İvaz Pasha and Yorgancılar Bazaars, Çukur Han, Tuz Han, Fidan Han, Koza Han and Pirinç Han) which were built in the Hans District - Bursa between 14^{th} -16^{th} centuries were examined.

According to this study, composite brick and stone masonry technique (3 courses cut stone + 1 course brick, 3 courses bricks + 3 courses cut stone, etc.) was used to construct the piers of porches. Although arches, vault, domes are covered by plaster in most of the buildings; from the un-plastered buildings, we can see that brick was used to construct these architectural elements, too. The exterior walls of these buildings were constructed with the same technique but with different alternating layers (two courses brick + one course rubble stone, *etc.*). The thickness of these walls gets thinner in the upper story. In general, to build thick rubble stone walls, bonding timber was employed. As binder material, lime mortar including cracked stone, pozzolan, cracked bricks and tiles was used (e.g.: Pirinç Han) (Table 2.11) (Bağbancı and Bağbancı, 2005).

Table 2.11. Buildings in the Hans District and materials of construction (Source. Bağbancı and Bağbancı, 2005)

No	**Name of the Building**	**Material Choice and Pattern in Masonry Work**					
		Pier		**Vault**	**Arch**	**Dome**	**Wall Pattern**
		Ground Floor	**1st Floor**				
1	Emir Han (Bey Han)	cut-stone	100x100 2 courses brick + 1 course stone	plastered	plastered	plastered	2 courses brick + 2 courses stone
2	Bedesten	150x150 3 courses stone + 1 course brick	-	-	plastered	plastered	3 courses brick + 1 course stone
3	İpek Han (Old İpek Han, Sultan Han, Arabacılar Han)	124x146 cut stone	120x120 brick		brick	plastered	rubble stone +brick
4	Geyve Han (İvaz Pasha Han, Payigah)	100x100 3 courses brick + 3 courses stone	100x100 brick	plastered	brick	-	rubble stone +brick

Table 2.11 cont'd

5	Gelincik Bazaar (Hallaçlar Bazaar)	90x110	_	plastered	brick	plastered	2courses brick + 1 course stone
6	Sipahi Bazaar	Küfeki stone + brick	-	brick	brick	brick	2 courses brick+ 1 course stone
7	Hacı İvaz Pasha Bazaar	60x100 1 course cut stone + 2 courses brick	-	plastered	plastered	-	2courses brick+ 1 course stone
8	Yorgancılar Bazaar	90x100	_	plastered	plastered	_	2courses brick 1 course
9	Çukur Han (Kütahya Han)	cut stone + brick	cut stone + brick	plastered	plastered	-	cut stone + brick
10	Tuz Han (Tuz Bazaar, Umur Bey Han)	cut stone + brick	cut stone + brick	plastered	brick	-	rubble stone + brick
11	Fidan Han (Mahmut Pasha Han)	140x140 2 courses brick+ 1 course stone	140x140 2 courses brick + 1 course stone	plastered	brick	plastered	2 courses brick+ 1 course rubble stone
12	Koza Han (Simkeş, Sırmakeş, Beylik Caravanserai,	140x140 2 courses brick + 1 course stone	130x130 cut stone	plastered	brick	plastered	2 courses brick+ 1 course stone
13	Pirinç Han (Han-ı Cedid-i Sani, Han-ı Cedid-i Evvel)	153x155 cut stone	134x135 cut stone	brick	brick	plastered	3 courses brick+ 2 courses rubble stone

To sum up, the new rulers, the Ottoman State, of the former Byzantine city, Bursa, organized the settlement by constructing new buildings to meet their own social demands. As the choice of materials were related to economic condition of the state and prevalent materials of the region, both materials and construction elements collected from the remains of the Byzantine buildings and ancient cities such as columns, capitals and bases of columns, which were re-used, and brick and stone were preferred in different combinations.

2.4.2. World Heritage Sites in Bursa (Khans Area, Sultan Complexes and Cumalıkızık)

Bursa has a unique city planning methodology with the relationship of the five sultans' social complexes, one of which constitutes the core of the city's commercial center; and Cumalıkızık which is the best preserved waqf village in Bursa. For this reason it has been included in the UNESCO World Heritage List as "Bursa and Cumalıkızık: the Birth of the Ottoman Empire" (UNESCO, 2014b).

Bursa and Cumalıkızık Management Area is within the administrative boundaries of Osmangazi and Yıldırım Districts (Figure 2.61). Bursa's Historical Sites [Hüdavendigar (Murad the First) Complex, Muradiye (Murad the Second) Complex, Yıldırım (Bayezid the First) Complex, Yeşil (Mehmed the First) Complex and Khans District] are spatially and functionally connected with each other (Figure 2.62). They have value both separately and as a group. Complexes, khans/bazaars, neighborhoods, and waqfs (including Waqf's revenue source village), represent a specific location, function, and institution in an Ottoman city (Bursa Metropolitan Municipality - Bursa Site Management Unit, 2013).

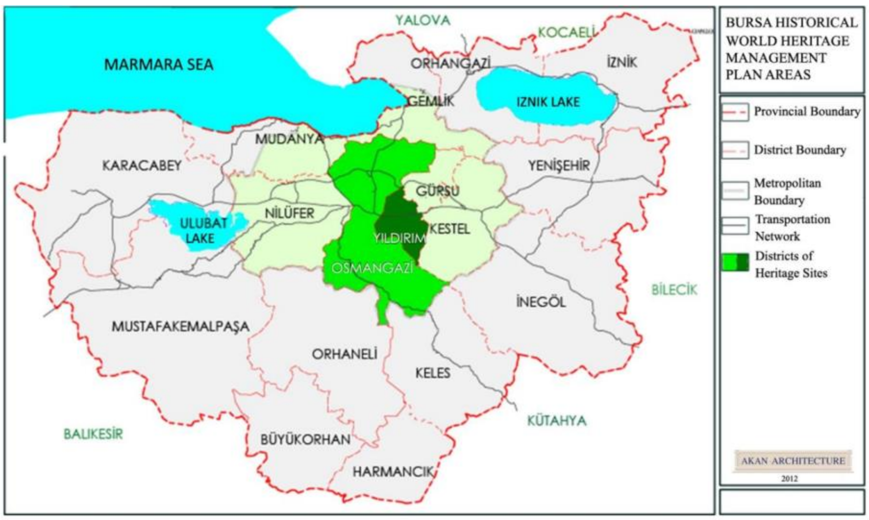


Figure 2.61. The map of Bursa showing the districts of heritage sites: Osmangazi and Yıldırım Districts.
(Source. Bursa Metropolitan Municipality - Bursa Site Management Unit, 2013)

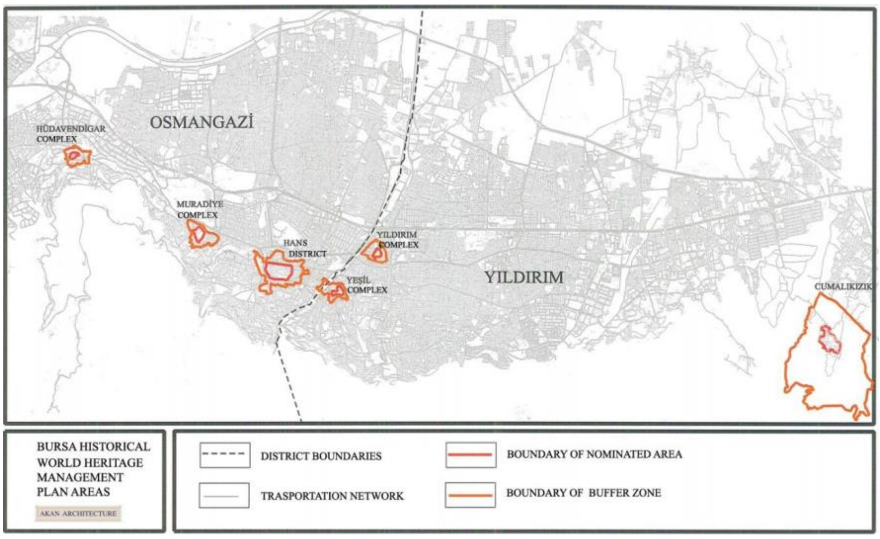


Figure 2.62. Boundaries of World Heritage Sites in Bursa (Khans District and Sultan Complexes) and Cumalıkızık (drawing prepared by Akan Architecture) (Source. Bursa Metropolitan Municipality - Bursa Site Management Unit, 2013)

After visiting the Sultan Complexes, Khans District and Cumalıkızık in August 2014, Muradiye Complex was selected to investigate in detail among the other sites to due ongoing restoration project.

2.4.3. Muradiye Complex

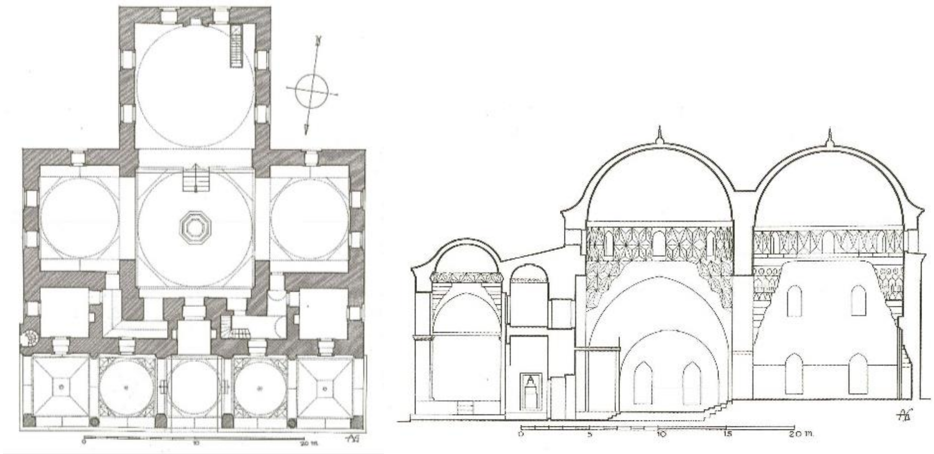
Muradiye Complex is composed of a mosque, bath, madrasah, public kitchen and twelve tombs. These tombs which belong to the members of the Ottoman Royalty such as spouses, children, close relatives of Sultans, and various courtiers are the resting places for Sultan Murad the Second [and Şehzade (Prince) Allaaddin], Şehzade Ahmed, Şehzade Mustafa, Cem Sultan, Şirin Hatun, Gülruh Sultan, Gülbahar Hatun (Ebe - Obstetrician Lady), Şehzade Mahmud, Mükrime Hatun, Hüma Hatun, Saraylılar (Female Servants) and Gülşah Sultan (Figures 2.63 and 2.64) (Aslanapa, 1986). Details regarding buildings in Muradiye Complex are given in the following sections.

Figure 2.63. The aerial view of the Muradiye Complex
(Source. Survey report on Sultan Murad the Second obtained from Metropolitan Municipality of Bursa, 2010)

Figure 2.64. A view from southeast (from left to right, the tomb of Sultan Murat the Second, the Tomb of *Şehzade* Ahmet, the Muradiye Mosque and the tombs called Hüma Hatun and Saraylılar (photo taken by Beatrice St. Laurent)
(Source. Courtesy Aga Khan Visual Archive, MIT, 1981)

2.4.3.1. Muradiye Mosque

The Mosque was the first project in the complex, completed in 1426. It is built in a simplified inverse T plan with a five-bay portico, constructed of brick and with three major domes and two cross cavetto vaults (Figure 2.65). The portico is carried on four marble and two granite columns. The construction method is three courses of clay brick to one of coursed rubble stone block. The central hall is flanked by *iwans* on the east, west and south where a larger *iwan* with *mihrab* niche is located. The *mihrab* was rebuilt in the rococo style after a fire in the early 18th century. The mosque has two minarets on the northeast and northwest corners (Figure 2.66). One of them is old and the other is new which was built in 1904 after an earthquake in the 19th century (Baykal, 1950; Ayverdi, 1972; Freely, 2011, Archnet, 2015; and Bursa, 2015).



(a) (b)

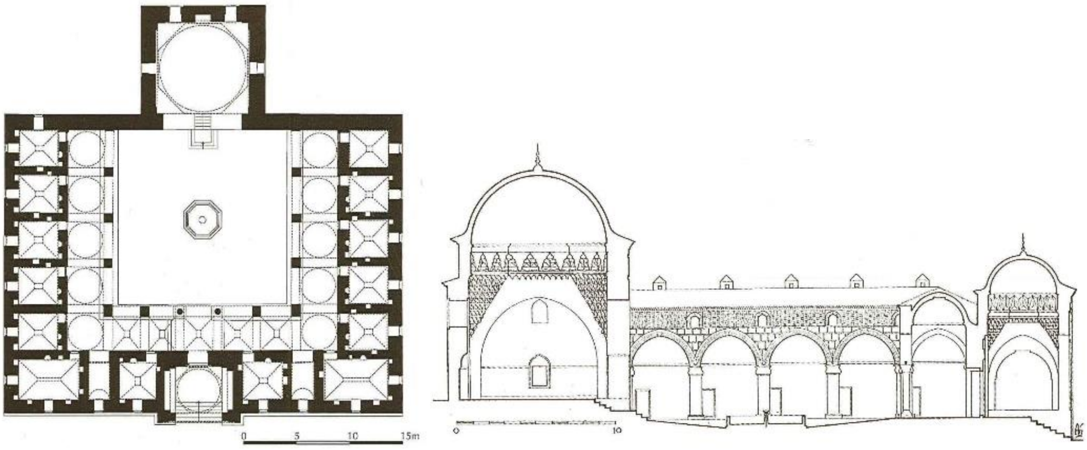
Figure 2.65. (a) Inverse T plan and (b) the longitudinal section of the Muradiye Mosque. (Source. Gabriel, 1958)

Even though it has a fairly simple plan, the portico and the interior are very rich in terms of decoration. The weaving patterns of brick and blue tiles are on the upper part of portico while the colorful enamels and various motifs of glazed-tiles in turquoise and dark blue are inside of the mosque (Baykal, 1950; Ayverdi, 1972; Freely, 2011, Archnet, 2015; and Bursa.com.tr, 2015).

Figure 2.66. The minaret on the northwest corner is old while the one on the northeast, which was built in 1904 after an earthquake in 19th century, is new (Source. Metropolitan Municipality of Bursa, 2011)

2.4.3.2. Muradiye Madrasa

The Muradiye Madrasa, which is dated 1426, stands on the west side of Muradiye Mosque as a the second largest building in the complex. The *iwan* of the portal to the north, which is covered with a dome resting upon Turkish triangles, opens to the cavetto cross vaulted portico. The madrasa is composed of a square shape inner courtyard (17 m x 17 m) surrounded by 16 cells and an *iwan* used as a classroom on the south side. The *iwan* is also covered by a dome. The other two sides (east and west sides) of the courtyard surrounded with domed porticoes. In the middle of the courtyard, octagonal pool was placed (Figure 2.67) (Ayverdi, 1966; Dostoğlu, 2001; and Kuban, 2007).



(a) (b)

Figure 2.67. (a) The plan and (b) the longitudinal section of the Muradiye Madrasah. [Source. (a) Ayverdi, 1966; and (b) Gabriel, 1958]

The alternating courses of brick and stone were employed to built main walls whereas the porticoes are supported by piers built with brick. The exception is seen in the marble columns with Corinthian capitals (used as bases) of the portico in front of the entrance (Dostoğlu, 2001 and Kuban, 2007). The madrasa is known with its decoration. The interior of the classroom iwan was decorated with dark blue and turquoise glazed tiles while the facades are decorated with brick and stone, which is similar to that on the portico spandrels of Muradiye Mosque (Figure 2.68) (Öney, Bulut, Çakmak, Daş, Demir, Demiralp and *et al.*, 2010).

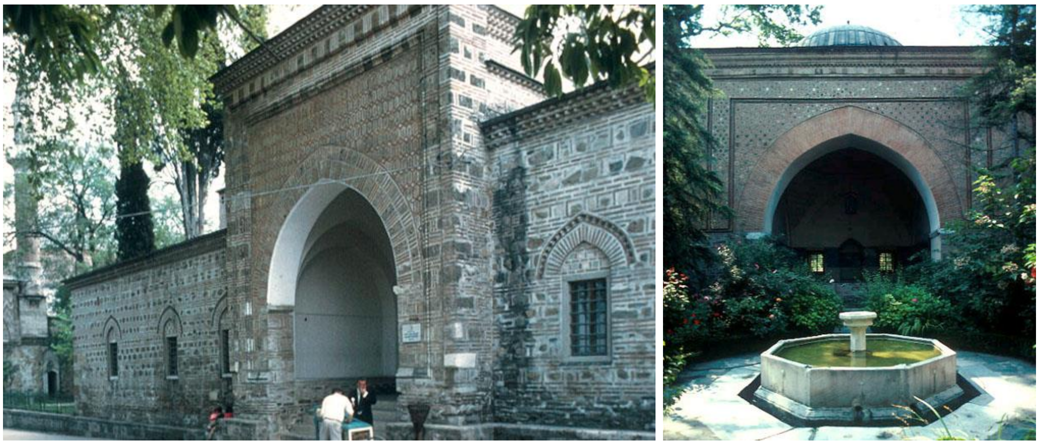

(a) (b)

Figure 2.68. (a) The entrance facade of the madrasa showing the decorated brick and stone orders on the portal and alternating stone and brick courses of the main walls; and (b) the decorated facade of the classroom iwan.
[Source. (a) Walter B. Denny, ca. 1960; and (b) Beatrice St. Laurent, 1981]

The madrasa, which was restored in 1603 and 1851, was used as the dispensary to fight tuberculosis after being restored in 1950 (Dostoğlu, 2001). In 2004, the building was repaired again to use as both the Center of Early Diagnosis and Treatment of Cancer and a community clinic.

2.4.3.3. Muradiye Hammam

The hammam, which is the third largest building in the complex, is the further to the west of the madrasa. It was built in 1425 with a basic layout (Figure 2.69). The entrance of the hammam on the east facade, which is above the street level, has a portal built with alternating courses of brick and stone. The dome of the changing section of the hammam, whose diameter is 10 m., rests upon squinches and has two octagonal drums. Due to the second drum, the slope of the eaves was diminished. The roof lantern is at the top of this main dome. The next room is the hot room in which there are three sections including the marble basin (common bathing place), two partially enclosed bathing cubicles *(halvet)* and middle heated marble platform (*göbektaşı*). The central space, iwans and halvets are illuminated by the skylights on the domes. At the end of the hammam, there are a boiler room (*külhan*), where the fire burn, and a water tank (Ayverdi, 1966 and Şehitoğlu, 2008).

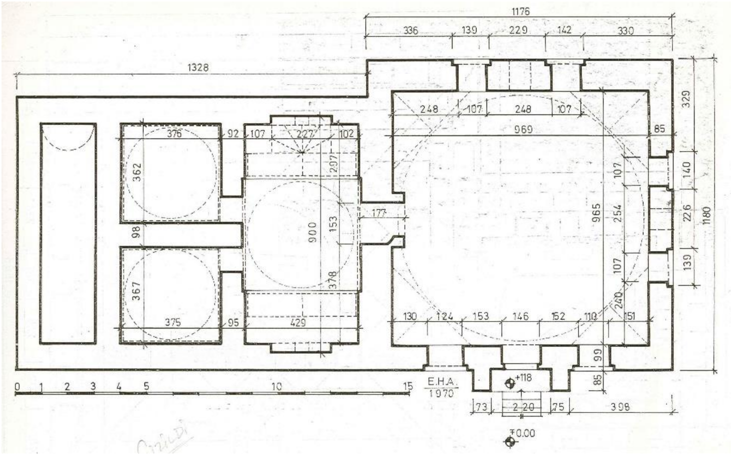


Figure 2.69. The floor plan of the hammam.
(Source. Ayverdi, 1966)

The alternating three courses of brick and two or three courses of stone were employed to built main walls (Ayverdi, 1966). The thickness of the walls is 85 cm (Yenal, 2013). The drums are constructed with two courses of brick and one course of cut-stone. Bricks were also placed vertically in between stones (Figure 2.70) (Ayverdi, 1966).

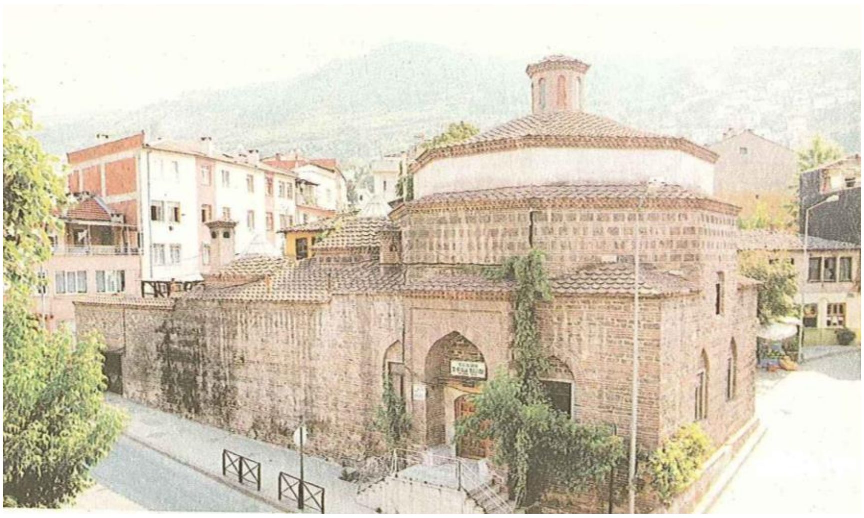


Figure 2.70. The exterior of the hammam.
(Source. Şehitoğlu, 2008)

The hammam, in which three comprehensive conservation repair and maintenance programmes were conducted in 1523, 1634 and 1742 (Ayverdi, 1966), passed into private ownership in the first decade of the Republic. In 1980s, the restoration works were conducted; and the hammam was run as its original purpose until 1996 (Şehitoğlu, 2008). After that date, the hammam was expropriated by Osmangazi Municipality and restored to be used as a center for disabled people (Arkitera, 2009).

2.4.3.4. Muradiye Tombs

In the garden of the Muradiye Complex, there are 12 mausoleums, which belong to Ottoman family and their servants, dating from various periods (Figure 2.71). They are located under plane trees and cypresses (Öney *et al.*, 2010).

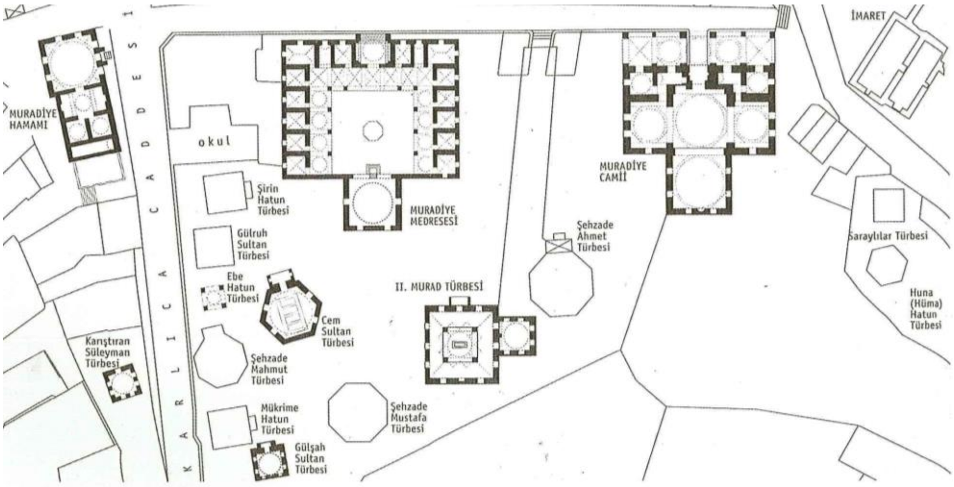


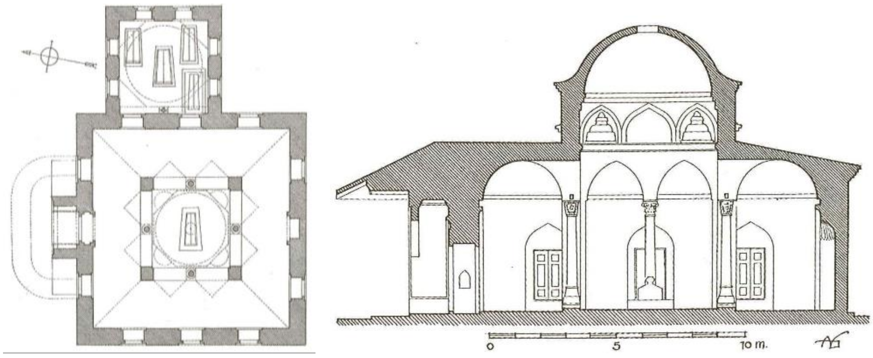
Figure 2.71. The tombs in the Muradiye Complex
(Source. Cengiz, 2008)

(i) Tomb of Murad the Second [and *Şehzade* (Prince) Alaaddin]

The tomb of the Last Ottoman Sultan, who was buried in Bursa, is the biggest one among the tombs in the complex (Figure 2.72). It was built in 1451 in accordance with the will of Sultan Murad the Second as a square-shaped building with an open roof on top of the grave, in order to get rain inside. The tomb is located on the south side of the Complex and is entered by passing through a marble portico. A large wooden canopy protects the entrance whose ceiling is embellished with gilded star patterns carved and in relief. The construction method is two courses of brick and one of ashlar blocks. On the eastern side of the tomb, a large adjacent window is used to enter the tomb of *Şehzade* Alaaddin who died before his father but whose tomb was built after his father's tomb. Inside the square shaped tomb, besides Şehzade Alaaddin, the graves of Şehzade Ahmed, Şehzade Orhan and his daughter Hatun Sultan are also found (Yavaş, 2006, Yenal, 2012; and Bursa, 2015).

Figure 2.72. The aerial view of the complex (red circle shows the Tomb of Murad the Second)
[Source. The web site of Bursa Site Directorate (taken in 2012)]

The building consists of two adjacent spaces that house the graves of Sultan Murad the Second and *Şehzade* Alaaddin are square shaped with sides measuring 13.45 x 13.45 m and 6.90 x 6.90 m, respectively (Figure 2.73). The dome of the tomb, which is surrounded by vaults, sits on an octagonal hoop (Yavaş, 2006).



(a) (b)

Figure 2.73. The plan of the Tomb which is consisted of two adjacent spaces which belong to Sultan Murad the Second and *Şehzade* Alaaddin
(Source. Gabriel, 1958)

(ii) Tomb of *Şehzade* (Prince) Ahmed

The tomb was built in 1513 in the memory of Şehzade Ahmed the son of Beyazid the Second (Yavaş, 2006). The tomb, which has an octagonal plan scheme, was built by using alternating two courses of brick to one course of cut-stone. The dome stands on eight pendentives. There are three rows windows in every facade, whose arches were constructed with brick. The impressive wooden door made by using *kündekari* technique was protected by the entrance canopy standing on marble Bursa style arches (Figure 2.74). The interior walls were decorated with turquoise and dark blue hexagonal glazed tiles (Aslanapa, 1971 and Gabriel, 1958).

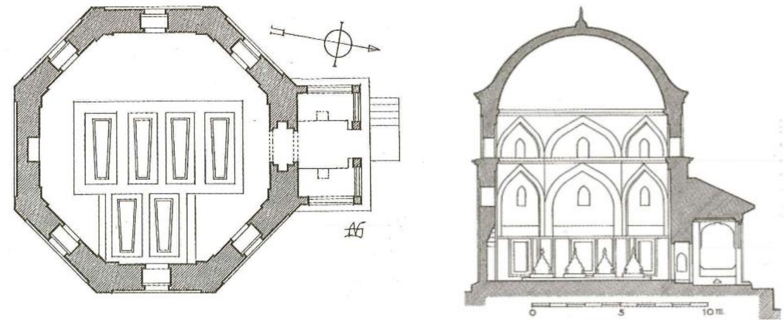
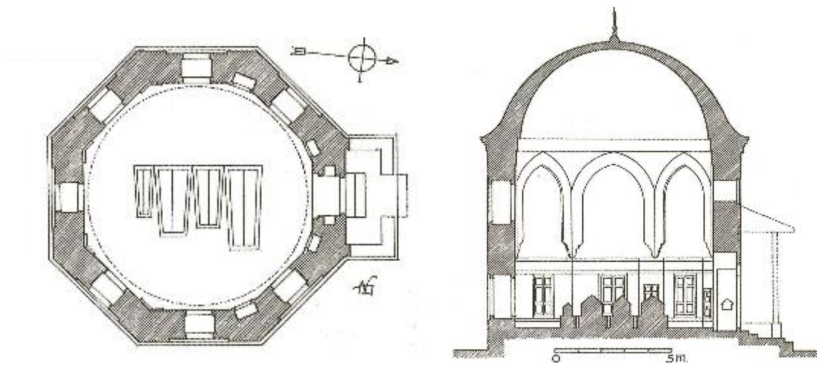


Figure 2.74. The plan and the section of the Tomb of
(Source. Gabriel, 1958)

(iii) Tomb of *Şehzade* (Prince) Mustafa

The tomb was built in the sixteenth century to the memory of the son of Süleyman the First, Mustafa. The tomb, which has an octagonal plan scheme, was built by using alternating three courses of brick to one course of cut-stone. The building has seven windows with marble casing at the lower part and seven windows with pointed arches (Figure 2.75) (Yavaş, 2006).

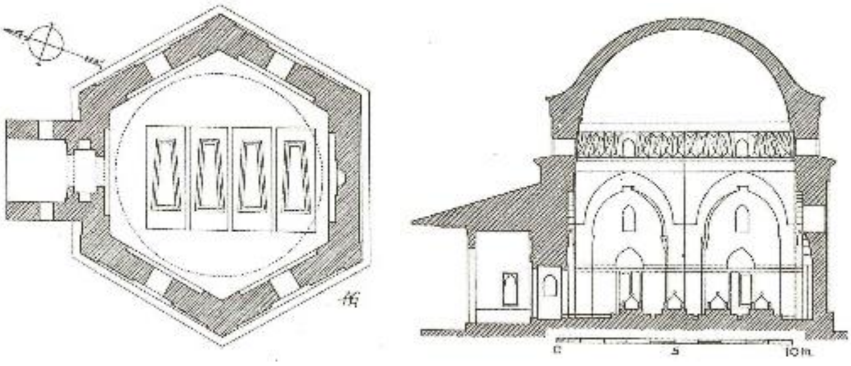


(a) (b)

Figure 2.75. (a) The plan and (b) the section of the tomb.
(Source. Gabriel, 1958)

(iv) Tomb of Cem Sultan

The tomb was built in 1479 to the memory of the son of Fatih the Conqueror, Mustafa. It has a regular hexagonal plan, whose sides' common length is 7 m. The dome rests on the hexagonal drum and is covered with lead sheets. The entrance is protected by a huge wooden canopy, which stands on marble walls. There are two openings in each sides (Figure 2.76) (Ayverdi, 1966 and Eyice, 1993).



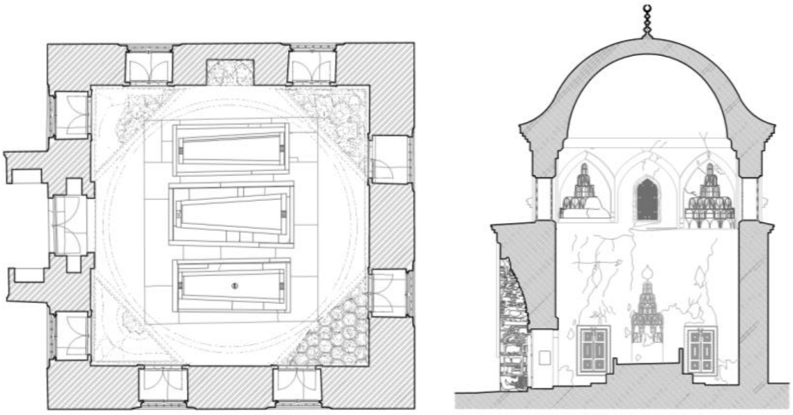
(a) (b)

Figure 2.76. (a) The plan and (b) the section of the tomb.
(Source. Gabriel, 1958)

Two courses of brick to one course of stone were employed to build main walls. The vertical bricks were laid in between stones. The hexagonal tiles in turquoise and dark blue decorate the interior. The wooden entrance door was constructed by *kündekari* technique. The wooden door, shutters and the gypsum framed windows are in their original form (Gabriel, 1958; Aslanapa, 1971 and Eyice, 1993).

(v) Tomb of Şirin *Hatun*

The tomb, which is located near the madrasa, was built in the end of fifteenth century. It is similar with the tombs of Gülruh Hatun and Mükrime Hatun. It has a square plan topped with a dome. The dome covered with lead sheets rests upon squinches with muqarnas and the octagonal drum (Figure 2.77). The four brick courses constitute the half-dome muqarnas hood (*kavsara*) of the entrance portal. There are two niches in the left and the right sides. The building has eight windows with marble casing and pointed arch pediment, and four windows at the drum with pointed arch and gypsum frame (Yavaş, 2006 and Vakıflar Genel Müdürlüğü, 1983).



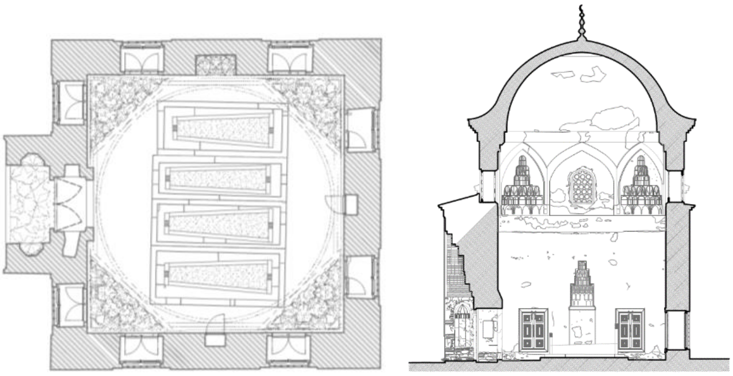
(a) (b)

. **Figure 2.77.** The survey drawings of the latest restoration project of the tomb; (a) the plan and (b) the section.
(Source. The firm titled D2 Tasarım Mimarlık , 2010)

One course of cut- stone to two courses of brick were employed to build main walls, which ends with the saw-tooth brick courses. The vertical bricks were laid in between stones.

(vi) Tomb of Gülruh Hatun

The tomb, which was built in the beginning of the sixteenth century, has a square plan topped with a dome. The wife of Beyazıd the Second was buried in 1502. The dome covered with lead sheets rests upon squinches with muqarnas and the octagonal drum having four windows (Gabriel, 1966 and Dostoğlu, 2001). The entrance iwan has four rows of stalactite and niches in the left and the right sides. The wooden entrance door, which has marble casing, and wooden window shutters are original. The building has twelve windows with marble casings (Figure 2.78) (Dostoğlu, 2001).



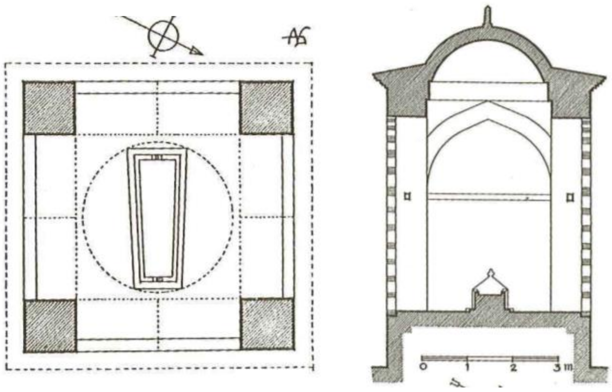
(a) (b)

Figure 2.78. The survey drawings of the latest restoration project of the tomb; (a) the plan and (b) the section.
(Source. The firm called D2 Tasarım Mimarlık , 2010)

Two courses of brick to one course of stone were employed to build main walls, which ends with the saw-tooth brick courses. The vertical bricks were laid in between stones (Dostoğlu, 2001).

(vii) Tomb of Gülbahar *Hatun* (Ebe - Obstetrician Lady)

It is one of the examples of baldachin tombs like the Tomb of Saraylılar in the complex. The plan of the tomb is square (4.46 x 4.46 m). The piers with the square cross section (0.78 x 0.78 m.) stand on the base, which is constructed with rubble stone. The piers are built with alternating one course of cut-stone to two courses of brick while the pointed arches are built with one course of cut-stone to three courses of brick (Figure 2.79). The dome is made of concrete whose appearance like lead sheets. Although there is any inscription on the tomb, it is assumed that the grave belongs to obstetrician of Mehmed the Conqueror (Yavaş, 2006).

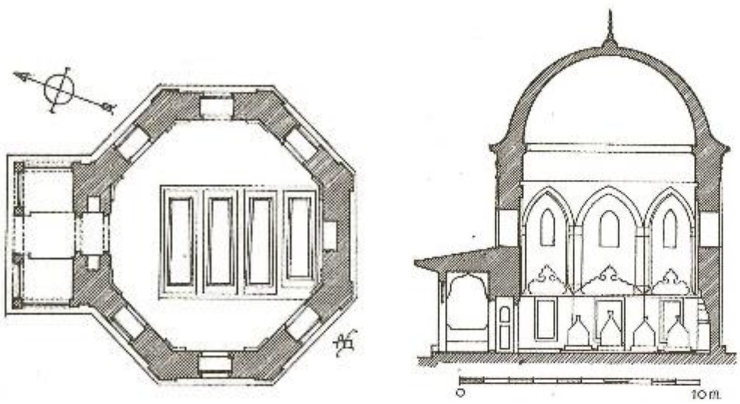


(a) (b)

Figure 2.79. (a) The plan and (b) the section of the tomb.
(Source. Gabriel, 1958)

(viii) Tomb of *Şehzade* (Prince) Mahmut

The tomb was built in 1505-1506. The floor plan, which is similar with the tomb of *Şehzade* Ahmed, son of Sultan Beyazid the Second, is octagonal. The entrance is reached through the marble portico, which has "Bursa style" arches (Figure 2.80) (Aslanapa, 1971).



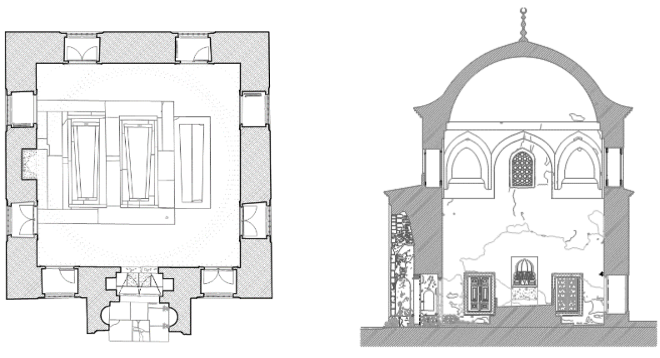
(a) (b)

Figure 2.80. (a) The plan and (b) the section of the tomb.
(Source. Gabriel, 1958)

The alternating one course of cut-stone and three courses of brick were employed to build main walls. The interior is rich in turquoise and dark blue hexagonal glazed tile decoration and plaster relief in *malakari* technique (Aslanapa, 1971 and Yavaş, 2006).

(ix) Tomb of Mükrime *Hatun*

The tomb, which is located at the southeast of the complex, was built in 1515. It has a square plan topped with a dome. The dome covered with lead sheets rests upon squinches with muqarnas and the octagonal drum (Figure 2.81). The four brick courses constitute the half-dome muqarnas hood (*kavsara*) of the entrance portal. There are two niches in the left and the right sides. The building has eight windows with marble casing and pointed arch pediment, and four windows at the drum with pointed arch and gypsum frame (Yavaş, 2006 and Vakıflar Genel Müdürlüğü, 1983).



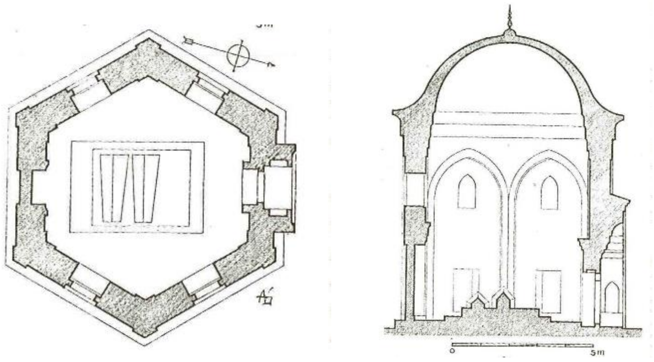
(a) (b)

Figure 2.81. The survey drawings of the latest restoration project of the tomb; (a) the plan and (b) the section.
(Source. The firm called D2 Tasarım Mimarlık , 2010)

One course of cut- stone to three courses of brick were employed to build main walls, which ends with the saw-tooth brick courses.

(x) Tomb of Hüma *Hatun*

The tomb, which was built in 1449 to the memory of one of the wives of Murad the Second, is located at the east of the mosque. The hexagonal plan of the tomb is placed in the circle whose radius is 4.40 m. The dome, which has not a drum, is covered with lead sheets. The entrance is reached through a small iwan (Figure 2.82) (Ayverdi, 1966 and Vakıflar Genel Müdürlüğü, 1983)



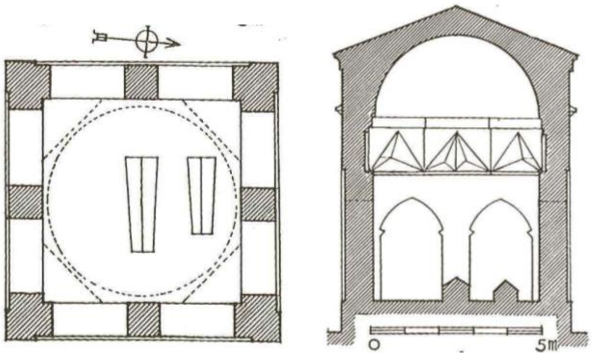
(a) (b)

Figure 2.82. (a) The plan and (b) the section of the tomb.
(Source. Gabriel, 1958)

One course of pitched face stone to two courses of brick were employed to build main walls, which ends with the saw-tooth brick courses. The vertical bricks were laid in between stones (Ayverdi, 1966).

(xi) Tomb of *Saraylılar*

The tomb, which is located southeast of Muradiye Mosque, was built in fifteenth century. The square based plan (6.68 x 6.68 m) is topped with the pyramidal roof standing on Turkish triangles as a transition element, eight pointed arches and eight piers. It is one of the examples of baldachin tombs like the Tomb of Gülbahar Hatun (Figure 2.83) (Kılcı, 2005 and Yavaş, 2006).



(a) (b)

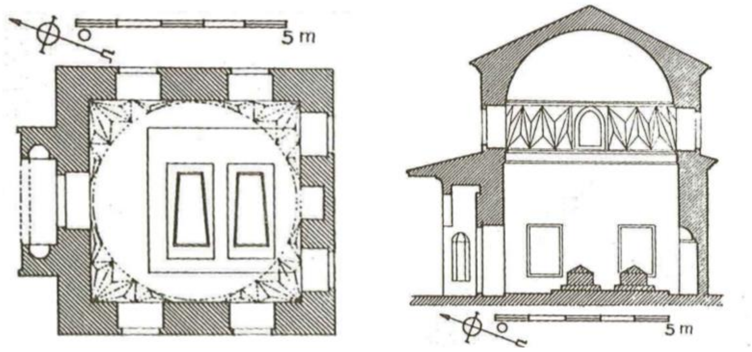
Figure 2.83. (a) The plan and (b) the section of the tomb.
(Source. Gabriel, 1958)

The alternating one course of cut-stone and three courses of brick were employed to build eight piers. The vertical bricks were laid in between stones. The pyramidal roof of the tomb stands on eight pointed arch. The saw-tooth courses were used around and above the pointed arches, and under the eaves (Kılcı, 2005).

(xii) Tomb of Gülşah *Hatun*

The tomb was built in fifteenth century in the memory of one of the wives of Mehmed the Conqueror. The square based plan is topped with the dome standing on squinches. The drum of the dome is octagonal (Figure 2.84) (Yavaş, 2006).

The tomb entrance is reached through a small *iwan* where two niches are at both sides (left and right). The portal has a pointed arch while the casing of the door is marble. The wooden entrance door was constructed by *kündekari* technique. The windows at the lower part have pointed arches and marble casings whereas the windows at drum have pointed arches and gypsum frames (Yavaş, 2006 and Vakıflar Genel Müdürlüğü, 1983).



(a) (b)

Figure 2.84. (a) The plan and (b) the section of the tomb.
(Source. Gabriel, 1958)

Alternating one course of stone to two courses brick were employed to build the main walls whose thickness is in range between 0.82 m and 0.85 m. The walls are ended with the saw-tooth brick courses under the eaves (Vakıflar Genel Müdürlüğü, 1983).

2.4.4. Changes in Local Climate Trends

In the twentieth century, the rapid urbanization and the growth of cities have been two of the major forces that effect climate systems; as urbanization reshapes the surface of the earth that results in a number of governance, infrastructural and environmental issues, and alters the characteristics of the surrounding atmospheric conditions. Therefore, the effects of cities and human activities on the climate, and the impacts of climate change on cities are being studied in depth.

As urbanization rate has also increased significantly in Turkey, the effect of urbanization on local climate trends, especially temperature and precipitation trends has become significant. In order to understand these effects, many studies have focused on illustrating changes in annual temperature and precipitation trends in Turkey. As the case study area of this dissertation is Bursa, the studies including detection of changes in local climate trends of Bursa have been investigated, and a few of them are presented in the following paragraphs.

The research was conducted by Vardar, Kurtulmuş and Darga (2011) to detect the local indications of global climate change in Bursa during the 1975-2005 time period. The four different meteorological stations *i.e.* Bursa city center, top of Uludağ Mountain, Yenişehir and Keleş were selected. Meteorological data used in the study are daily mean temperature (◦C), daily minimum and maximum temperature (◦C), insolation intensity (cal/cm2), daily total insolation duration (hour), minimum temperature above soil (◦C), daily soil temperatures at depths of 5 cm, 10 cm, and 20 cm, daily mean pressure (mb), daily total rainfall (mm), daily mean wind speed (m/s) values. These data indicate that there was a considerable warming at statistically 1% and 5% levels of significance in summer months, particularly in July. The increase in July and August on a yearly basis and yearly maximum increase in Bursa is significant at 1% significance level (Figure 2.85). Mean temperature values were also higher than long-term mean value nine years repetitively in the last twelve years, contrary to previous 18 years. To conclude, data belonging to the last 12 years clearly highlights the occurrence of some changes in climate trends.

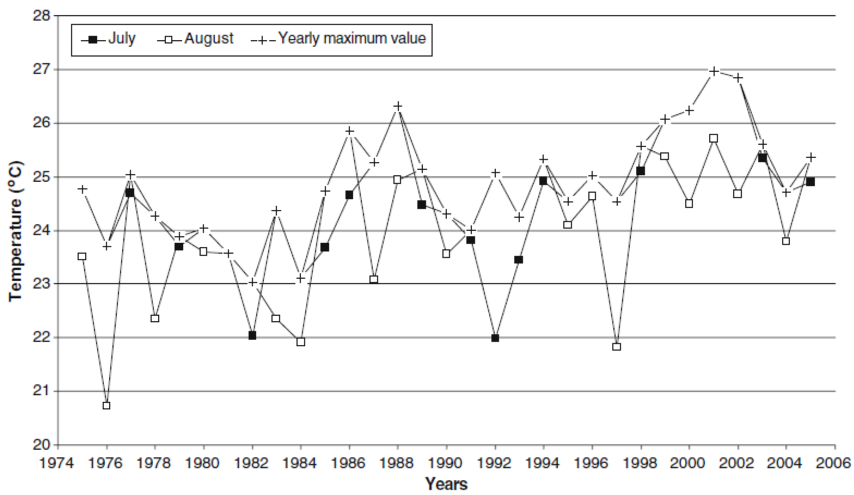


Figure 2.85. Change of the mean temperatures depending on years in Bursa center (Source. Vardar, Kurtulmuş and Darga, 2011)

According to the study of Kindap *et al.* (2012) which covers 8 cities with a population of more than 1,000,000, namely İstanbul, Ankara, İzmir, Bursa, Gaziantep, Mersin, Kayseri and Şanlıurfa, the measurements in all selected urban stations show significant increases between 1965-2006. It is indicated that average temperatures in all eight cities are higher than temperatures in 1960s, as of 2009 (Figure 2.86).

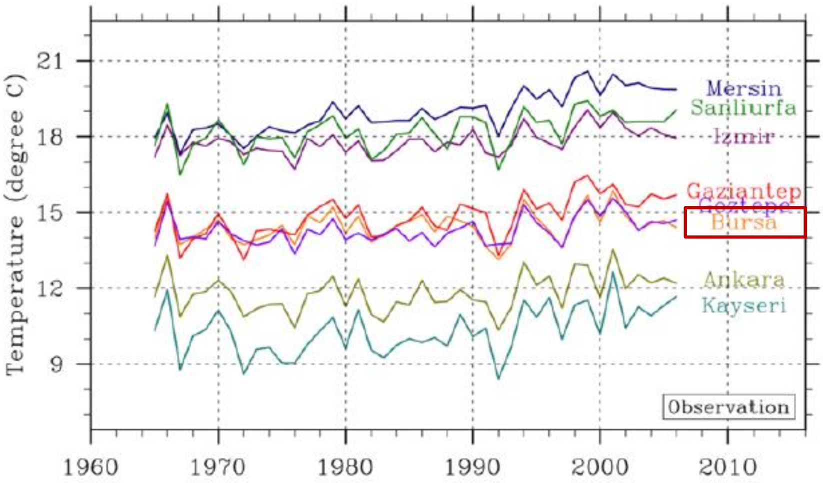
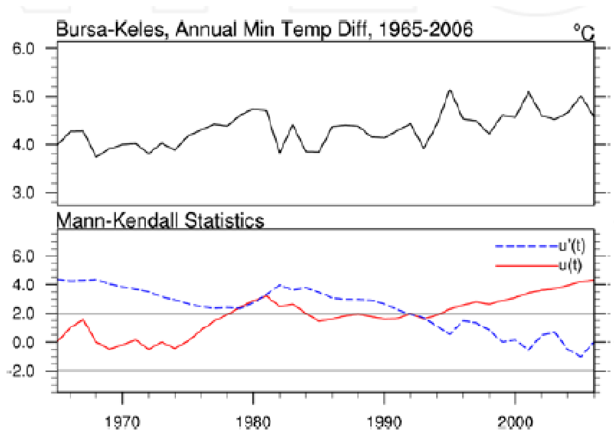


Figure 2.86. Average temperatures in the selected cities from 1965 to 2006 (Source. Kindap *et al.*,2012)

It is also indicated that the minimum temperature difference series for Bursa and Keleş stations show significantly increasing warming trend with a Mann-Kendall statistic of 4.30 (Figure 2.87).



Station pairs (urban-rural)	T_{min} Statistics (1965-2006)
Ankara Bolge – Polatli	5.88
Ankara Bolge - Kizilcahamam	2.92
Ankara Bolge – Beypazari	6.25
Ankara Bolge - Esenboga	4.30
Ankara Bolge - Nallihan	5.13
Bursa - Keles	4.30
Gaziantep - Islahiye	5.82
Istanbul (Florya) - Kirecburnu	2.66
Istanbul (Florya) - Kumkoy	3.74
Istanbul (Florya) - Sile	4.63
Istanbul (Goztepe) - Kirecburnu	6.01
Istanbul (Goztepe) - Kumkoy	4.63
Istanbul (Goztepe) - Sile	5.75
Izmir Bolge - Dikili	2.13
Kayseri Bolge - Develi	5.06
Kayseri Bolge - Pinarbasi	5.86
Kayseri Bolge - Tomarza	6.93
Mersin - Erdemli Alata	6.82
Sanliurfa Bolge - Birecik	5.54

Mann Kendall statistics of the urban and rural minimum temperature differences

(a) (b)

Figure 2.87. (a) The annual time series and Mann-Kendall tests for the minimum temperature differences between urban and rural stations of Bursa; (b) Mann-Kendall statistics of the urban and rural minimum temperature differences
Source. Kindap *et al.* (2012)

To conclude, the studies show that there is an increasing trend in both average temperatures and minimum temperatures in Bursa. Since the changes in temperature values have effects in weathering processes, these upward trend should be investigated in terms of management of historic buildings. Therefore, in the following chapters, trend analysis for temperature and precipitation values, which were conducted by using climate data of the weather stations in Bursa for the period of 1965-2014, are presented with the interpretation of both previous studies and the projections.

CHAPTER 3

RESEARCH MATERIALS

This research was conducted with an aim to understanding the links between the anticipated impacts of climate change and the deterioration mechanisms on tangible heritage over this century; and to contribute to the development of more effective and efficient management responses / strategies, which are capable of helping heritage managers implement relevant actions to cope with the changes, by producing overlay maps, heritage climate maps and heritage risk maps. This requires combining analyses and evaluation of different data sets from various sources.

Various softwares were employed to execute the research, such as ArcGIS 10, which provides spatial analysis tools to produce the above-mentioned maps, Adobe Photoshop CS 5.1, AutoCAD 2014 and Microsoft Office Excel with Addinsoft's XLSTAT 2015 add-in, which is used for performing the statistical Mann-Kendall trend tests.

The initial phase of the research includes a thorough literature review, which is focused on cultural heritage, changes in climate system and an analysis of the link between the two. In this phase:

- both international and national policies, adaptation strategies, decision papers, communication and progress reports, charters, guidelines and manuals on both climate change and cultural heritage were reviewed;
- scientific articles published in peer-reviewed journals, books and conference proceedings were examined in terms of climate trends (observations and projections), climate models and scenarios, various hazards affecting tangible heritage, historic buildings, traditional building materials and their deterioration processes, and climate change parameters related to these processes.

Apart from the literature review, data and information regarding the context of Turkey and the case study area 'Bursa' were collected from international projects, and various institutions, which are presented in the following sections.

3.1. Hierarchical Climate Maps

The hierarchical maps, such as climate maps, heritage climate maps, damage maps, risks maps and thematic maps, were produced within the European Union funded research project titled Noah's Ark (Global climate change impact on built heritage and cultural landscapes), which aimed to assess the risk of buildings and monuments over the century (see Chapter 2 and Appendix A). These maps, which were the outputs of the global and regional Hadley Models (HADCM3 and HADRM3), were used to outline the climatic parameters that affect historical buildings, and mitigation strategies for sites, monuments and specific materials that may be under risks. In brief, the outputs of this project include important information, which link meteorological risks to tangible heritage.

Within this study, the output maps of this project that outline areas with increased or decreased risks, where deterioration mechanisms of buildings were most likely to be affected, were used in order to produce overlay maps focusing on Turkey. These overlay maps were analyzed to construct the base of the case study.

3.2. Climate Data Series

The climate data focusing on Bursa and its surrounding cities (Balıkesir, Bilecik, Kütahya, Kocaeli and Sakarya) were obtained from the meteorological stations' database of Turkish Ministry of Forestry and Water Affairs - General Directorate of Meteorology (GDM) (TC Orman ve Su İşleri Bakanlığı - Meteoroloji Genel Müdürlüğü) (Table 3.1). The data series from 1965 to 2014 include:

- daily and monthly average / minimum / maximum temperature data;
- daily average / minimum / maximum relative humidity data;
- monthly total precipitation;

- monthly number of days with precipitation of greater than or equal to 0.1 mm,
- monthly number of days with maximum temperatures of greater than or equal to 30 °C.

After checking the completeness of the data series, it was noticed that some of the stations were closed after a few years while some of them were opened recently; and some daily measurements were missing. Therefore, extra data were obtained from the synoptic[18] stations' measurements of the GDM to complete missing ones.

Table 3.1. Brief information about the weather stations in Bursa and its surrounding cities.

Station Codes	Stations	Height (m)	X-longitude	Y-latitude
17152	Balıkesir	100	27° 55'	39° 36'
17114	Balıkesir - Bandırma	63	27° 59'	40° 19'
17120	Bilecik	539	29° 58'	40° 9'
17116	Bursa	100	29° 0'	40° 13'
17118	Bursa - Yenişehir	238	29° 33'	40° 15'
17663	Bursa-Gemlik	10	29° 9'	40° 26'
17670	Bursa-İnegöl	280	29° 29'	40° 5'
17661	Bursa-İznik	90	29° 44'	40° 26'
17675	Bursa-M.Kemal	60	28° 24'	40° 2'
17676	Bursa-Uludağ	1877	29° 7'	40° 7'
17673	Bursa-Karacabey	15	28° 22'	40° 13'
17695	Bursa-Keles	1063	29° 4'	39° 55'
17066	Kocaeli	76	29° 56'	40° 46'
17155	Kütahya	969	29° 58'	39° 25'
17069	Sakarya	30	30.38	40.77

[18] Synoptic Weather Observation: "A surface weather observation, made at periodic times (usually at 3- and 6-hourly intervals specified by the World Meteorological Organization), of sky cover, state of the sky, cloud height, atmospheric pressure reduced to sea level, temperature, dew point, wind speed and direction, amount of precipitation, hydrometeors and lithometeors, and special phenomena that prevail at the time of the observation or have been observed since the previous specified observation." (http://encyclopedia2.thefreedictionary.com/synoptic+weather+observation)

3.3. Inventories and Archive Records on Tangible Heritage in Bursa

Information focusing on tangible heritage in Bursa is derived from the inventories of the Ministry of Culture and Tourism / General Directorate of Cultural Heritage and Museums (GDCHM) and the General Directorate for Foundations (GDF) in Ankara. The inventory of the Ministry includes name, address, map section, lot number, and names of the preservation boards that are responsible for historic assets, type of historic assets, and numbers and dates of boards' decisions (Table 3.2 and Appendix D).

As the inventory of the General Directorate for Foundations has not been completed yet, different amount of information is found for different assets. There are four main files: photographs, administrative, technical, and video recording, which are not available for all of the assets. Scanned and digitized photographs were available without a record of the date when the photograph was taken, and the report or a correspondence to which they were attached.

Table 3.2. Partial table showing the inventory obtained from MoCT-GDCHM (for full table see Appendix D)

CITY	DISTRICT	ADDRESS	NAME	MAP SECTION		LOT NUMBER	TYPE	NAME OF PRESERVATION BOARD	DECISION NUMBER AND DATE
BURSA	ORHANGAZİ	Camii Kebir Mah. Orhanbey Cad. No:31	Orhangazi Hamamı	10	290	e:1378 y:14	Kültürel Yapılar	GEEAYK/GEEAYK/BURSA KBK BURSA	12.2.1972 6118/14.10.1977 826/17.2.2006 1271/koruma
BURSA	İZNİK		İznik Surları(Nicaea)				Askeri Yapılar	GEEAYK	20.12.1975 8857
BURSA	ORHANGAZİ	İznik Gölü batısında	Tarihi Hamam				Kültürel Yapılar	GEEAYK	10.9.1976 153
BURSA	KELES	Cuma Mah.	Yakupbey Hamamı	2429UB	12	9	Kültürel Yapılar	GEEAYK/BURSA KBK	10.3.1979 11046/24.1.2008 3266
BURSA	MUDANYA	Kumyaka Köyü	Kumyaka Köyü Hamamı				Kültürel Yapılar	GEEAYK	16.1.1982 13447
BURSA	MUSTAFA KEMAL PAŞA		Lala Şahin Paşa Külliyesi (Türbesi ve Camiden Kalan Minare)		343	Nov-21	Kültürel Yapılar	TKTVYK/BKTVKK	30.5.1985 1010/23.12.1994 3858
BURSA	MUDANYA	Güzelyalı Mah.	Kalıntılar	25	222	8	Kalıntılar	TKTVYK	18.7.1985 1232
BURSA	MUDANYA	Güzelyalı Mah.	Hamam Kalıntısı	25	404	20	Kalıntılar	TKTVYK	18.7.1985 1233
BURSA	İZNİK	Eşrefzade Mah. Kılıçaslan Cad.	Karahalil Paşa /Türbesinin Duvarları				Kalıntılar	TKTVYK	17.10.1985 1500
BURSA	ORHANELİ	Harmancık Bucağı	Karaveyisoğlu Konağı	37	-	1450	Sivil Mimarlık Örneği	TKTVYK	17.10.1985 1501
BURSA	KELES	Kemaliye Köyü	Kemaliye Köyü Camii				Dinsel Yapılar	TKTVYK	14.2.1986 1894
BURSA	MUDANYA	Zeytinbağı Bucağı Merkezi	Panagia Pantobasilissa Kilisesi				Dinsel Yapılar	BKTVKK	24.6.1988 43
BURSA	MUDANYA	Kumkaya köyü içinde	Hagios Taxiarchoi Kilisesi				Dinsel Yapılar	BKTVKK	24.6.1988 43

As the local impacts of climate change must be addressed on a practical level, and increased knowledge about the extent of damage on tangible heritage assets derived from deterioration mechanisms is necessary, the survey was limited to Bursa, and carried out in Muradiye Complex. In this regard, general information about Muradiye Complex as obtained from published sources were presented in Chapter 2 while historical records in the archives of Bursa Cultural and Natural Heritage Preservation Regional Board (CNHPRB), Bursa Regional Directorate of Foundations, and Metropolitan Municipality of Bursa; the survey drawings of the latest restoration project prepared by an architectural firm, D2 Architecture; and the revised restoration project of the Muradiye Hammam obtained from the personal archives of Professor Neslihan Dostoğlu are given from the perspective of the deterioration mechanisms, and their possible reasons and consequences in Chapter 5.

3.4. Field Surveys in Bursa

The field surveys were executed in August 2014 (summer season) and November 2014 (fall season). The following materials were gathered from the buildings in the complex:

- photographs taken by the author;
- decay mapping and condition assessment of deteriorated parts of the assets;
- identification of remedial actions.

CHAPTER 4

RESEARCH METHODOLOGY

This research was designed to examine the current debate on the anticipated impacts of climate change on tangible heritage, to determine the areas in Turkey under the threats of hazards derived from changing climate, and to produce overlay maps, heritage maps, and heritage-climate risk maps of tangible heritage. The research methodology, based on a mixed-method approach, consisted of five main steps and their sub-sections.

Delimitations: This integrated and broad methodology was made feasible by concentrating the study on the risks posed by climate change to tangible cultural heritage in a particular region of Turkey, which is expected to be under great risk in future. As Turkey has always been a melting pot for different cultures throughout its history, it has a large number of unique and valuable cultural properties. Among, civilizations settled in Anatolia, Ottoman Empire ruled over a period of about 700 years. Numerous changes have been observed in the character of Ottoman architecture over the course of this lengthy era. As it is a very broad subject to deal, the study is delimited to the early periods of Ottoman Architecture.

During the production of overlay maps, Istanbul, which is very rich in tangible heritage, was accepted as an outlier because the number of historic buildings is further away from the sample mean. Among the cities, which came to forefront in the overlay maps, Bursa was selected as being an important city during the early periods of Ottoman Empire; and also because it is listed as a UNESCO World Heritage site. These historic sites and buildings are expected to be under many risks due to climate change. Further, among these historic sites and buildings, the Muradiye Complex, which includes a mosque, a madrasah, a hammam, a soup kitchen, and 12 tombs, was selected as the case study area. Remedial activities have been conducted in the complex buildings and those in the tombs are ongoing. Hence, it was possible to obtain data on deteriorations and remedial works from the restoration project available from official records and in archives. In other words, the study is focused on the Muradiye Complex and the building materials used for construction of the buildings: stone, brick, timber, and metals.

4.1. Structuring GIS Data Model

Hierarchical maps, such as climate maps, heritage climate maps, damage maps, risks maps and thematic maps, which were produced by employing the outputs from Hadley Models (HADCM3 and HADRM3) within the European Union Project titled Noah's Ark (see Chapter 2 and Appendix A), were derived from the published sources in order to produce different types of maps focusing on Turkey, especially on Bursa. Reclassifying, visualizing, analyzing, and interpreting data to understand relationships, patterns, and trends needed to be elaborated in a systematic way. To this end, different tools of the ArcGIS 10 software were employed to produce, assess, and present the result of the study. The details of the processes are given in the following sub-sections.

4.1.1. Producing Overlay Maps

Hierarchical maps mentioned above were used to produce overlay maps of the climate parameters critical to heritage conservation and expected to change in the far future (2070-2099), and the map of areas by distribution of historic buildings in Turkey.

Overlay maps were prepared:

- to understand how buildings and materials could be vulnerable to potential impacts of climate change;
- to assess changing climate parameters' role in accelerating or decelerating the degradation of selected building materials through different weathering processes.
- to show the areas which are susceptible to the increasing risks of changing climate and being rich in historic buildings;
- to determine the most critical area for a case study.

Since the hierarchical maps were obtained by scanning from the Noah's Ark Project publication ‘The Atlas of Climate Change Impact on European Cultural Heritage’, spatial references of these maps were not defined. Therefore, a variety of tools was used to prepare scanned maps for further spatial analysis with ArcGIS 10. These tools allow raster data to be viewed, queried, and analyzed with other georeferenced data layers. In this regard, the process and the results are given in the following paragraphs.

1. Steps of Processing Raster Data: After uploading rasters to ArcGIS 10 software, they were georeferenced to a map coordinate system in order to use them in conjunction with spatial data. Then, a variety of tools was used to prepare rasters for visualization and spatial analysis applications. First, Image Classification Toolbar was operated to convert multiband (RGB) raster data into a single-band raster with a number of classes. To this end, training samples were collected with polygons, a signature file was created, and a Maximum Likelihood Classification Tool was executed on the raster to create a classified raster as output (Figures 4.1 and 4.2).

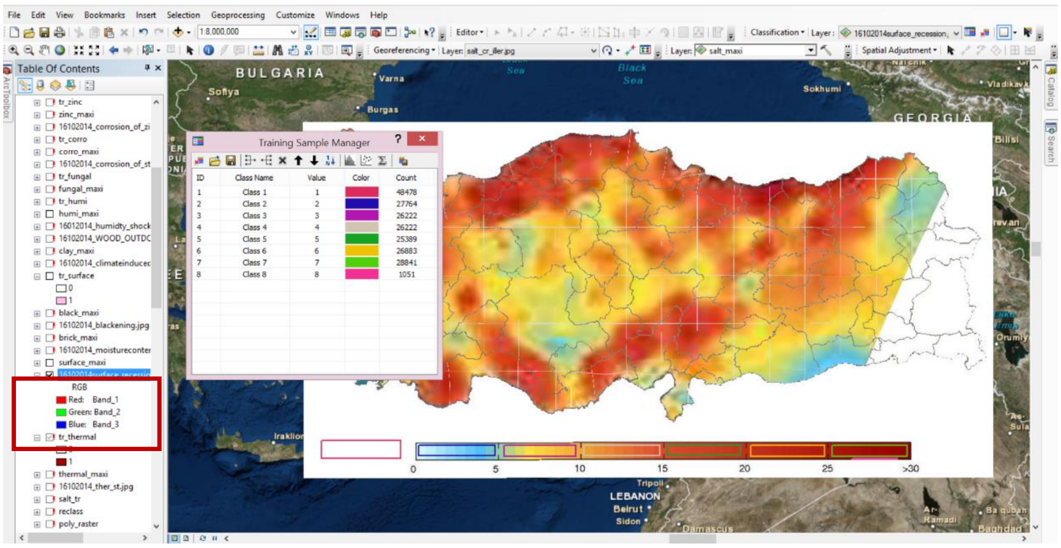


Figure 4.1. The snapshot view of ArcGIS 10 software shows creating classes in the training sample manager by choosing areas, which have relatively uniform appearance on the image (prepared by the author).

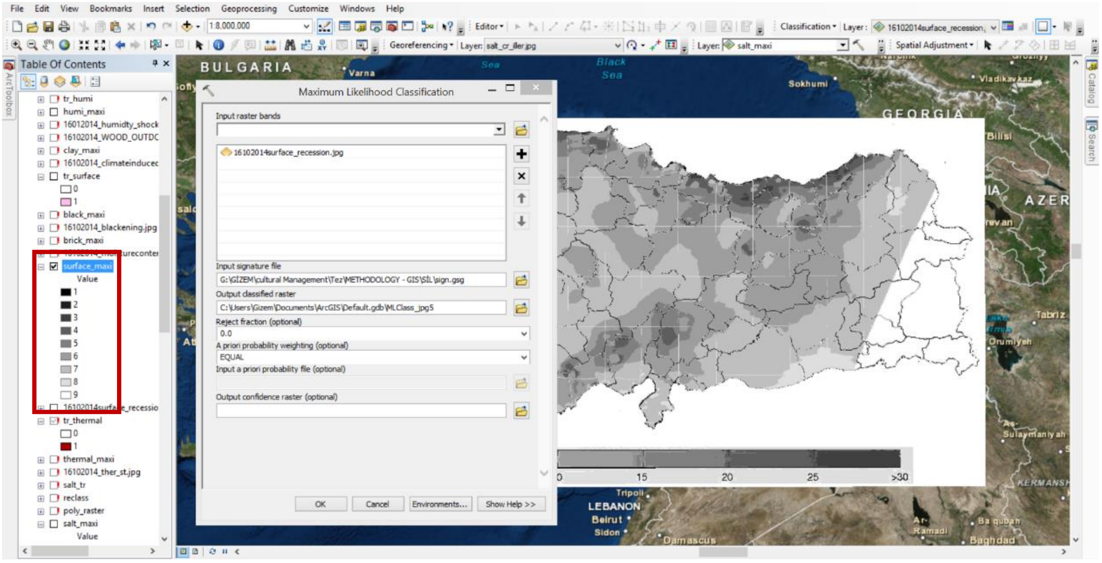


Figure 4.2. The snapshot view of ArcGIS 10 software shows Maximum Likelihood Classification Tool used to classify the image (prepared by the author).

2. Steps of Processing a Feature Class: The map of Turkey, which is a shapefile (.shp), was converted to raster data according to total number of historic buildings of each city. Before this conversion, an attribute table was created, which shows the statistical data of historic buildings by cities in Turkey. Then, in order to classify data on total number of historic buildings in Turkey, standard deviation distribution was employed in ArcGIS 10. The Standard deviation classification method shows how much a feature's attribute value varies from the mean. The program calculates the mean and places class breaks with equal value ranges above and below the mean, which are 1, ½, ⅓, or ¼ standard deviations until all the data values are contained within the classes. The more spread apart the data, the higher the deviation. A two-color ramp is used to emphasize values above the mean (shown in green) and values below the mean (shown in light orange) in the map of Turkey (Figure 4.3). As the number of historic buildings in İstanbul is further away from the sample mean than what is deemed reasonable, it was not included in the data; as it was accepted as an outlier (see Chapter 2).

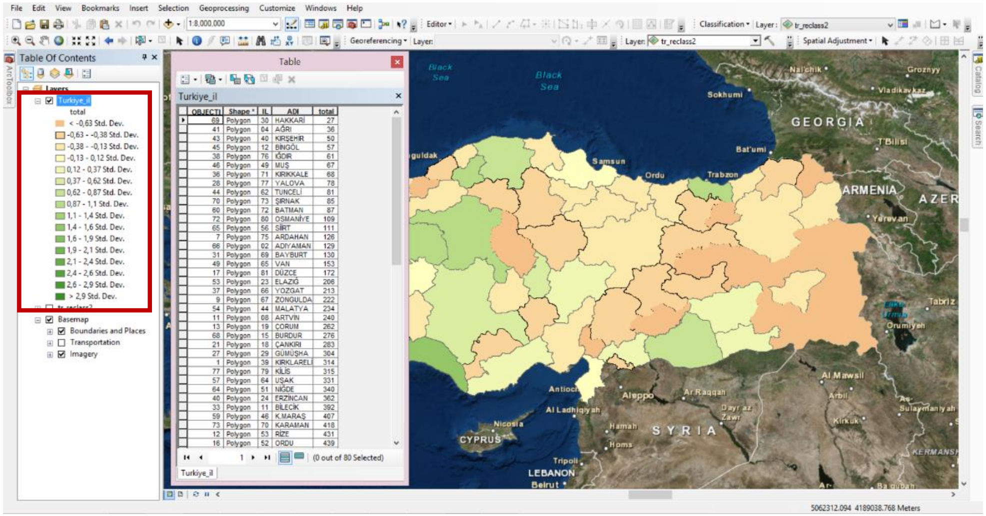


Figure 4.3. The snapshot from ArcGIS 10 software shows the attribute table and the classes according to standard deviation (prepared by the author).

After determining classes according to standard deviation, the shapefile (polyon feature) was converted to raster data according to total number of historic buildings of each city. Feature to Raster tool, which is under ArcToolbox / Conversion Tools / To Raster, was employed (Figure 4.4).

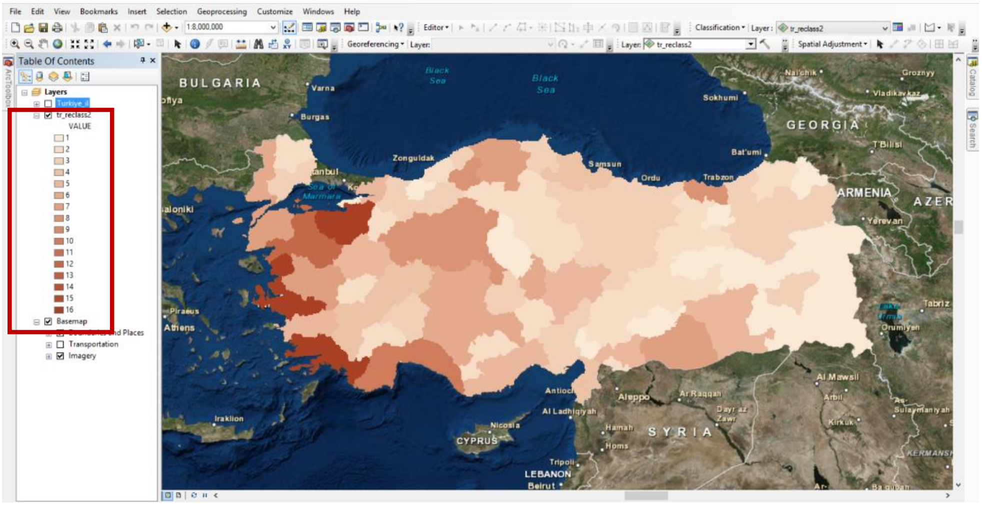


Figure 4.4. The raster data as a result of the feature to raster tool shows the classes of the historic buildings, which was determined according to the standard deviation (prepared by the author).

3. Raster Calculator and Overlay: Raster Calculator, which is a simple tool interface, is employed to operate three or more inputs in a single algebraic expression. In the following paragraph, an example of Raster Calculator Tool's results is given. The rest of the overlay maps, which were interpreted within the case of Bursa, are presented in Chapter 6.

An overlay map is created by combining the map of salt crystallization frequency for far future (2070-2099) (See Appendix A) with the map of areas by distribution of historic buildings. The regions where the number of salt crystallization events in a year is greater than 15, and regions where total number of listed buildings is above the standard deviation were chosen. The operator 'Boolean And' (&) was selected and a new raster below was obtained (Figure 4.5). In this map, for every cell which is an intersection of two maps, the value was set to 1, otherwise to 0 (pink = 1).

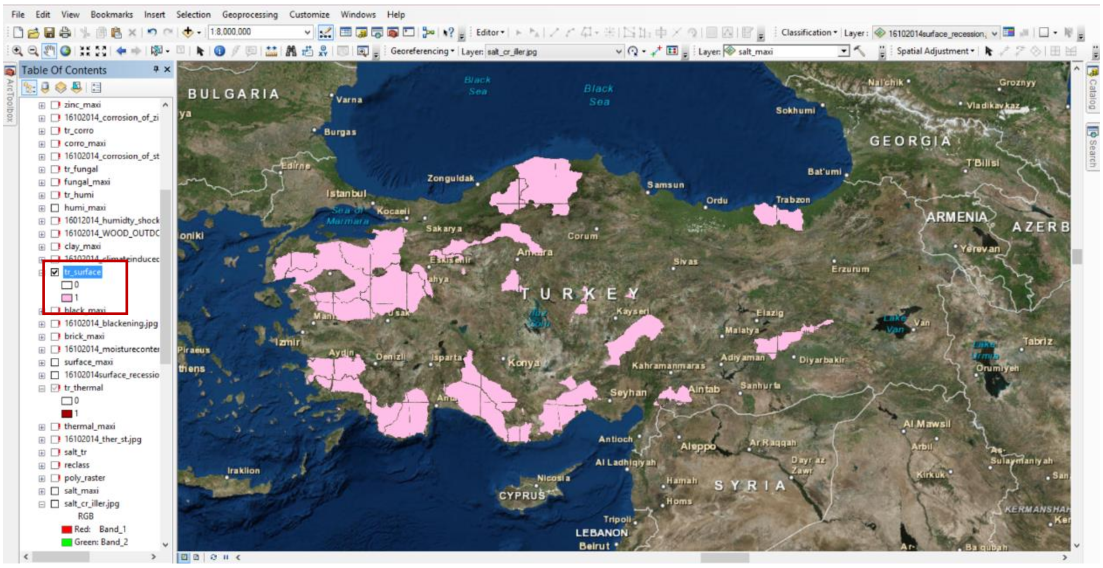


Figure 4.5. The overlay map shows the areas, which are rich in historic buildings, and under the risk of surface recession (prepared by the author).

To sum up, overlay analysis was used to combine the characteristics of several datasets into one. By this way, specific areas, which have a certain set of attribute values and are susceptible to variety of risks due to changing climate, are determined. Below is a work flow diagram, which summarizes the process of producing overlay maps (Figure 4.6).

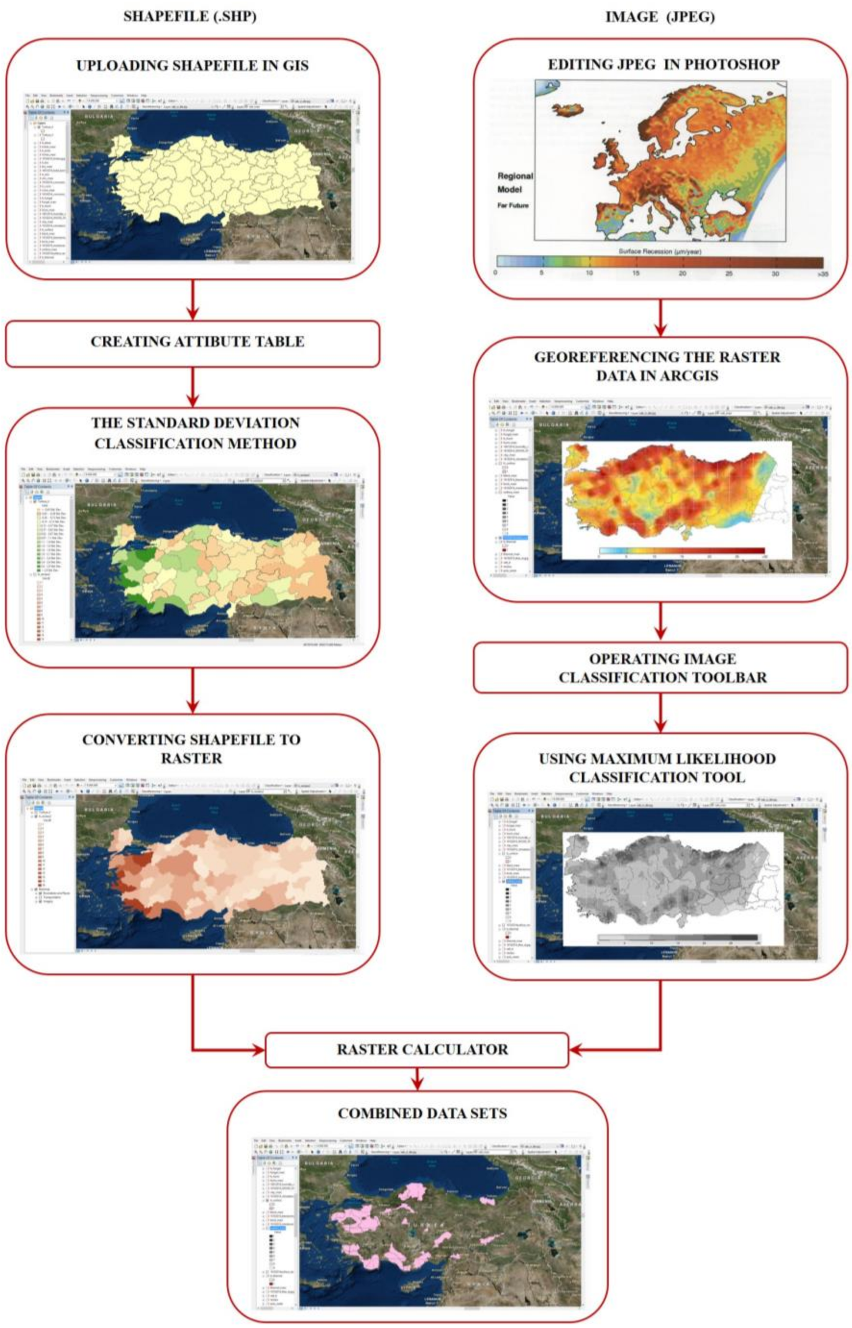


Figure 4.6. An example of a work flow diagram. At the end, a map, which combines different datasets, is produced (prepared by the author).

4.1.2. Producing Heritage Maps

Tangible heritage assets were selected from the web page of the inventory of culture prepared by the Ministry of Culture and Tourism. The filter option is used to limit the assets i.e. the assets built during the Ottoman Empire in Bursa. The number of assets is limited to 295. Since, X and Y coordinates of these assets cannot be obtained either from the inventory of the Ministry or the web page, the coordinates were found one by one via Google Maps. Therefore, selected number of assets (181 in number) and World Heritage Sites as zones were uploaded to ArcGIS 10 software (Figure 4.7). The list of the selected assets and their geographical locations were given in Appendix B.

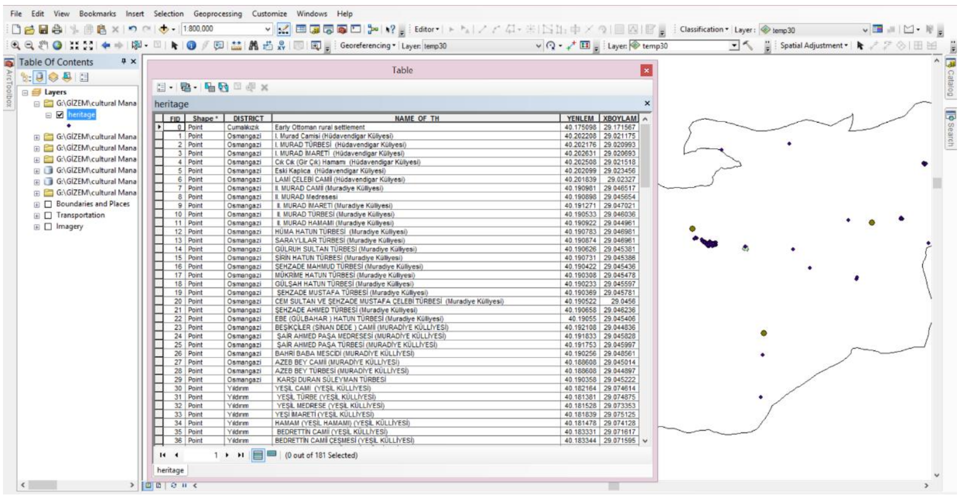


Figure 4.7. The attribute table shows the X and Y coordinates of the heritage assets (prepared by the author).

4.1.3. Mapping Climate Data Series

The climate data series from 1961 to 2014, which were obtained in Microsoft Excel format from the MoFWA – GDM, were revised to check the completeness of the series of each weather station in Bursa and its surrounding cities. The climate data of the stations were evaluated in terms of daily minimum and maximum temperature values, daily minimum and maximum RH values, monthly number of days with maximum temperatures greater than or equal to 30 °C. As some of the weather stations were closed and some of them have recently opened, the climate data series of 30 years from 1985 to 2014 were selected among the series from 1965 to 2014. The missing data in the number of days with maximum temperatures ≥ 30 °C were completed from the daily maximum temperature data, and the data obtained from the synoptic observations. For instance, as climatic observations have not been made in Balıkesir-Bölge station number 17152 since 2007, the synoptic observations of the Balıkesir-Airport station number 17150 were used. Additionally, as Bursa - Yenişehir station number 17678 was officially closed, after February 2004, the data series of Bursa-Yenişehir Meydan station number 17118 were used. The selected weather stations are given in Appendix C.

In order to map the monthly number of days with maximum temperatures of greater than or equal to 30 °C, Inverse Distance Weighting[19] (IDW), which is an interpolation method, in a Spatial Analysis Extension of the ArcGIS10 software was employed. Thus, the table showing the name of the weather stations, their geographic locations, and climatic data were prepared in Microsoft Office Excel 2013. Then, it was added to ArcGIS10 according to their X and Y coordinates (Figures 4.8 and 4.9).

[19] "IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance, hence the name inverse distance weighted" (ArcGIS Resource Center, 2013).

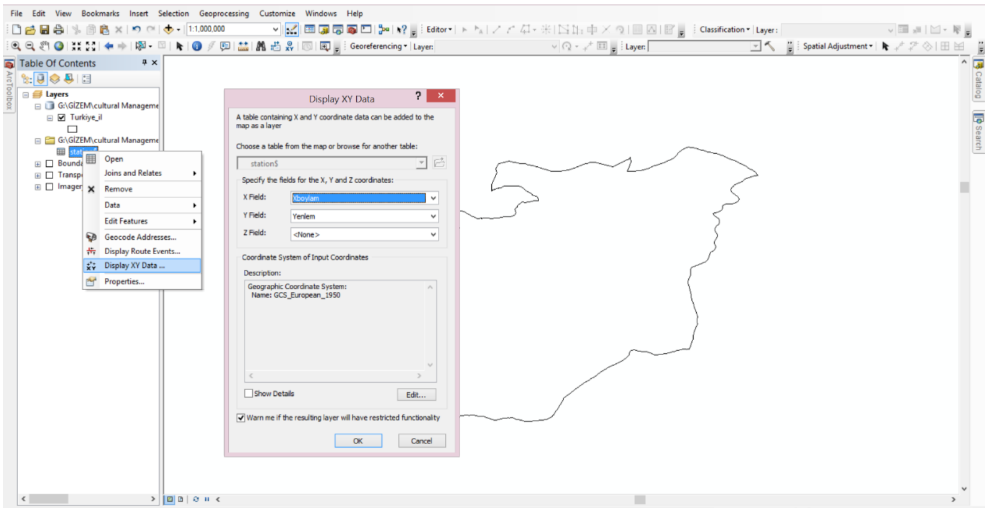


Figure 4.8. After adding the table as an Excel format to ArcGIS10, the weather stations were inserted according to X and Y coordinates (prepared by the author).

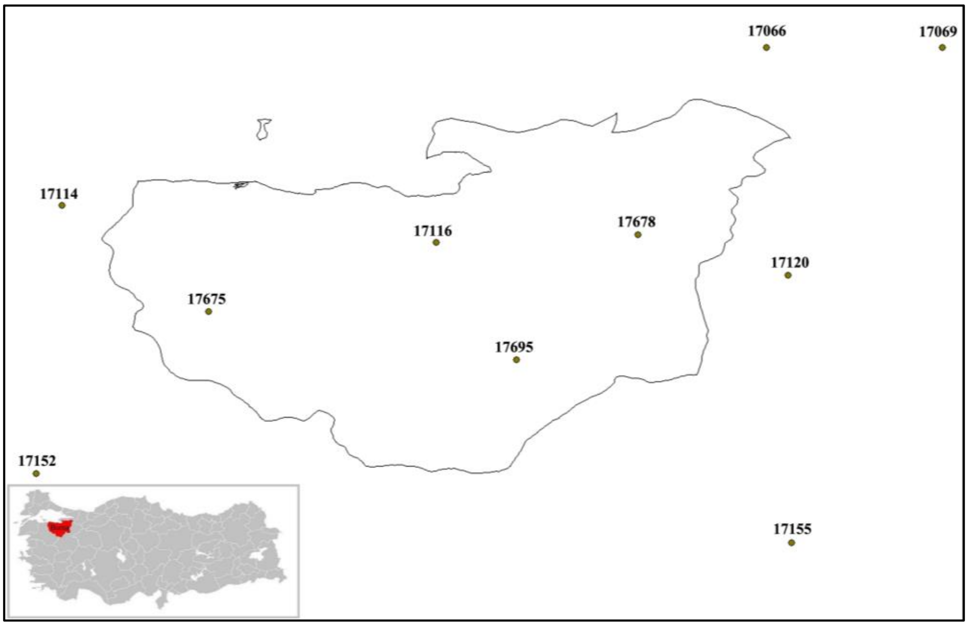


Figure 4.9. The geographic locations of the weather stations[20] (prepared by the author).

[20] The codes of the stations: 17152: Balıkesir; 17114: Bandırma; 17120: Bilecik; 17116: Bursa; 17678: Yenişehir; 17695: Bursa-Keleş; 17675: Bursa-Mustafa Kemal; 17155: Kütahya; 17066: Kocaeli; 17069: Sakarya

The data were exported as a shapefile containing readings from ten weather stations' in its attribute table; and Arch Toolbox / Spatial Analyst / Interpolation / IDW tool was employed to convert the data storing in the attribute table into a statistical surface. The result was an interpolated raster surface of the monthly number of days with maximum temperatures of greater than or equal to 30 °C values, which were contoured (Figure 4.10).

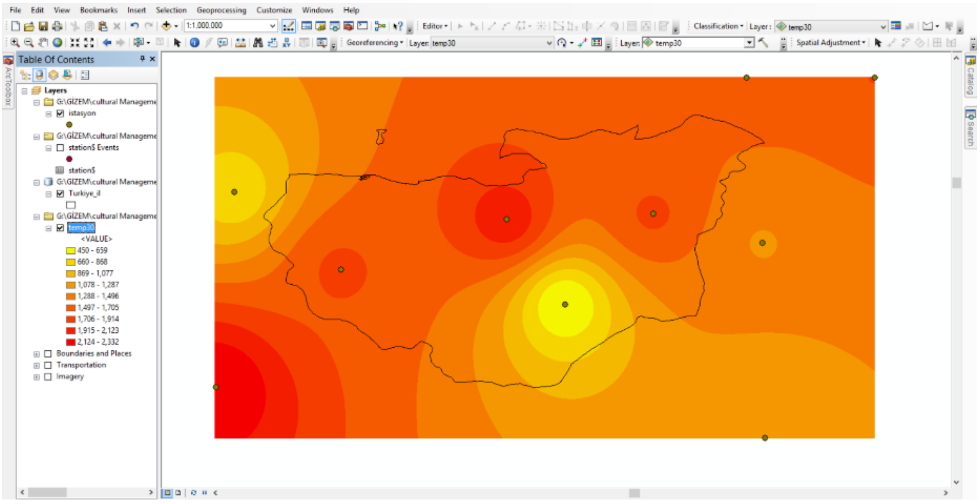


Figure 4.10. Spatial data from attribute table converted into a statistical raster surface showing the monthly number of days with maximum temperatures ≥30 °C (prepared by the author).

At the end, the results were reclassified in Symbology dialog box. The equal interval option with five classes representing Low, Low-Medium, Medium, Medium-High and High were selected to divide the range (Figure 4.11).

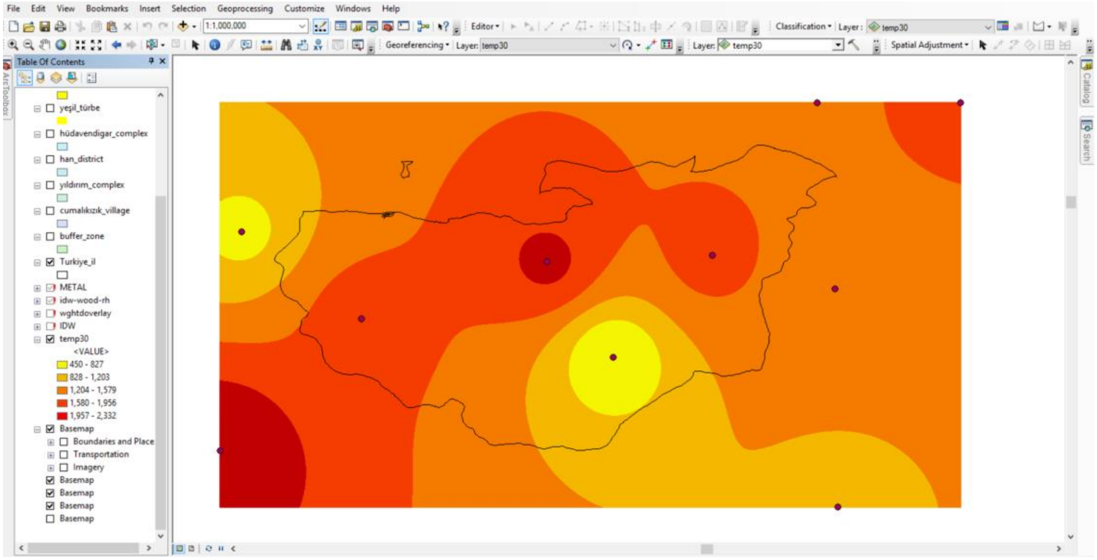


Figure 4.11. Raster image showing the five classes representing Low, Low-Medium, Medium, Medium-High, and High (prepared by the author).

In terms of RH, the number of events when RH fell below and rose above 75 % was calculated in Excel by using daily minimum and maximum relative humidity data. Then, the series of actions mentioned above were conducted in a certain manner to create an interpolated raster surface.

4.1.4. Producing Heritage-Climate Risk Maps

After the climate data series and X – Y coordinates of tangible heritage assets were mapped in ArcGIS 10; they were superimposed to create heritage-climate risk maps (Figure 4.12). As multiple climate parameters, which operate deterioration mechanisms affecting materials of construction, act together most of the time, these maps allow evaluating different risks both separately and together by focusing on a particular material or a particular asset.

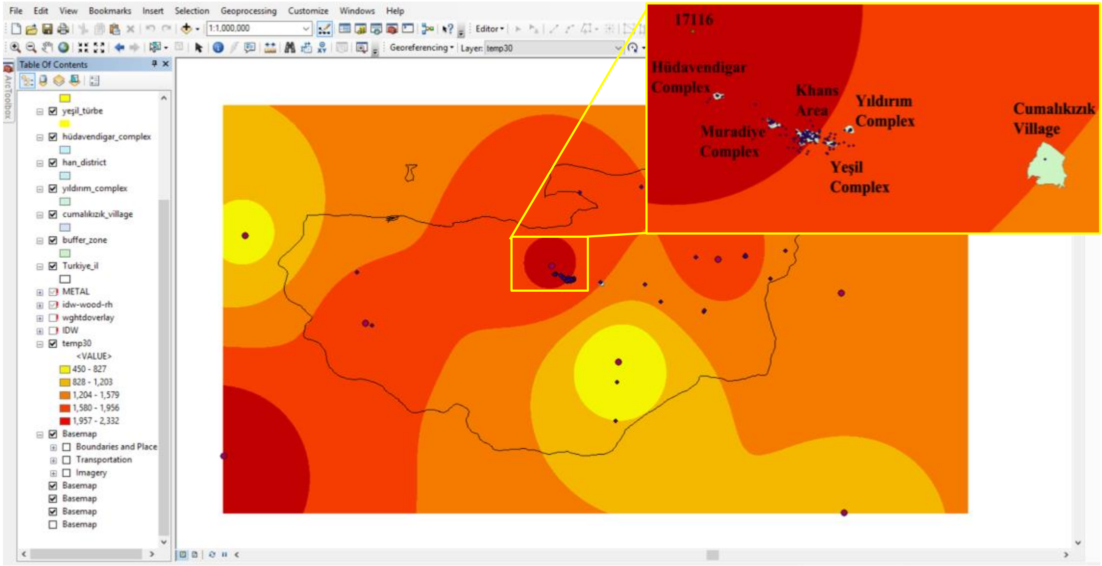


Figure 4.12. Image from ArcGIS 10 software shows the superimposed rasters, which display both the monthly number of days with maximum temperatures ≥30 °C values and geographical locations of heritage assets (prepared by the author).

4.2. Trend Analysis

The climate data series, such as the monthly minimum / maximum temperature data, monthly number of days with precipitation of greater than or equal to 0.1 mm and monthly total precipitation pertaining to Bursa were obtained from the MoFWA – GDM. The data are available from 1965 to 2014, from which the annual maximum, minimum, and mean temperatures were calculated (Table 4.1).

For this study, the widely used Mann-Kendall test was run at 5% significance level on data series from 1965 to 2014. Software used for performing the statistical Mann-Kendall test is Addinsoft's XLSTAT 2015 add-in for Microsoft Office Excel. Additionally, in order to evaluate and make a comparison the results obtained from the Mann-Kendall test, linear trend lines are plotted. The outcomes of Mann-Kendall test statistic given in the Chapter 6 point out to how strong the trend in temperature and precipitation is, whether it is increasing or decreasing.

Table 4.1. Annual, maximum, minimum, and mean temperatures in Bursa from 1965 to 2014

Year	Temperatures (^{0}C)			Year	Temperatures (^{0}C)		
	Mean	Max.	Min.		Mean	Max.	Min.
1965	14.0	27.95	0.86	1990	14.4	28.16	3.09
1966	15.6	27.98	3.43	1991	13.6	26.72	2.61
1967	13.8	27.55	0.02	1992	13.1	27.86	1.06
1968	14.0	27.52	2.05	1993	13.8	28.99	2.79
1969	14.3	28.37	1.53	1994	15.5	29.39	3.91
1970	14.7	29.9	2.57	1995	14.8	28.5	3.56
1971	14.0	27.92	2.02	1996	14.3	27.14	4.06
1972	13.7	26.88	0.98	1997	13.6	27.71	1.54
1973	13.9	27.68	2.08	1998	14.8	28.77	3.28
1974	14.1	27.17	2.32	1999	15.7	28.55	3.4
1975	14.5	28.08	2.72	2000	14.6	28.92	2.1
1976	13.7	26.7	1.48	2001	15.9	29.77	3.25
1977	14.9	29.49	2.72	2002	14.9	28.43	3.69
1978	14.6	27.86	3.07	2003	14.3	28.51	2.79
1979	15.2	28.86	2.98	2004	14.6	29.63	1.32
1980	14.2	27.36	2.38	2005	14.7	27.94	2.08
1981	14.8	27.18	3.59	2006	14.4	28.06	2.87
1982	13.8	28.28	1.23	2007	15.8	29.93	3.92
1983	14.1	27.84	2.03	2008	15.5	30.1	4.23
1984	14.5	28.15	2.68	2009	15.1	28.68	4.57
1985	14.6	28.97	1.49	2010	16.3	29.67	4.61
1986	14.9	27.42	2.89	2011	14.0	26.03	2.77
1987	14.3	28.22	1.42	2012	15.3	28.39	4.13
1988	14.9	27.89	2.76	2013	15.6	28.41	3.92
1989	14.7	28.54	2.94	2014	16.7	29.23	5.78

4.3. Archive Records for Tangible Heritage in Bursa

The archival research was conducted in Bursa Metropolitan Municipality, Bursa Cultural and Natural Heritage Preservation Regional Board, and Bursa Regional Directorate of Foundations on January 26 to 28, 2015. The historical records of the Muradiye Complex in Bursa were investigated by considering the following issues:

- understanding the types and causes of deterioration mechanisms that heritage assets faced in the past;
- identifying most common deterioration types;

- understanding maintenance, preventive and remedial activities that heritage professionals employed to solve the problems derived from deterioration mechanisms;
- making a comparison between before and after interventions.

4.4. Surface Area of Deteriorations

The survey drawings of the latest restoration project, which were prepared by the architectural firm and obtained from the archive of the Bursa Regional Directorate of Foundations, represents the classification of deterioration types into a limited number of significant categories, such as carbon accumulation, disintegration, recessed mortar, surface erosion, dampness, biomass (algae / moss), soiling, corrosion, lead decay. These drawings were used to calculate surface area of the various types of deteriorations in AutoCAD 2014. The results are interpreted to understand how much of a facade was affected by certain deterioration forms.

4.5. Field Surveys in Bursa

Muradiye Complex was visited on August 23, 2014 and on November 29, 2014 to collect research materials, such as taking photographs, making visual observations on decay forms, mapping deteriorated parts of the assets; and identifications of remedial actions. The details of these field-based investigations are presented in the following paragraphs.

Study visit in August 2014: The site, in which the tombs are located, was closed to visitors due to suspended restoration works, which were stopped due to technical and administrative processes. As it was forbidden to enter the site, taking photographs of all facades of the tombs, and making observations extensively and properly were impossible. It was noticed that the work on areas outside the tombs had been completed; therefore, scaffoldings were removed from the facades of the tombs, except the tomb of Sultan Murad the Second’s entrance canopy. In spite of these restrictions, apart from the tombs of Cem Sultan, Gülşah Hatun, and *Şehzade* (Prince) Mustafa, the tombs were photographed locally.

As the restoration project was completed in 2012, Muradiye Mosque is open to public. Besides, there were no on-going restoration works in both the madrasah and the hammam. Therefore, the facades of these buildings were photographed. The visual observations were made on decay forms; and comparisons were made between photographs taken before and after restoration works.

Study visit in November 2014: As it is necessary to get permission to enter the construction site, the permission was obtained from the Bursa Metropolitan Municipality. Photographs of all buildings in Muradiye Complex were taken to make a comparison between the conditions before and after restoration, and between the previous stages of these buildings. Additionally, the visual observations were made on decay forms again. The photographs were used to make a comparison between the dry season (August) and the wet season (November) on the amount of decay.

To conclude, all the stages mentioned in this Chapter are summarized and presented here in a flow-chart, which is composed of five stages (Figure 4.13). In the first stage, literature review was conducted on cultural heritage and climate change to determine which traditional building materials were included and to find how climate change may affect physical, chemical and biological deterioration mechanisms. After completing the review, in the next stage the findings were evaluated and the inventory of the historic buildings in Turkey was obtained. Then, they were prepared to use in the third stage. In this stage, different databases were gathered by using ArcGIS 10 software. The overlay maps were produced to determine the cities, which are likely to be under the risk of different deterioration mechanisms that were anticipated to change over the century, and were rich in cultural heritage assets. Once the city was selected, past records on climate data of the city, such as temperature and relative humidity, and on the remediation processes to address defects of the selected historic buildings in that city were gathered at the fourth stage. The findings were reclassified to produce maps, such as heritage maps, and heritage-climate risk maps. At the last stage, the surface areas of various types of deteriorations, which were mapped in the latest survey drawings of the buildings, were calculated by employing AutoCAD 2014 software. The field survey based on observations was conducted and photos were taken. The findings at this stage and the maps produced previous stages were compared with the past records of the selected buildings to understand the prolonged defects and their relationship with climate parameters and/or inaccurate repairs. Finally, the results were evaluated to guide heritage management strategies and further studies. The results of the stages are presented in detail in Chapter 6 and 7.

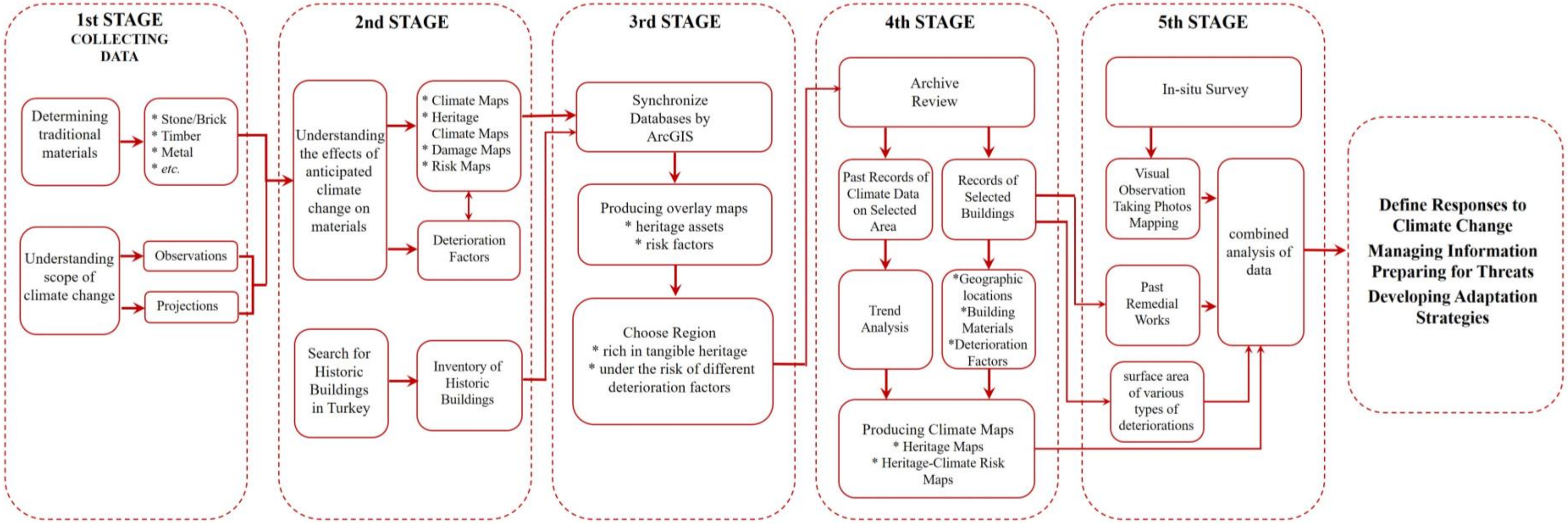


Figure 4.13. Flow-chart represents steps, which have been applied in this research.

CHAPTER 5

INFORMATION AND DATA ON RESTORATION INITIATIVES IN THE CASE STUDY AREA

As mentioned in Chapter 4, after visiting World Heritage Sites (Khan Area, Sultan Complexes and Cumalıkızık) in Bursa, the Muradiye Complex was selected as the case study area due to ongoing remedial activities. Therefore, archival records on the complex were collected from Bursa-CNHPRB (Figure 5.1). The findings were reorganized according the chronological order of events. The content of the official correspondences between different public institutions on remedial activities that were implemented on the buildings in Muradiye Complex, and survey reports of experts, are presented for each buildings in the following sections.

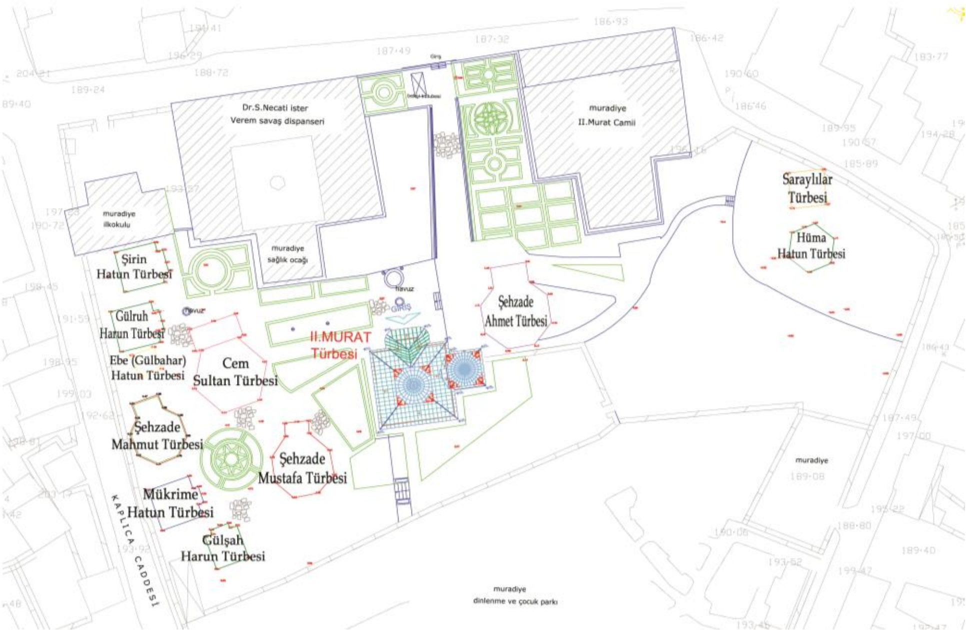


Figure 5.1. Site plan of Muradiye Complex
(Source. D2 Tasarım Mimarlık, 2010)

5.1. Muradiye Mosque

i) Official correspondences from 1974: According to several official correspondences between Head of the Department of Painting, Prime Ministry Undersecretary of Culture – Istanbul Directorate of the Academy of Fine Arts, Directorate of High Commission on Ancient Arts and Monuments and General Directorate of Foundations, it was noticed that repair work was conducted without a commission decision. However, during the research in the archives of Bursa Cultural and Natural Heritage Preservation Regional Board, official documents on contents and consequences of repair works and photographs, which show the existing state before and after repairs, have not been found.

ii) Expert Report of December 1995: A report including observations and suggestions, which is given below was prepared by an expert from the General Directorate of Foundations.

On the northeast corner, upper portion of the minaret's shaft was plastered and its hood is covered with lead sheets while on the northwest corner, upper portion of the shaft and the hood of the minaret are made of stone (Figures 5.2). Glazed tile courses and mortar joints under the balcony of both minarets fell down in patches. Repointing of mortar joints at the minaret on the northeast corner was suggested after scraping plaster on the upper portion of the shaft to check the condition of bricks. Besides, stones of the portico for latecomers were also deteriorated (Figure 5.3). To conclude, the expert suggested basic repair activities to solve the issues mentioned above.

(a) (b)

Figure 5.2. The photos show (a) the minaret on the northwest corner, whose shaft is made of brick while the upper portion of the shaft and the hood is made of stone; and (b) the minaret on the northeast corner, whose shaft is made of brick while the upper portion of the shaft was plastered and the hood is covered with lead sheets.
(Source. Bursa-CNHPRB, 1995)

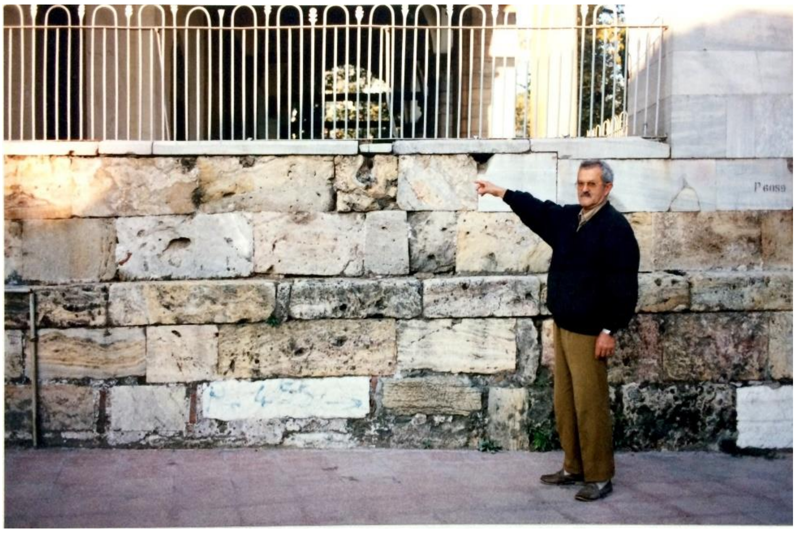


Figure 5.3. The photo from the wall of the portico for late comers shows damaged mortar joints, surface erosion, cavities, and detachments.
(Source. Bursa - CNHPRB, 1995)

iii) Official correspondences from July 2000: After official correspondences between Bursa Regional Directorate of Foundations and Bursa Cultural and Natural Heritage Preservation Regional Board, members of the Regional Board made a decision, which is presented in the following paragraphs:

- Changing or repairing damaged lead sheets covered the roof and the dome (Figures 5.4 and 5.5);
- Changing the doors at the east and west facades, which were deteriorated due to weathering, in compliance with the original ones (Figures 5.6 and 5.7);
- Removing canopies above the doors at the east and the west facades (Figures 5.6 and 5.7a);
- Repairing wooden doors under the control of Bursa Regional Directorate of Foundations (Figures 5.6 and 5.7).

Figure 5.4. Damaged lead sheets covered the dome
(Source. Bursa - CNHPRB, 2000)

Figure 5.5. Missing and damaged lead sheets covered the dome.
(Source. Bursa - CNHPRB, 2000)

(a) (b)

Figure 5.6. Both photos from the west facade showing (a) the door of a room and (b) the door of the west entrance.
(Source. Bursa - CNHPRB, 2000)

(a) (b)

Figure 5.7. Both photos from the east facade showing (a) the door of the east entrance of the mosque and (b) the door of the minaret.
(Source. Bursa – CNHPRB, 2000)

iv) Official correspondence from August 2001: After an official correspondence between the Regional Directorate of Foundations and Bursa Cultural and Natural Heritage Preservation Regional Board, the Preservation Board made the following decision:

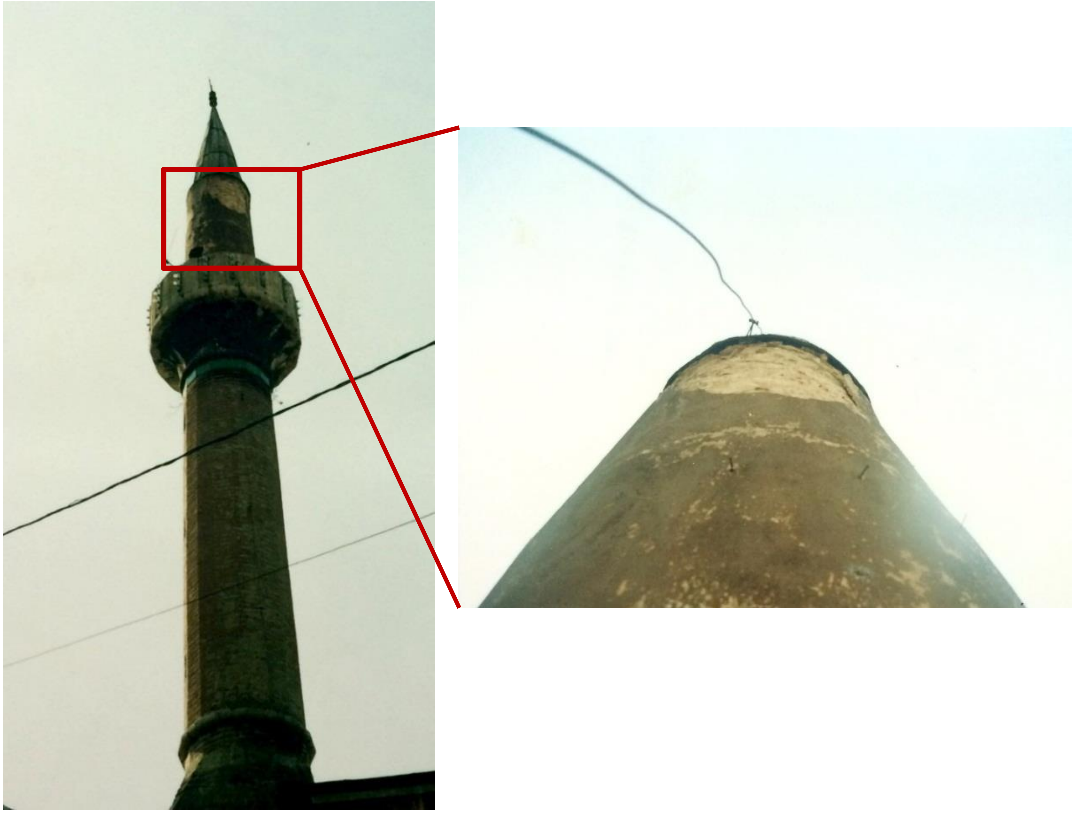
- Repointing mortar joints of the garden wall built of rough stones (Figure 5.8);
- Repairing the parts of the garden wall, which was physically damaged by a plane tree (Figure 5.8);
- Repointing mortar joints in the walls of the portico in compliance with the original ones as it is necessary to restore the visual and physical integrity of the masonry (Figure 5.9);

Figure 5.8. Damaged garden wall due to the roots of the plane tree.
(Source. Bursa – CNHPRB, 2001)

Figure 5.9. Eroded mortar joints in the walls of the portico for late comers.
(Source. Bursa – CNHPRB, 2001)

v) Expert Report of October 2001: Content of the report prepared by an expert from Bursa Regional Directorate of Foundations is presented below:

- Repairing plaster on the shaft's upper portion of the northeast minaret as it was impossible to repoint mortar joints in bricks (Figure 5.10);



(a) (b)

Figure 5.10. (a) The minaret on the northeast corner, and (b) spalling plaster on the upper portion of the shaft.
(Source. Bursa – CNHPRB, 2001)

- Changing the hood covered by lead sheets and horizontal wood sheating under the hood of the northeast minaret;
- Repointing swollen and spalling mortar joints in the shaft of the northwest minaret made of brick without giving harm to glazed tiles under the balcony (Figure 5.11);
- Repointing mortar joints in the saw-tooth and common brick courses, and the main walls of the mosque (Figures 5.12 and 5.13);

(a) (b)

Figure 5.11. Both (a) and (b) show damaged mortar joints of the minaret on the northwest corner.
(Source. Bursa – CNHPRB, 2001)

(a) (b)

Figure 5.12. Both (a) and (b) show eroded mortar joints in the saw-tooth and common brick courses.
(Source. Bursa – CNHPRB, 2001)

Figure 5.13. Swollen mortar joints in the wall, which was filled too full, showing changes in the actual joint thickness and the character of the original brickwork. (Source. Bursa – CNHPRB, 2001)

vi) Expert Report of 2011: A restoration project was approved following the survey carried out by experts, as per the decision of the Preservation Board dated 23.12.2011. The restoration interventions had being carried out by the Regional Directorate of Foundations. According to the report of the restoration project following works were completed:

- Open and closed subsurface drainage systems at the foundation level were constructed around the mosque.
- Lead sheets of the domes were preserved, whereas the ones covering the small domes and vaults were changed.
- The copper finials (the crescent and the star on top of a minaret) were cleaned.
- Window frames were replaced with wooden windows made of oak and chestnut.
- The door of the *iwan* on the east facade was changed while the other doors were preserved.
- *Portico:* Original brick floor covering of the portico was preserved and detached bricks were changed in accordance with the original ones. Mortar

covered bricks were cleaned. Cracks were repaired. Detached parts were completed with same kind of marble. Oil paint was cleaned on the wooden tie rods in between arches in the portico. The wooden tie rods were refreshed with wood paint and preserver. Rails of the portico were changed. Marble floor covering of the entrance, staircases, arches and columns were cleaned.

- *Minarets*: Damaged stones and bricks were changed with new ones by eroding. Small cavities were filled with epoxy. Some parts of the minarets, where massive damage was observed, were dismantled and reconstructed. Blackening and biological growth were cleaned. Mortar joints were repointed with *horasan* mortar. Eroded parts of the minarets where they meet the roof were replaced if they were greater than 5 cm. Glazed tile courses under the balconies were cleaned, repaired and preserved.

  * Minaret on the northwest corner: Marble rail, and stones under the balcony and of the hood were cleaned. Missing parts were completed with the same kind of stones. Cracks were repaired (Figure 5.14).

  * Minaret on the northeast corner: Stones under the balcony were cleaned. Missing parts were completed with same kind of stones. Lead sheets covered the hood were changed. Plaster on upper portion of the shaft was cleaned and mortar joints were repointed with *horasan* mortar (Figure 5.14).

(a) (b)

Figure 5.14. The photos showing (a) the minaret on the northwest corner and (b) the minaret on the northeast corner before the restoration work.
(Source. Bursa – CNHPRB, 2011)

- *Facades:* cement-based mortar and plaster was cleaned especially on stones. Mortar joints were repointed with *horasan* mortar. Sheet iron, nails, pipes, clamps and air conditioner etc., were removed from the facades (Figure 5.15). Saw-tooth brick courses and stone moulding were completed or changed. Blackening, which formed due to dampness and carbon accumulation (blackening) on facades, and biological growth were cleaned (Figures 5.16 and 5.17). Composite patching was carried out where the surface erosion was greater than 10 cm. Bricks which had damaged parts were changed with bricks which were of the same type and had the same dimensions as the old ones. Irregularity of the alternate walls' courses was left as they are.
- *Windows:* Some of the windows' iron grills were renewed whereas rest of them were cleared from paint and then repainted. Cracks in marble and stone window casings were repaired; and composite patching was carried out for missing parts.

Figure 5.15. The photo showing the places of the exterior mechanical units and related fixtures of the air conditioning system, such as air conditioning condenser unit, which impact the mosque’s historic character. They were removed during the restoration, and placed after restoration.
(Source. Bursa – CNHPRB, 2011)

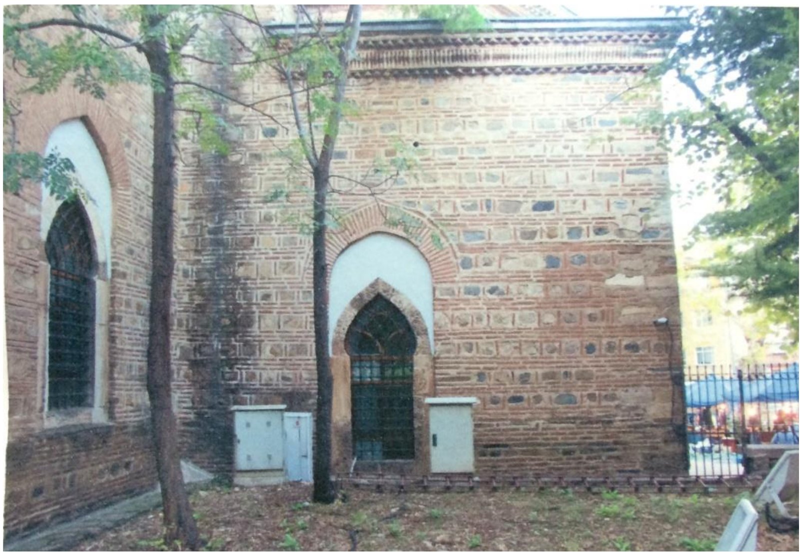


Figure 5.16. Blackening and biological growth on the facades before the restoration project
(Source. Bursa – CNHPRB, 2011)

Figure 5.17. Blackening and soiled surfaces were seen before restoration on the east facade.
(Source. Bursa – CNHPRB, 2011)

As it is understood from the archival records of Muradiye Mosque, various remedial activities were conducted with/out a commission decision in different dates. As well as the problems derived from using cement-based mortar, the building was subject to processes of deterioration through weathering, soiling and development of patinas on the stone surface through its documented life time.

5.2. Muradiye Madrasa

Apart from two comprehensive conservation repair and maintenance programmes, which were conducted in 1603 and 1851; in 1951 the fund to fight tuberculosis repaired the madrasa and used it as a dispensary. In 2004, the building was repaired again to use as both the Center of Early Diagnosis and Treatment of Cancer (KETEM) and a community clinic.

i) Expert Report of December 2013: Content of the report prepared by an architect from an architectural firm called *Desem Mimarlık,* that was submitted to the Bursa Regional Directorate of Foundations is presented below.

- Dampness problem was observed from both inside and outside of the building. One of the reasons of dampness problem was derived from an intervention to the portico. The openings of the portico were closed with glass panes (Figure 5.18). The other reason is the missing parts of lead sheets of the roof.
- Biological growth was also observed on the surfaces (Figure 5.19).

(a) (b)

Figure 5.18. Both the photos (a) and (b) display the transformation of the portico to a corridor by closing its openings.
(Source. Bursa – CNHPRB, 2013)

Figure 5.19. Biological growth started on the roof and covered the facade.
(Source. Bursa – CNHPRB, 2013)

It was noted that the problems of the building and their consequences were explained in detail in another report of the conservation project; however, this report could not be found in the archives. Photographs, which were attached to the report, display several problems of the building, which are listed below.

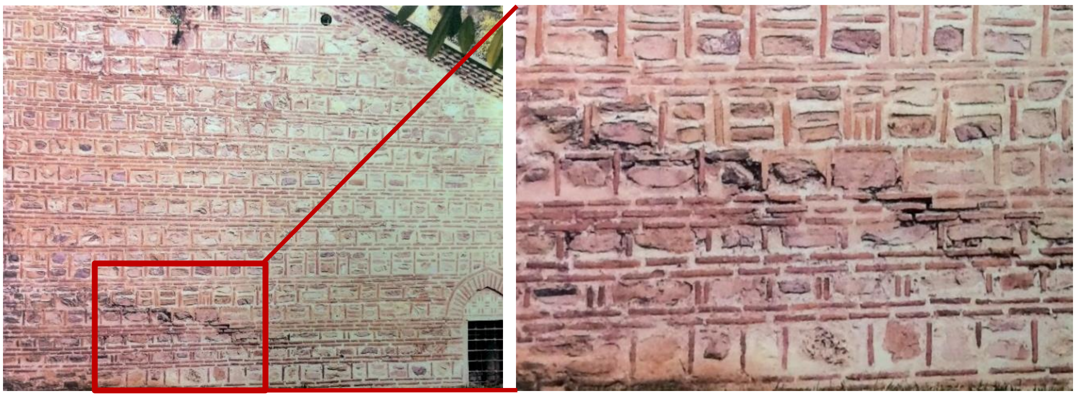
- Blackening, soiling, and water stains due to dampness were observed on all facades of the madrasah (Figures 5.20 and 5.21).

(a) (b)

Figure 5.20. The north (a) and the east facades (b) of the madrasah suffering from dampness problems.
(Source. Bursa – CNHPRB, 2013)

Figure 5.21. The southern and southeastern facades having serious problems, such as blackening, soiling, and water stains, due to dampness.
(Source. Bursa – CNHPRB, 2013)

- Poor repointing work raised the level of the mortar joint above the face of the masonry unit, which was aesthetically undesirable and caused performance problems as a thin layer of mortar eroded quickly. In addition, filling joints too completely hid the actual joint thickness and changed the character of the original wall bonding (Figure 5.22).
- Soiling was observed on the marble parts of the facades (Figure 5.23).



(a) (b)

Figure 5.22. Both (a) and (b) showing the poor repointing work, which caused the eroded mortar joints and detachments of stones.
(Source. Bursa – CNHPRB, 2013)

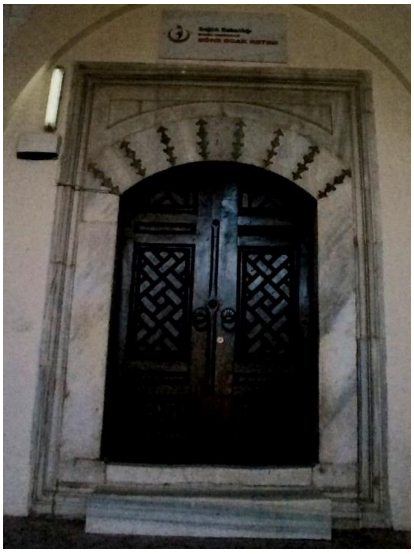


Figure 5.23. Soiled marble sections of the main gate
(Source. Bursa – CNHPRB, 2013)

ii) Expert Report of February 2014: The content of the report prepared by an expert from Bursa Cultural and Natural Heritage Preservation Regional Board are listed below:

- ***Entrance iwan:*** After scraping the plaster from the walls, the dome and the drum, they were replastered with *horasan* plaster, and then painted. The marble parts of the entrance portal on which soiling and discoloration were observed due to weathering processes, were cleaned. The paint on the wooden door was scraped off and given a coat of vapor-permeable finish that allows for movement and the release of moisture. The terrazzo flooring was cleaned and preserved.
- ***Portico:*** After removing the layer of paint, tie-rods were inserted between the arches, deteriorated ones were replaced with new ones, which were compatible with the original ones.
- ***Rooms:*** Wooden window sashes and wooden doors were cleaned from paint and given a coat of flexible vapor-permeable finishes. Iron grills of the windows were cleaned and re-painted with anti-rust paint.

- ***Courtyard:*** Soiled marble tiles of the ornamental pools were cleaned and preserved.
- ***Main iwan:*** Wood paneling on the walls were removed. The plaster under these panels was scraped, and then the walls were replastered with *horasan* plaster.
- ***Roof:*** Lead sheets covering the roof, and layers under them were renewed. Biological growth was cleaned.
- ***Facades:*** Biological growth was cleaned. Cracks were repaired. Mortar joints were repointed with *horasan* mortar. Drainage system was constructed to prevent dampness problem.

As it is understood from the archival records of Muradiye Madrasa, various remedial activities were conducted in different dates. As well as the problems derived from using inappropriate techniques and materials, the building was subject to processes of deterioration through weathering, biological growth and soiling, which includes deposition of pollutants, such as black carbon, organic and inorganic particulate matter, and dust through its documented life time.

5.3. Muradiye Hammam

The hammam, in which three comprehensive conservation repair and maintenance programmes were conducted in 1523, 1634 and 1742, passed into private ownership in the first decade of the Republic. In 1985, the restoration works were conducted according to the approved project; and the hammam was operated as its original purpose until 1996.

i) Expert Reports of 1984: Reports were prepared by an expert from Governorship of Bursa – Directorate of Museum and unknown architect in 1984. After being used as a refinery for a long time, the hammam building was being used as a barn when this report was prepared.

- Deterioration of stones and bricks were observed on the facades (Figure 3.24).
- Saw-tooth courses were also damaged.

- Deteriorated pantiles, which were used as the roof material, were going to be changed (Figure 5.24).
- Since the roof lantern at the top of the main dome had collapsed, a new one was going to be built (Figure 5.25).
- The holes at the center of the domes covering the warm room (*ılıklık*) and the hot room (sıcaklık) were going to be closed with skylights composed of bell jars (*fil gözü*)
- Chimney of the boiler room (*külhan*) was going to be completed with bricks.

The photos attached to the reports, and important points from the restoration project are presented below.

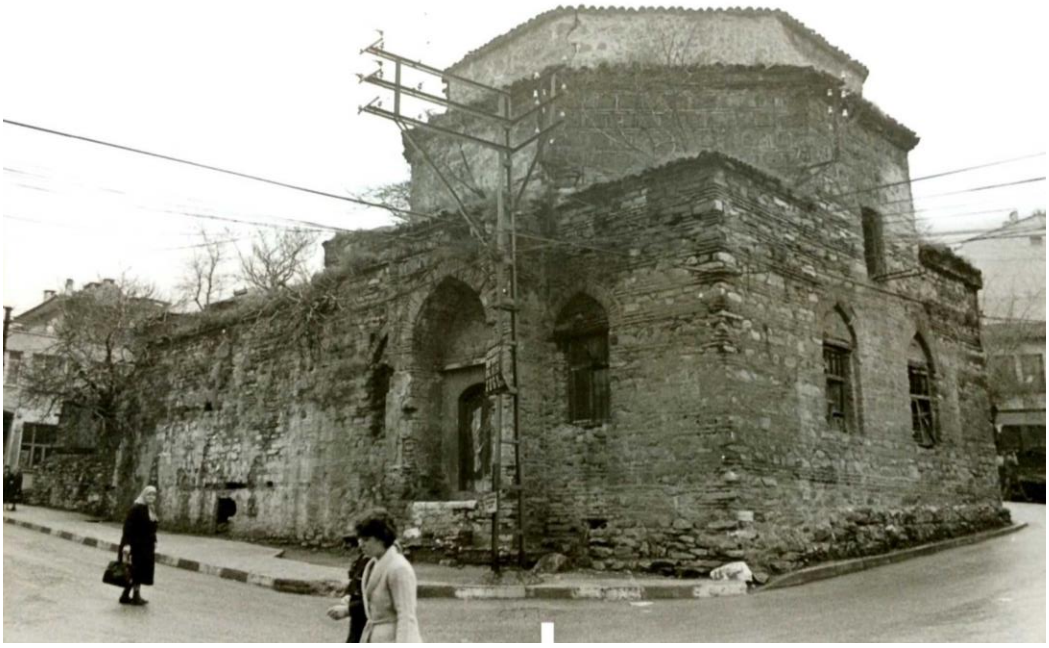


Figure 5.24. Material loss, biologic growth, blackening, soiling, and decayed pantiles were seen on the eastern facade of the building. (Source. Bursa – CNHPRB, 1984)

(a) (b)

Figure 5.25. The collapsed roof lantern at the top of the dome (a) causing the rainwater leakage and the damage inside of the building as shown in (b).
(Source. Bursa – CNHPRB, 1984)

ii) Expert Report of 1987: According to a report of an expert from Bursa from Governorship of Bursa – Directorate of Museum in October 1987, the restoration activities were conducted in keeping with the project and the original building materials. After completing the restoration project, the building had been used for its original purpose until 1996.

The photos showing the state of the building after restoration activities are presented below (Figures 5.26 and 5.27).

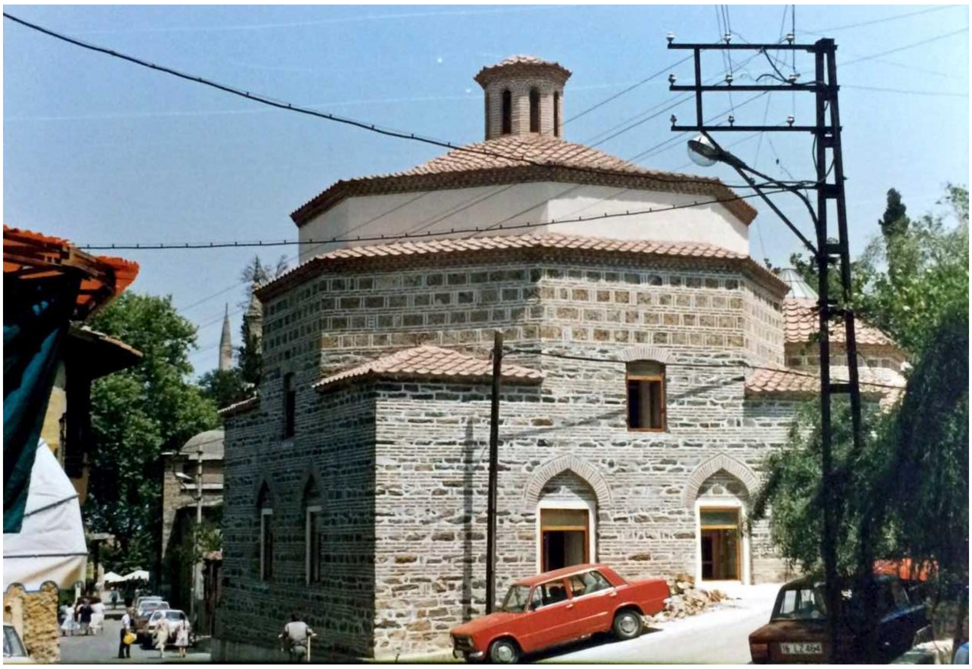


Figure 5.26. The photo showing the solved issues, such as biologic growth, blackening, soiling, decayed pantiles and material loss on the northern and the western facades of the building.
(Source. Bursa – CNHPRB, 1987)

(a) (b)

Figure 5.27. The both (a) and (b) showing the altered wooden parts of the building, the repaired entrance stairs, the plinth with cut stone finishing, and the places of power cables and utility pole on the facade.
(Source. Bursa – CNHPRB, 1987)

iii) Expert report of 2007: According to a report of the survey prepared within the restoration project in 2007, formation of algae and moss, and swelling of plaster due to the dampness problem were observed inside of the dome covering the warm room, therefore the integrity of the plaster was in question.

The photo showing the state of the building in 2007 is presented below (Figure 5.28).

Figure 5.28. A view from the entrance of the building showing biologic growth, black streaks, and soiling, which dominated on the facade.
(Source. Bursa – CNHPRB, 2007)

iv) Expert Report of 2007: A report was written by an architect working in the firm, which had prepared the restoration project of the Turkish bath. The restoration activities were executed to make alterations for changing the function of the building. After the completion of restoration, the building was used as a Training and Rehabilitation Center for People with Disabilities. The details on conservation activities directed to improve the facades are presented below.

- Soiling was cleaned by using atomized water spray method.
- The opening, which was made in the western facade in the previous interventions, was closed in compliance with the original wall bond, i.e. *almaşık*.
- Both in the western and southern facades, facing materials were removed.
- Composite patching was conducted on all facades, saw-tooth course of bricks, and the materials of the dome.
- All wooden window frames and doors were changed in compliance with the original ones.
- The roof lantern, which is placed at the top of the dome, was transformed into its original state.

The restoration project, which was approved by Bursa Cultural and Natural Heritage Preservation Regional Board in July 2007, was modified and re-approved in March 2008 due to a proclamation about misapplications; and May 2010 due to a desire for transforming the woodshed into a hair salon.

In summary, the archival records of Muradiye Hammam show that although various remedial activities were conducted in different dates, several problems, such as biological growth, blackening and soiling were repeated after each activity and remained as stubborn problems.

5.4. Muradiye Tombs

According to the archives of Bursa Cultural and Natural Heritage Preservation Regional Board, reports were prepared by different institutions in different years. In April 1996, minor repair and maintenance works were defined for each tomb in the report of experts from the Directorate of Bursa Museum. On May 11, 2004, twelve tombs were visited by a committee, which was composed of experts from the Metropolitan Municipality of Bursa, Bursa Cultural and Natural Heritage Preservation Regional Board, Bursa Directorate of Surveying and Monuments, and Uludağ University. The committee prepared a report on the conditions of the tombs and suggestions for repair and maintenance works. In 2010, the extensive restoration project for the tombs was commissioned through a tender floated by Bursa Special Provincial Administration; which was won by an architectural firm called D2 Architecture. Several meetings were held in October and December 2010 by Bursa Cultural and Natural Heritage Preservation Regional Board to evaluate the project; thereafter, the project was approved. The restoration works started on October 16, 2012 by the Metropolitan Municipality of Bursa within the framework of the protocol signed in 2010 between the Municipality and the General Directorate of Foundations. Restorations works are continuing especially inside of the tombs.

The details on preservation activities mentioned above are presented below for each tomb.

5.4.1. Tomb of Murad the Second [and *Şehzade* (Prince) Alaaddin]

According to the restoration reports, despite absence of proper care and maintenance, and regarding dampness leading to deterioration of the building materials, the tomb has survived for centuries. Details of these reports are given below.

i) Expert Report of 1996: According to the experts' report from the Directorate of Bursa Museum, basic maintenance and repair was recommended, without preparing a restoration project, such as fixing cracks in plaster of interior walls, and re-plastering areas where flaking had occurred due to dampness; and painting the walls.

ii) Expert Report of 2004: The tomb walls are constructed with alternating walls of brick and stone; while the stone used from ground up to window sill is rough stone and that above this level is cut stone. The mortar joints up to sill level had been filled with cement based mortar, which deteriorated with passing of time.

Above the windows sill level, one course of "*küfeki*" stone and two courses of brick form the walls. Joints of these parts filled with the mixture of fragmented brick and lime had been deteriorated locally in the course of time.

The roof and coping were covered with lead sheets but they had deformed and the seams had speared up. Therefore, water had seeped through and caused deterioration on the surface. Damp stains were observed on the fascia (Figure 5.29). Construction of drip-edge flashing was suggested. Moreover, inside of dome there were also the effects of degradation due to damp, which penetrated from deformed lead sheets.

It was stated that the deterioration of lower parts of main walls indicates the problems of rising damp from ground and of soluble salts. Besides, occurrence of the biological growth due to rising damp was also observed (Figure 5.30). Construction of a drainage system was suggested to solve this problem.

(a) (b)

Figure 5.29. The both photos (a) and (b) showing the deformed eaves and lead boards.
(Source. Bursa – CNHPRB, 2004)

Figure 5.30. The photo showing the entrance facade on which there were black streaks due to rising damp and dirt.
(Source. Bursa – CNHPRB, 2004)

(iii) Survey Report of 2010: Blackening and biological growth (algae) due to dampness were determined on the marble parts of entrance portal (Figure 5.31). The canopy made of wood and covered with lead showed signs of decay of in patches (Figures 5.32). Besides, lead sheets of the canopy deformed and damaged (Figure 5.33).

(a) (b)

Figure 5.31. The exterior views (a) and (b) showing blackening and biological growth (algae) on the canopy and the portal.
(Source. D2 Tasarım Mimarlık, 2010)

Figure 5.32. The photo shows the ceiling of the entrance canopy whose wooden parts embellished with hand-carvings and gilded were deteriorated.
(Source. D2 Tasarım Mimarlık, 2010)

Figure 5.33. The photo showing deformed and torn lead boards of the entrance canopy.
(Source. D2 Tasarım Mimarlık, 2010)

Cracked masonry, eroded mortar joints (Figure 5.34), and dirt stains and blackening due to water leakage from underneath the eaves were determined (Figure 5.35 and Figure 5.36).

Dampness and salts deposits that had accumulated on due to the use of cement-based mortars during previous repairs were observed, along with blackening on the walls.

Figure 5.34. The photo displays poor repointing work raises the level of the mortar joint above the face of the masonry unit. This is aesthetically undesirable and can cause performance problems as a thin layer of mortar will quickly erode.
(Source. D2 Tasarım Mimarlık, 2010)

Figure 5.35. The view from south facade of the tomb shows dirt stains and blackening due to water leakage from underneath the eaves.
(Source. D2 Tasarım Mimarlık, 2010)

Figure 5.36. The photo zooms the detail from the deteriorated eaves, which cause water leakage.
(Source. D2 Tasarım Mimarlık, 2010)

Excessive blackening and biological growth, such as algae, plants, grasses, ivy and climbers, was found on both the plinth and the upper parts of walls (Figure 5.37a). Formation of algae was also noticed on the floors (Figure 5.37b).

Figure 5.37. Both (a) and (b) display biological growth (plants and algae) at the intersection of walls and the plinth, respectively.
(Source. D2 Tasarım Mimarlık, 2010)

The double-leaf door of the tomb, which was produced with *kündekari* technique and made of timber, decayed due to wood beetles / termites attack. Its lock / hinge rails and stiles were destroyed. Metal parts were lost. Doorsill completely disappeared (Figure 5.38).

(a) (b)

Figure 5.38. Both (a) and (b) showing the details of decayed wooden entrance door. (Source. D2 Tasarım Mimarlık, 2010)

Tomb of Şehzade Alaaddin: Deformed and damaged lead sheets over the eaves caused formation of black streaks on walls, damp penetration through the walls, and blackening and watermarks on a saw-tooth course of brick and the moulding on the eaves (Figure 5.39 and Figure 5.40).

Deterioration of brick, stone and marble; accumulation of dirt; and cracks on stones were observed. Although facades were maintained during the previous interventions, formation of black streaks and eroded mortar joints were noticed because of advance level of dirt and degradation (Figures 5.40 and 5.41).

Due to rising damp, formation of algae was locally identified on both the plinth and the upper parts of walls.

Figure 5.39. Damaged lead sheets, which caused penetrating damp to inside, accumulation of dirt and black streaks, were seen on the north facade of the *Şehzade* Alaaddin Tomb.
(Source. D2 Tasarım Mimarlık, 2010)

(a) (b)

Figure 5.40. (a) and (b) zoom to damaged lead sheets and blackening on a saw-tooth course of brick and the moulding, and deteriorated stones.
(Source. D2 Tasarım Mimarlık, 2010)

Surface erosion and the detachments of stones were noticed on the facades (Figure 5.41).

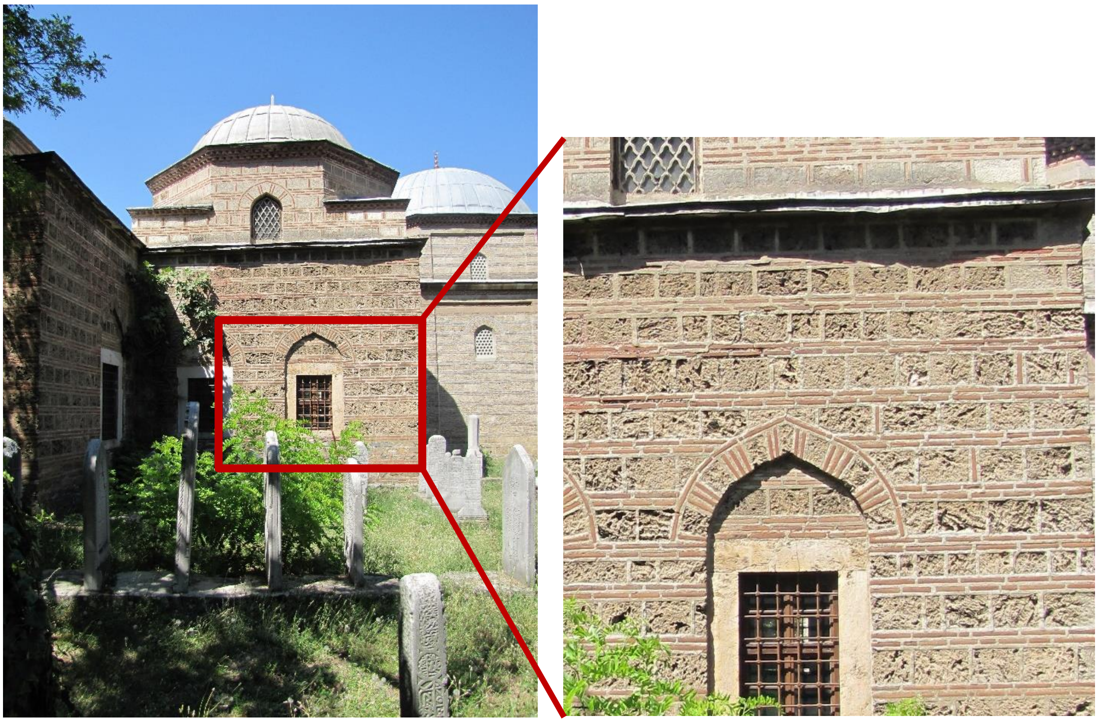


Figure 5.41. Surface erosion is clearly observed on the south facade of the *Şehzade* Alaaddin Tomb.
(Source. D2 Tasarım Mimarlık, 2010)

(iv) Restoration Report of 2010:

- Subsurface drainage system at the foundation level was constructed around the tomb.
- Lead sheets of the dome, the entrance canopy and of the eaves were changed where it was necessary.
- The marble parts of the portal were cleaned and composite patching was done where the surface erosion is greater than 10 cm. Cracks were repaired.
- Missing timber parts of entrance canopy were completed.

- Cement-based mortars and plaster were removed. After performing a mortar analysis in order to make recommendations for replacement mortar that is both physically and aesthetically compatible with the materials, repointing process was carried out.
- The saw-tooth courses of brick, which had missing parts, were changed with the bricks, which were the same type and had the same dimensions with the old ones.
- Irregularity of the alternate walls' courses was left as they are.
- Blackening, which formed due to dampness and carbon accumulation on facades, was cleaned.
- Composite patching was done where the surface erosion is greater than 10 cm.
- Biological growth was removed.
- All sashes were conserved after rehabilitating.

5.4.2. Tomb of *Şehzade* (Prince) Ahmet

i) Expert Report of 1996: According to the experts' report from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as repairing the wooden frames of the windows.

ii) Expert Report of 2004:

- The dome and copings were covered with lead sheets but they had deformed and the seams had speared up. Therefore, water had seeped through and caused deterioration on the surface. Damp stains, soiling and blackening were observed on the fascia (Figure 5.42).
- Cement-based mortars were swollen.
- Excessive biological growth was especially observed on both the plinth and the mortar joints (Figure 5.43).
- The windows decayed due to wood beetles / termites attack. The paint peeled off from the window frames.

It was stated that the deterioration of lower parts of main walls indicates the problems of rising damp from ground and of soluble salts. Besides, occurrence of the biological growth due to rising damp was also observed. Construction of a drainage system and waterproofing for the foundation were suggested to solve this problem.

(a) (b)

Figure 5.42. Both (a) and (b) showing damp stain, soiling and blackening on the moulding and the facade due to deformed lead sheets covering copings; and damaged saw-tooth course of bricks and plaster.
(Source. Bursa – CNHPRB, 2004)

Figure 5.43. Biological growth was observed on the mortar joints.
(Source. Bursa – CNHPRB, 2004)

iii) Expert Report of 2010: The report was prepared to approve whether the survey project is appropriate or not. The photos attached the report are presented below to understand the condition of the building in 2010 (Figures 5.44 and 5.45):

Figure 5.44. Blackening and biological growth were observed due to dampness problem on the plinth and around the copings.
(Source. Bursa – CNHPRB, 2010)

Figure 5.45. Blackening, soiling and biological growth were seen on the marble portal
(Source. Bursa – CNHPRB, 2010)

iv) Survey Report of 2010:

- *Küfeki* stones and facing stones of the stairs in front of the portico eroded and were detached. Several stones displaced while some of them were missing. Soiling and biological growth due to excessive dampness problem were observed (Figure 5.46).

Figure 5.46. Biological growth and soiling were observed due to excessive dampness problem.
(Source. D2 Tasarım Mimarlık, 2010)

- Lead sheets, which covered the roof of the portico, had deformed and the seams had speared up. Therefore, water had seeped through and caused deterioration on the wooden parts of the roof (Figure 5.47).
- Surface erosion was observed in the saw-tooth brick courses.

Figure 5.47. Deformed lead sheets of the portico's roof caused deterioration of wooden parts of the roof.
(Source. D2 Tasarım Mimarlık, 2010)

- Water had seeped through the deformed lead sheets, which covered the coping. Therefore, blackening was observed on materials such as stone, marble and bricks. Motifs below the moulding were wiped away due to blackening (Figure 5.48).

Figure 5.48. Deformed lead sheets on moulding caused deterioration on motifs and blackening on the facade.
(Source. D2 Tasarım Mimarlık, 2010)

- Excessive soiling was observed on marble sections of the building (Figure 5.49).

Figure 5.49. Excessive soiling was easily observed on marble sections of the portico. (Source. D2 Tasarım Mimarlık, 2010)

- Cement-based mortar was extensively used during the previous repairs (Figure 5.50).
- Surface erosion and soiling were identified on the facades. Although facades were maintained several times, blackening and eroded mortar joints were observed (Figure 5.51).

Figure 5.50. Mortar joints were repointed by cement-based mortar in the previous interventions.
(Source. D2 Tasarım Mimarlık, 2010)

Figure 5.51. A view from northern facade of the tomb showing different problems, such as blackening, damp stains, biological growth and misapplication of repointing.
(Source. D2 Tasarım Mimarlık, 2010)

- Detached parts and pitting were observed on *küfeki* stone.
- Due to rising damp, biological growth was found on both the plinth and the upper parts of walls.
- Cracks in the marble window casings and surface erosion on arch pediment of the windows made of *küfeki* stone were identified. Wooden frames decayed and window glazing was broken (Figure 5.52).

Figure 5.52. The arch pediment of the window eroded; and marble casing cracked. (Source. D2 Tasarım Mimarlık, 2010)

- The wooden door of the tomb was in the good condition whereas the shutters of the windows were in need of maintenance.

v) Restoration Report of 2010:

- Subsurface drainage system was constructed around the tomb.
- All marble sections of the entrance portal were cleaned. Cracks were repaired.

- Marble, which had detached parts, was completed with the marble, which were the same type with the old ones.
- Lead sheets of the main dome were preserved whereas ones cover copings and entrance canopy were changed.
- Missing wooden parts of the entrance canopy were completed in compliance with the original ones.
- The copper finial was cleaned.

Facades:

- Cement-based mortars and plasters were cleaned especially on stones. After performing a mortar analysis in order to make recommendations for replacement mortar that is both physically and aesthetically compatible with the materials, repointing process was carried out.
- Bricks, which had missing parts in a saw-tooth course of bricks and in the main walls, were changed with the bricks, which were the same type and had the same dimensions with the old ones.
- Missing parts of the stone moulding were completed in compliance with the original one.
- Blackening on the facades due to damp and carbon accumulation were cleaned.
- Composite patching was done where the surface erosion is greater than 10 cm.
- Biological growth on facades was cleaned.
- Geometric patterns were recolored and completed.

Windows and Door:

- Cracks in marble and stone window casings were repaired and composite patching was carried out for missing sections.
- Iron grills of the windows were cleared from paint and re-painted with anti-rust paint.
- Wooden window sashes and shutters were reinstated and preserved. Fumigation method was employed. Missing shutters were produced in compliance with the original ones. A coat of flexible vapor-permeable finishes was applied. Broken glasses were replaced.

- The gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*), which are constructed with multi-colored small glass pieces setting into plaster frames, were repaired. Broken glasses were replaced.
- Wooden door was preserved.

5.4.3. Tomb of *Şehzade* (Prince) Mustafa

i) Expert Report of 1996: According to the experts' report from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as repairing the wooden frames of the windows, and constructing a canopy similar the one of Cem Sultan's Tomb to preserve golden-gilded inscription above the entrance and to prevent entering of damp to inside. Bursa Cultural and Natural Heritage Preservation Regional Board made a decision about not to construct the canopy without preparing a restoration project.

ii) Expert Report of 2004:

- Traces above the entrance door pointed an entrance canopy (Figure 5.53).
- Cracks were observed on the marble casings of all windows at the lower row.
- Although traces of glazed tiles, which embellished the arch pediments of the windows, were found, there was not any piece of these tiles.
- All gypsum framed exterior windows (*dışlık*) displaced from their original place.
- Lead sheets covering the eaves did not performed their duties; and damp stains were observed on the fascia.

Figure 5.53. Missing entrance canopy caused excessive blackening and soiling on the portal. Besides, surface erosion and material loss were also seen at the facades. (Source. Bursa – CNHPRB, 2004)

- The effects of deterioration due to damp inside of the dome indicated the water penetration problem from deformed lead sheets of the dome.
- Fascia boards, which are at right-hand side of the entrance, displaced.
- Significant material loss (brick and mortar) were determined in the walls that caused the penetration of water through the building (Figure 5.54).

(a) (b)

Figure 5.54. The photos showing (a) deformed lead sheets on the eaves; blackening on the moulding; and material loss, especially bricks; and (b) material loss (bricks and stones).
(Source. Bursa – CNHPRB, 2004)

- Surface erosion on the *küfeki* stones composing the plinth indicated the problems of rising damp from ground and of soluble salts. Constructing of a drainage system around tomb and applying waterproofing barrier protection were suggested to solve these problems.
- Occurrence of the biological growth due to rising damp was also observed.
- Finial is made of brass, which is any of various metal alloys consisting mainly of copper and zinc. Re-using of the brass finial was offered.

iii) Survey Report of 2010: In this report, the expert summarized the history of Bursa and Muradiye Complex; however, the condition of the Tomb of *Şehzade* Mustafa was not explained, i.e. the problems and possible reasons. The photos of this report are presented below with the explanation of the author (Figures 5.55 and 5.56).

(a) (b)

Figure 5.55. The photos showing (a) the entrance facade and traces of the missing canopy; and (b) blackening, soiling, and greening due to algae growth on the facade. (Source. D2 Tasarım Mimarlık, 2010)

(a) (b)

Figure 5.56. The photos showing the facades on which there were black streaks and biologic growth due to rising damp and dirt; and material loss. (Source. D2 Tasarım Mimarlık, 2010)

- The improperly done repointing, which not only affected negatively the overall appearance of the facade but also caused physical damage to the masonry, was seen in Figure 5.57.

Figure 5.57. The photos displaying the improperly done repointing. (Source. D2 Tasarım Mimarlık, 2010)

- The gypsum frames of the exterior windows (*dışlık*), which secured the glass pieces, had gradually been deteriorated due to weathering and / or the lack of regular maintenance. Blackening and soiling were also observed on the frames (Figure 5.58).
- Cracks in the marble casings of windows; and blackening and soiling on them were seen. Wooden window frames had damaged due to weathering and /or the lack of regular maintenance.

(a) (b)

Figure 5.58. The photos displaying (a) the deteriorated window frame made of plaster; and (b) the problems, such as cracks, blackening and soiling.
(Source. D2 Tasarım Mimarlık, 2010)

- The wooden entrance door, which was constructed by *kündekari* technique. It had deteriorated due to weathering and / or the lack of regular maintenance. Greening and darkening were seen on the marble parts of the portal (Figure 5.59).
- Biologic growth, such as algae and different kinds of plants, was easily observed on the base of the missing entrance portico. It had a significant contribution to the stone damage through various deterioration mechanisms (Figure 5.60).

(a) (b)

Figure 5.59. Both photos displaying the deteriorated wooden entrance door from outside and inside, and greening and darkening on the marble parts of the portal. (Source. D2 Tasarım Mimarlık, 2010)

(a) (b)

Figure 5.60. Both (a) and (b) showing the biologic growth and deteriorated stone. (Source. D2 Tasarım Mimarlık, 2010)

Restoration Report, 2010:

- Subsurface drainage system was constructed around the tomb.
- The marble floor finishing of the entrance was cleaned. Cracks were repaired. Detached parts were completed with same type of marble.

- After checking sub-layers of the dome whether there were any signs of damp or not, lead sheets were changed or not.
- The copper finial was cleaned and replaced.

Facades:

- Cement based mortars and plaster were removed. After performing a mortar analysis in order to make recommendations for replacement mortar that is both physically and aesthetically compatible with the materials, repointing process was carried out.
- Metal angle bars and nails were removed from the facade and composite patching was conducted.
- Composite patching was conducted where the surface erosion is greater than 10 cm.
- Blackening due to dampness and carbon accumulation was cleaned.
- Eroded or detached bricks constituted the *almaşık* walls were changed with the bricks, which were the same type and had the same dimensions with the old ones.
- Biologic growth was cleaned.

Windows and Door:

- Cracks in marble and stone window casings were repaired and composite patching was carried out for missing sections.
- Iron grills of the windows were cleaned from paint and re-painted with anti-rust paint.
- Wooden window sashes and shutters were reinstated and preserved. Fumigation method was employed. A coat of flexible vapor-permeable finishes was applied. Broken glazing was replaced.
- The gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*), which are constructed with multi-colored small glass pieces setting into plaster frames, were repaired. Broken glasses were replaced.
- Cracks in the marble sections of the portal were repaired. Detached parts were completed with the same type of marble.
- Wooden door were retained and preserved.

5.4.4. Tomb of Cem Sultan

i) Expert Report of 1996: According to a report of experts from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as changing the lead sheets of the entrance canopy, repairing the wooden parts of the canopy, and removing plaster over the cut-stone.

ii) Expert Report of 2004:

- Damp stains were observed on the eaves fascia.
- Lead sheets had deformed and the seams had speared up.
- Bricks were placed vertically between the stones in the main walls (*almaşık)*, which are composed of alternating one course of stone and two courses of brick. The cement-based plaster covered all mortars and calcareous stones. The cement-based plaster disintegrated in patches. The deterioration in physical properties of the stone was observed.
- Eroded brick and stonework was determined especially in the lowest two rows of *almaşık* wall of the south facade (Figure 5.61).
- The effects of deterioration due to damp inside of the dome indicated the water penetration problem due to deformed lead sheets covering the dome.

(a) (b)

Figure 5.61. Both (a) and (b) showing the deteriorated stone and brick courses.
(Source. Bursa – CNHPRB, 2004)

It was stated that the deterioration of lower parts of the main walls indicates the problems of rising damp from ground and of soluble salts. Construction of a drainage system and waterproofing for the foundation were suggested to solve this problem.

ii) Expert Report of October 2010:

- Dampness problem was observed due to the deformed lead sheets.
- Repointing was conducted with cement-based mortar.
- Cracks were observed in the marble window casings.
- Deterioration problem was observed in the wooden frames of the windows.
- The gypsum frames of the interior windows (*içlik*) were deteriorated because of using cement-based mortar in the previous remedial works.

iii) Restoration Report of 2010:

- Subsurface drainage system was constructed around the tomb.
- Lead sheets covering the main dome were retained. Lead sheets and the sub-layers covering the copings and the entrance canopy were replaced.
- Marble parts of the portico were cleaned. Cracks were repaired. Detached portion of marble parts were completed with the same type of marble (Figure 5.62a).
- Detached portions of the woodworks of the entrance canopy were completed. Retained woodworks were treated. Geometric patterns on the wooden parts of the canopy were revived with the same type of paint (Figure 5.62b).
- The copper finial was cleaned.

(a) (b)

Figure 5.62. Both (a) and (b) showing soiling on the marble parts and the deteriorated woodwork of the portico.
(Source. D2 Tasarım Mimarlık, 2010)

Facades:

- Cement based mortars and plaster were removed. After performing a mortar analysis in order to make recommendations for replacement mortar that is both physically and aesthetically compatible with the materials, repointing process was carried out.
- Composite patching was conducted where the surface erosion is greater than 10 cm.
- Blackening due to dampness and carbon accumulation was cleaned (Figure 5.63).
- Eroded or detached bricks constituted both the *almaşık* walls and the saw-tooth courses were changed with the bricks, which were the same type and had the same dimensions with the old ones (Figure 5.63).
- Biologic growth was cleaned.
- Irregularity of the alternate walls' courses was left as they are.

(a) (b)

Figure 5.63. Both (a) and (b) showing blackening, and eroded stone and brickworks. (Source. D2 Tasarım Mimarlık, 2010)

Windows and the Door:

- Wooden window and doorframes were cleaned from paints; missing parts were completed, and then a coat of flexible vapor-permeable finishes was applied. Broken glazing was replaced.
- Iron grills of the windows were cleaned from paint and re-painted with anti-rust paint.
- The gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*) were repaired. Broken glasses were replaced.
- Cracks in marble and stone window casings were repaired; and composite patching was carried out for missing sections.
- The original wooden shutters were retained; and a coat of flexible vapor-permeable finishes was applied. The missing shutters were appropriately reproduced to the original ones.
- Wooden door was preserved.

5.4.5. Tomb of Şirin *Hatun*

i) Expert Report of 1996: According to a report of experts from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as removing plaster over the cut-stone, repairing the wooden door and the window shutters, and repairing the gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*). Besides, the activities, such as repairing the brick-built muqarnas hood on the portal of the tomb (Figure 5.64), and re-plastering areas inside the tomb where flaking had occurred due to dampness were included in the extensive remedial activities conducted by preparing survey and restoration projects.

Figure 5.64. Excessive deterioration of the brick-built muqarnas hood on the portal of the tomb.
(Source. Directorate of Bursa Museum, 1996)

ii) Expert Report of 2004:

- Saw-tooth courses of brick were in good state (Figure 5.65).
- Lead sheets, especially on the eaves, were deformed (Figure 5.65). The seams speared up.
- Cracks were observed in the marble window casings.
- Deterioration on wooden window frames was determined.
- Poor repointing work raised the level of the mortar joint above the face of the masonry unit. Therefore, lime plaster was swollen, and spalled in patches (Figure 5.66).
- Window shutters were excessively deteriorated due to fungal decay and infestation.

Figure 5.65. The photo showing the deformed lead sheets and saw-tooth courses of brickwork which were sound.
(Source. Bursa – CNHPRB, 2004)

Figure 5.66. The photo showing the poor repointing and spalling of the plaster. (Source. Bursa – CNHPRB, 2004)

iii) Restoration Report of 2010:

- Subsurface drainage system was constructed around the tomb.
- The copper finials were cleaned.
- Lead sheets of the dome were preserved while the ones covering copings and the roof of the portal were changed.
- Cracks in the marble portions of the entrance canopy were repaired.
- Eroded or detached brickworks constituted the entrance opening were removed, and then muqarnas was rebuilt (Figure 5.67). Selection of mortar materials for repointing or other masonry repairs was based on the results of the analysis.

Facades:

- Cement-based mortars and plaster were removed (Figure 5.67). Repointing was conducted according to results of the mortar analysis.
- After removing the detached portions of the saw-tooth courses of brick, the ones, which were same type and same dimensions, were placed.
- Irregularity of the alternate walls' courses was left as they are.
- Blackening due to dampness and carbon accumulation was cleaned (Figure 5.67).

- Composite patching was conducted where the surface erosion was greater than 10 cm.
- Biologic growth was cleaned.

Figure 5.67. The photo showing the eroded or detached brickwork of the portal, the cement-based mortar joints and the flaking plaster over the cut-stone, and dampness problem.
(Source. D2 Tasarım Mimarlık, 2010)

Windows and the door:

- The iron grills of the front facades' windows were completed while rest of them was cleaned from paint, and then anti-rust coating was applied.
- Cracks in marble window casings were repaired; and composite patching was carried out for missing sections. The marble portions were cleaned.
- The original wooden shutters were retained; and a coat of flexible vapor-permeable finishes was applied. The missing shutters were appropriately reproduced to the original ones. Broken glazing was replaced.

- The gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*) were repaired. Broken glasses were replaced.
- Wooden door was preserved.

5.4.6. Tomb of Gülruh Sultan

i) Expert Report of 1996: According to a report of an expert from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as removing plaster over the cut-stone (Figure 5.68), cutting out and repointing of mortar joints in alternating brick and stone rows, and repairing the wooden door and window frames. Besides, the activities, such as repairing the brick-built muqarnas hood on the portal of the tomb, and scraping off plaster on the brick courses of two niches on both sides of the portico were included in the extensive remedial activities conducted by preparing survey and restoration projects.

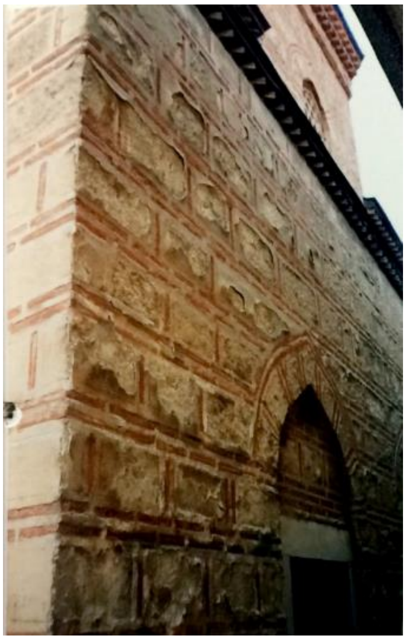


Figure 5.68. The flaking plaster over the facades
(Source. Directorate of Bursa Museum, 1996)

ii) Expert Report of 2004:

- All facades were covered with cement-based plaster, which swelled and spalled in patches (Figure 5.69).
- The saw-tooth brick courses were in good state.
- Lead sheets covering the coping were deformed. Unrepaired lead sheets covering the roof and the coping caused water seep through the deformed seams, and then led to interior wall damage.
- Swelling, formation of the crystalline deposit (efflorescence), and spalling in patches on the surface of the original fibered (*katıklı*) plaster were observed due to the dampness problem derived from capillary rise.
- The deteriorated gypsum framed exterior windows (*dışlık*) split from the facade. The bell jars (*fil gözü*) were broken (Figure 5.69).
- The deteriorated wooden framed windows split from the facade. The glazing was broken.

Figure 5.69. The photos showing the spalling lime mortar, which covered the surfaces of stone courses, and the deteriorated gypsum framed exterior window. (Source. Bursa – CNHPRB, 2004)

- The wooden window shutters and the entrance door of the tomb, which was produced with *kündekari* technique and made of timber, were damaged due to wood beetles / termites attack. Material loss was also observed.

It was stated that since the deterioration of lower parts of main walls indicated the problems of rising damp from ground and of soluble salts, and occurrence of the biological growth, construction of a drainage system was suggested to solve this problem.

iii) Survey Report of 2010:

- All facades were covered with cement-based plaster in the previous interventions. The plaster on the surfaces of the stonework and the mortar joints swelled and spalled in patches (Figure 5.70).

Figure 5.70. The photo showing the plaster spalling on the surfaces of masonry. (Source. D2 Tasarım Mimarlık, 2010)

- Completing detached parts of the stonework and repointing mortar joints of the portal were conducted by using cement-based mortar, which spalled in patches. Missing parts in brick courses of the muqarnas was also completed with cement-based mortar (Figure 5.71).

Figure 5.71. The photos showing the details from the problematic sections of the tomb, such as detached brick courses, broken gypsum framed exterior window and bell jars, and poor repointing.
(Source. D2 Tasarım Mimarlık, 2010)

- Lead sheets covering the dome were deformed. Unrepaired lead sheets caused water seep through the deformed seams, and then led to interior wall damage.

iv) Restoration Report of 2010:

- The subsurface drainage system and the sidewalk were constructed around the tomb.
- The copper finials were cleaned.
- Lead sheets of the dome were preserved while the ones covering copings and the roof of the portal were changed.
- The marble parts of the entrance were cleaned. Cracks were repaired. Detached parts were completed with the same type of marble.

Facades:

- Cement-based mortars and plaster were removed. Repointing was conducted according to results of the mortar analysis.
- After removing the damaged parts of the saw-tooth courses of brick, the ones, which matched in performance characteristics as well as appearance, were placed.
- Irregularity of the brick and stone courses was left as they are.
- Blackening due to dampness and carbon accumulation was cleaned.
- Composite patching was conducted where the surface erosion was greater than 10 cm.
- Biologic growth was cleaned.
- Brick courses of the muqarnas, which were disintegrated because of improper maintenance, and using wrong type of mortar when repointing, were replaced, and then the muqarnas were rebuilt.

Windows and the door:

- The iron window grills were cleaned from paint, and then anti-rust coating was applied.
- Cracks in marble and stone window casings were repaired; and composite patching was carried out for missing parts.
- The original wooden shutters and all wooden frames were preserved; and a coat of flexible vapor-permeable finishes was applied. The missing shutters were appropriately reproduced to the original ones. Broken glasses were renewed.
- The gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*) were repaired. Broken bell jars were replaced.
- The wooden entrance door was preserved.
- The window sills were reproduced in accordance with the original ones.

5.4.7. Tomb of Gülbahar *Hatun* (Ebe - Obstetrician Lady)

i) Expert Report of 1996: According to a report of experts from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as re-plastering and painting the inside, removing plaster over the cut-stone courses, and cutting out and repointing of mortar joints in alternating brick and stone courses (Figure 5.72)

Figure 5.72. The photo showing the stains of the dampness problem and deteriorated brickworks and mortar joints.
(Source. Directorate of Bursa Museum, 1996)

ii) Expert Report of 2004:

- Saw-tooth brick courses were deteriorated and disintegrated. Material loss was observed.
- Lead sheets covering the dome and the copings were deformed. Unrepaired lead sheets had failed to perform their duties.

- The deflection of the bonding timber and material loss were observed at the west and south facades.
- Brick courses above the plinth deteriorated and detached seriously.
- Mortar joints deteriorated especially in between bricks constituting of the lower parts of the piers (Figure 5.73).

Figure 5.73. The photo showing the deteriorated mortar joints, the spalled plaster covering the surfaces of stone courses, and blackening.
(Source. Bursa – CNHPRB, 2004)

iii) Survey Report of 2010:

- Cement-based plaster on the surfaces of the piers spalled in patches.
- In the arches, stone and brick courses were deformed, and mortar joints were deteriorated (Figure 5.74).
- The mortar joints in the piers were deteriorated (Figure 5.74).

- The mortar joints in the plinth, which was constructed of rubble stone, eroded and cracked due to dampness and excessive biological growth.
- Brick courses above the plinth were deteriorated.
- The bonding timber had rotted away, and thus it had not perform its duty.
- Excessive soiling was observed on the floor and the grave.

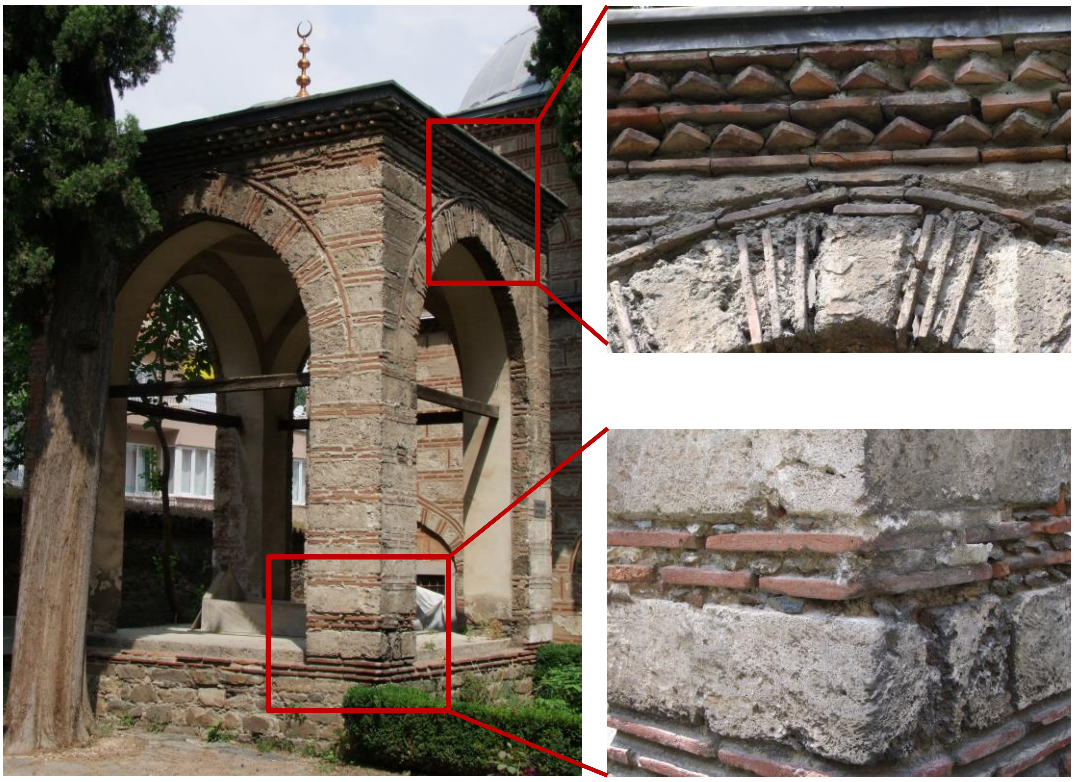


Figure 5.74. Deteriorated brick and stone courses, and mortar joints.
(Source. D2 Tasarım Mimarlık, 2010)

iv) Restoration Report of 2010:

- The subsurface drainage system was constructed around the tomb.
- The copper finials were cleaned.
- Lead sheets were replaced.
- Cracks in the floor and the grave made of marble were repaired.

- Composite patching was conducted where the surface erosion was greater than 10 cm.
- The deflected bonding timber was renewed with the same type of timber.
- The badly deteriorated and broken brick courses were removed and changed.
- Soiling was cleaned where it was necessary.
- Plaster covering the inside of the dome and the pendentives was analyzed, and according to the result, it was renewed.
- Plaster covering the inner sides of the piers were analyzed and renewed.
- The mortar joints were repointed.

5.4.8. Tomb of *Şehzade* (Prince) Mahmut

i) Expert Report of 1996: According to the experts' report from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as removing plaster over the stone, repairing the wooden window frames, the gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*).

ii) Expert Report of 2004:

- Eroded sections of the plinth were repaired by using mortar.
- The cement framed exterior window (*dışlık*), which is on the south facade, split from the facade (Figure 5.75a).
- Saw-tooth brick courses were in good state.
- Lead sheets covering the dome, the eaves and the roof of the canopy were deformed. Unrepaired lead sheets caused water seep through the deformed seams, and then led to interior wall damage (Figure 5.75b).

(a) (b)

Figure 5.75. The photos showing (a) the deteriorated cement framed exterior window and improper repointing, and (b) unrepaired lead sheets covering the dome. (Source. Bursa – CNHPRB, 2004)

- Material loss was observed in the marble parts of the portal and the portico (Figure 5.76).
- Swelling, formation of the crystalline deposit (efflorescence), and spalling in patches on the surface of the plaster were observed due to the dampness problem derived from capillary rise.
- The deteriorated gypsum framed interior windows (*içlik*) split from the facade. The bell jars (*fil gözü*) were broken.
- The window frames were in good state while the window shutters and the wooden door, which was produced with *kündekari* technique, decayed due to wood beetles / termites attack. Besides, material loss was also observed.

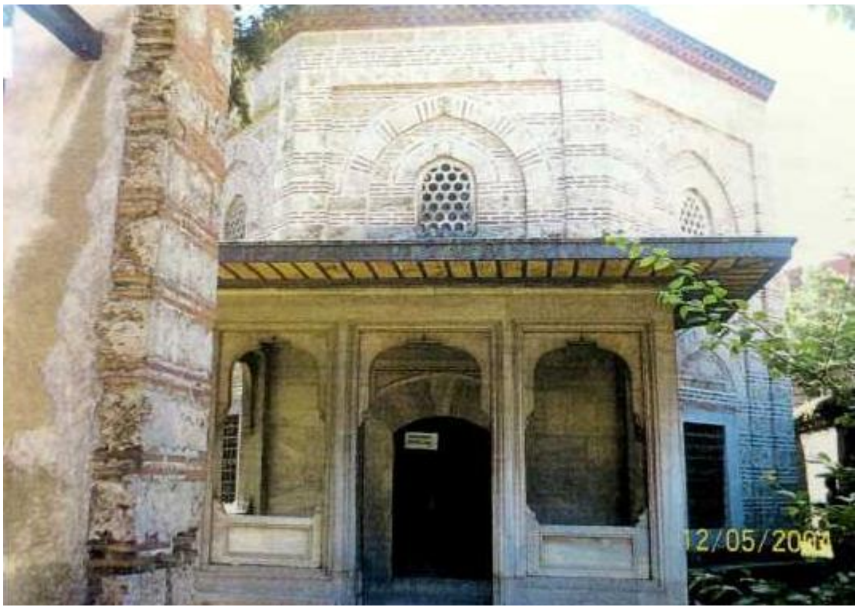


Figure 5.76. The photo showing material losses, blackening, soiling and greening on the marble portions of the portico and the portal.
(Source. Bursa – CNHPRB, 2004)

It was stated that the deterioration of the lower parts of the main walls indicates the problems of rising damp from ground and of soluble salts. Besides, occurrence of the biological growth due to rising damp was also observed. Construction of a subsurface drainage system around the tomb, removing cement-based plaster on the plinth and applying waterproofing agent on the foundation and the plinth were suggested to solve this problem.

iii) Survey Report of 2010:

- The effects of excessive dampness were observed on the surfaces of both exterior and interior walls.
- The presence of wood decay was identified in the wooden parts of the canopy (Figure 5.77).

- Biological growth was observed on the portico's plinth made of *küfeki* stone. It plinth was repaired by using cement-based mortar during the previous remedial works (Figure 5.77).
- Cement-based mortar was used for repointing.

Figure 5.77. The photos showing the decayed wooden parts of the canopy and the biological growth on the plinth.
(Source. D2 Tasarım Mimarlık, 2010)

- The wooden door, which was produced with *kündekari* technique, decayed (Figure 5.78a).
- The wooden parts of the gypsum framed exterior windows totally decayed. Besides, blackening was observed on the gypsum part of the windows (Figure 5.78b).

(a) (b)

Figure 5.78. The photos showing (a) the decayed wooden door, and (b) the discolored gypsum framed exterior window.
(Source. D2 Tasarım Mimarlık, 2010)

iv) Restoration Report of 2010:

- Subsurface drainage system was constructed around the tomb.
- The copper finials were cleaned.
- Lead sheets of the dome were preserved whereas the ones covering the copings and the roof of the portico were renewed.
- Cracks in the marble floor of the portico were repaired. Detached parts were completed with the same type of marble. Soiling was cleaned.
- Composite patching was conducted in the threshold of the portico where the surface erosion was greater than 10 cm.

Facades:

- Cement-based mortars and plaster were removed. Repointing was conducted according to results of the mortar analysis.

- Brick courses, which were disintegrated because of improper maintenance, and using wrong type of mortar when repointing, were cut from the walls, and substitute bricks were inserted into the walls.
- Irregularity of the brick and stone courses was left as they are.
- Blackening due to dampness and carbon accumulation was cleaned.
- Composite patching was conducted on stone surfaces where the surface erosion was greater than 10 cm.
- The disintegrated parts of the stone plinth were completed.
- Biologic growth was cleaned.
- Cracks in the marble parts of the portico were repaired.

Windows and the door:

- Cracks in marble and stone window casings were repaired and composite patching was carried out for missing parts.
- Iron grills of the windows were cleaned from paint and re-painted with anti-rust coating.
- The gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*) were repaired. Broken bell jars were replaced.
- Wooden window frames and shutters were reinstated and preserved. Fumigation method was employed. A coat of flexible vapor-permeable finishes was applied. The deteriorated or missing ones were reproduced in compatible with the original ones.
- Wooden door was preserved.

5.4.9. Tomb of Mükrime *Hatun*

i) Expert Report of 1996: According to a report of experts from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as repairing the wooden door and the window frames whereas repairing the brick-built muqarnas hood of the portal was included in the extensive remedial activities conducted by preparing survey and restoration projects.

ii) Expert Report of 2004:

- It was visually observed that cut-stone courses were covered with lime plaster (sand+lime), which was swollen and spalled in patches (Figure 5.79).
- Saw-tooth brick courses were in good state.
- Lead sheets covering the dome were deformed, and so unrepaired lead sheets did not performed their duties.

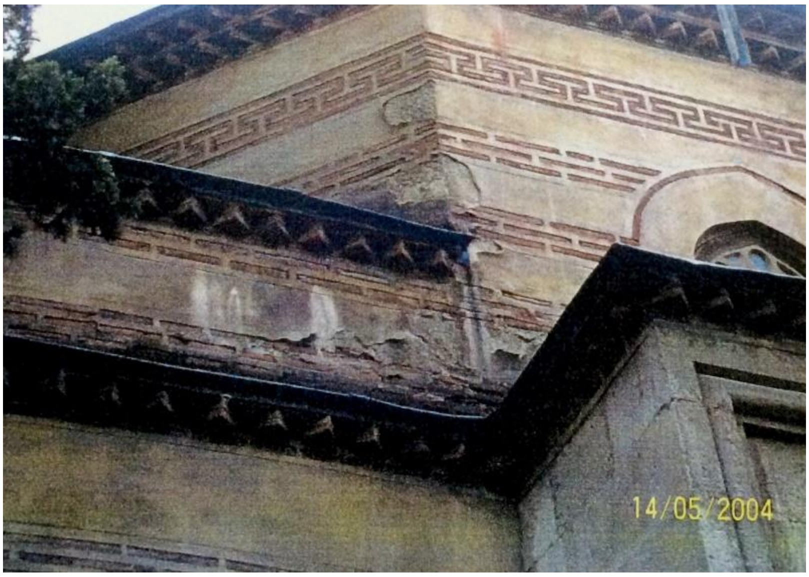


Figure 5.79. The photo showing the spalled plaster, blackening and improper repointing.
(Source. Bursa – CNHPRB, 2004)

- Material loss was observed in the plinth made of *küfeki* stone.
- The effects of excessive dampness were observed on the surfaces of both exterior and interior walls.
- The wooden window frames split from the facade. The glazing was broken. The wooden lintels decayed.

- The wooden door, which was produced with *kündekari* technique, and the wooden shutters were seriously deteriorated due to wood beetles / termites attack and fungal decay.

iii) Survey Report of 2010:

- The cut-stone courses were covered with cement-based plaster, which was swollen, and spalled in patches. Cement-based mortar was also used for repointing (Figure 5.80).
- In the previous remedial work, lead sheets of the dome were changed whereas lead sheets covering the squinches and eaves were left as they were. This caused dark patches on the facades (Figure 5.81). Unrepaired lead sheets caused water seep in between the deformed seams, and then led to interior wall damage.

Figure 5.80. The photo showing the spalled plaster covering the stone courses and poor repointing.
(Source. D2 Tasarım Mimarlık, 2010)

Figure 5.81. The photos showing the deformed lead sheets covering the eaves, dark patches and blackening on the facades.
(Source. D2 Tasarım Mimarlık, 2010)

- Biological growth was easily observed on the lowest parts of the walls due to excessive dampness.
- The mortar joints of the portal were repaired by using cement-based mortar. The brick courses constitute the half-dome portion (*kavsara*) of the portal were excessively deteriorated. The lintel above the wooden door was broken. Biological growth found on the lower sections of the portal due to excessive damp (Figure 5.82a).
- The wooden door, which was produced with *kündekari* technique, decayed drastically (Figure 5.82a).
- The wooden shutters decayed. Metal parts were corroded (Figure 5.82b).

(a) (b)

Figure 5.82. The photos showing (a) deteriorated brick courses, decayed wooden door and soiling on the portal, and (b) the decayed wooden shutter.
(Source. D2 Tasarım Mimarlık, 2010)

iv) Restoration Report of 2010:

- Subsurface drainage system and the sidewalk were constructed around the tomb.
- The copper finials were cleaned.
- After checking the dampness problem under the lead sheets of the dome, they were changed if necessary. Lead sheets covering the copings and the roof of the portico were renewed.
- Cracks in the marble floor of the portico were repaired. Material loss was completed with the same type of marble. Soling was cleaned.

Facades:

- Cement-based mortar and plaster were removed. Repointing was conducted. Selection of mortar materials for repointing or other masonry repairs was based on the results of the analysis.

- Eroded or detached brickworks in the saw-tooth courses and the main walls were cut from their places, and substitute bricks were inserted into these places.
- Irregularity of the alternate walls' courses was left as they are.
- Blackening due to dampness and carbon accumulation was cleaned.
- Composite patching was conducted on stone courses where the surface erosion was greater than 10 cm.
- Biologic growth was cleaned.

Windows and the door:

- Cracks in marble window casings were repaired, and composite patching was carried out for missing parts.
- Iron grills of the windows were cleaned from paint and re-painted with anti-rust coating.
- The gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*) were repaired. Broken bell jars were replaced.
- Wooden window frames and shutters were preserved. Fumigation method was employed. A coat of flexible vapor-permeable finish was applied. The deteriorated or missing ones were reproduced in compatible with the original ones.
- Wooden door was preserved.
- Eroded or detached brick courses constituted the half-dome portion (*kavsara*) of the portal were removed, and then muqarnas was rebuilt.
- Cracks in the marble parts of the portal were repaired.

5.4.10. Tomb of Hüma *Hatun*

i) Expert Report of 1996: According to a report of an experts from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as cutting out and repointing of mortar joints in brick and stone alternating masonry, purifying the wooden door from paints, and repairing wooden window frames. Besides, repairing the brick-built muqarnas hoods of the portal, and removing plaster from the brickwork of two niches on both sides of the portal were included in the extensive remedial activities conducted by preparing survey and restoration projects.

ii) Survey Report of 2010:

- The effects of weathering were easily observed on the facades.
- Cracks, material losses, and erosion of both brick-stone courses and mortar joints were common in all facades (Figure 5.83).
- Water stains and blackening were identified due to deformed lead sheets covering the saw-tooth courses and mouldings.
- Algae growth was on both the plinth and the facades due to rising damp.
- The muqarnas in the half-dome portion (*kavsara*) of the portal was totally destroyed (Figure 5.83a).
- In two niches of both sides of the iwan, brick courses decayed and joints weathered-out for a variety of reasons. Excessive soiling was also identified.

(a) (b)

Figure 5.83. The photos (a) and (b) showing the erosion of both brick-stone courses and mortar joints, excessive blackening and algae growth in the facades. (Source. D2 Tasarım Mimarlık, 2010)

- The wooden door, which was embellished with rosettes, lost its original state due to being painted several times.

iii) Restoration Report of 2010:

- The subsurface drainage system was constructed around the tomb.
- The copper finials were cleaned.
- Lead sheets of the dome were preserved whereas the ones covering the eaves and the roof of the iwan were renewed.
- Cracks in the marble floor of the portico were repaired. Material losses were completed with the same type of marble. Soiling was cleaned.

Facades:

- Cement-based mortar and plaster were removed. Repointing was conducted. Selection of mortar materials for repointing or other masonry repairs was based on the results of the analysis.
- Eroded or detached materials in the saw-tooth brick courses and the main walls were cut from their places, and substitute bricks were inserted into these places.
- Irregularity of the courses was left as they are.
- Blackening due to dampness and carbon accumulation was cleaned.
- Composite patching was conducted on stone surfaces where the surface erosion was greater than 10 cm.

Windows and the door:

- Cracks in marble and stone window casings were repaired, and composite patching was carried out for missing parts.
- Iron grills of the windows were cleaned from paint and re-painted with anti-rust coating.
- The gypsum framed exterior windows (*dışlık*) and interior windows (*içlik*) were repaired. Broken bell jars were replaced.
- Wooden window frames were preserved. The fumigation method was employed. A coat of flexible vapor-permeable finish was applied.

- Wooden door was preserved.
- Eroded or detached materials constituted the half-dome portion (*kavsara*) of the portal were removed, and then muqarnas was rebuilt.
- Cracks in the marble parts of the entrance opening, such as the arch pediment of the door, were repaired.

5.4.11. Tomb of *Saraylılar*

i) Expert Report of 1996: According to a report of experts from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as re-plastering and painting.

ii) Expert Report of 2004: Some of the wooden tie rods in between piers were lost. Spalled plaster should be renewed. The deteriorated joints between bricks should be repointed.

iii) Survey Report of 2010:

- Unrepaired lead sheets covering the upper structure caused water seep through the deformed seams, and the rain flowing over the surfaces. Therefore, the facades became spoiled through the pollution deposited on them. The plaster on both inside of the cone and the pendentive known as Turkish triangle spalled due to excessive dampness.
- The stone and brick courses were drastically deteriorated and mortar joints eroded (Figure 5.84).
- Formation of fungi was identified from bottom to the top of the piers due to dampness.
- Cement-based mortar and plaster, which were used in the previous remedial works, caused detachment of brick and stone courses, and erosion of joints.
- Excessive biological growth was especially formed on western and southern facades (Figure 5.84).

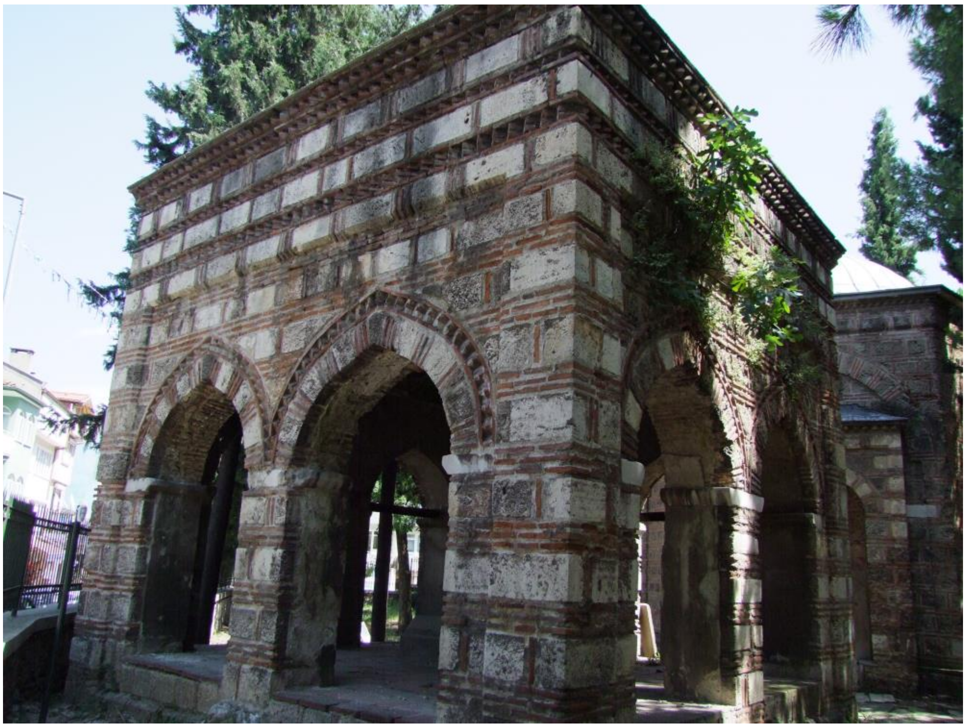


Figure 5.84. The photo showing the northern and western facades of the tomb. The deteriorated brick and stone courses, eroded mortar joints and blackening were identified.
(Source. D2 Tasarım Mimarlık, 2010)

- The wooden tie rods in between the piers were completely lost in the western and northern facades. The places of the missing tie rods were filled with cement-based mortar.
- The places of the missing square bricks covering the floor were filled with cast stone.
- Spalling and detachment were seen on the graves made from stone and brick.

iv) Restoration Report of 2010:

- Subsurface drainage system was constructed around the tomb.
- Lead sheets of the cone were renewed.
- The marble cornice was remediated.
- Cement-based mortars and plaster on inside of the cone and the pendentives were removed. Replastering and repointing were conducted. Selection of mortar

materials for repointing or other masonry repairs was based on the results of the analysis.

- Eroded or detached bricks were cut from their places, and substitute bricks, which matched in performance characteristics as well as appearance, were inserted into these places.
- The deflected wooden tie rods were renewed with the same type of timber, and a coat of boat varnish was applied.
- Blackening and efflorescence due to dampness and carbon accumulation was cleaned.
- Composite patching was conducted on stone surfaces where the surface erosion was greater than 10 cm.
- Spalled *horasan* mortar on the graves was renewed.

5.4.12. Tomb of Gülşah *Hatun*

i) Expert Report of 1996: According to a report of experts from the Directorate of Bursa Museum, basic maintenance and repairs were recommended, such as re-plastering and painting, and repairing the wooden door and the window frames.

ii) Survey Report of 2010:

- The detached parts of *küfeki* stone row under the saw-tooth brick courses were completed with cement-based mixture.
- The eroded or detached brick courses constituted the half-dome portion (*kavsara*) of the portal were repaired by applying cement-based plaster and repointing with cement-based mortar.
- Material losses were identified in the mouldings and the bases of both the portal and the niches of the portal.
- Blackening and soiling were dominant on the facades (Figure 5.85).
- Cracks were in the stone units of the portal's pointed arch.
- Algae growth was on the lower parts of the tomb due to damp (Figure 5.85).

Figure 5.85. The photo showing blackening and algal growth on the facades.
(Source. D2 Tasarım Mimarlık, 2010)

- The stone and brick courses deteriorated drastically and mortar joints eroded.
- The cement-based mortar joints fell down in patches.
- Material losses and detachments were identified (Figure 5.86).

(a) (b)

Figure 5.86. The photos showing (a) poor repointing and detachments in the western facade; and (b) eroded mortar joints in the eastern facade.
(Source. D2 Tasarım Mimarlık, 2010)

- The wooden window frames decayed totally.
- Iron grills of the windows were painted several times; therefore, they lost their originality.
- The wooden door, which was produced with *kündekari* technique, decayed excessively. The lower parts of the door deteriorated seriously. Its lock / hinge rails and stiles were destroyed. Metal parts were lost.
- The lead sheets of the dome were repaired in the previous intervention.
- Damp satins were observed from the lower parts of the walls to under the dome.

iii) Restoration Report of 2010:

- Subsurface drainage system was constructed around the tomb.
- Lead sheets were removed, and cement-based mortar on the sub-layer was cleaned. Then, *horason* mortar was applied and the lead sheets were replaced.
- The copper finials were cleaned.

Facades:

- Cement-based mortar and plaster were removed. Repointing was conducted. Selection of mortar materials for repointing or other masonry repairs was based on the results of the analysis.

- Eroded or detached materials in the saw-tooth brick courses were cut from their places, and substitute bricks were inserted into these places.
- Irregularity of the courses was left as they are.
- Blackening due to dampness was cleaned.

Windows and the door:

- Cracks in marble window casings were repaired.
- Iron grills of the windows were cleaned from paint and re-painted with anti-rust coating.
- The cement-based framed exterior windows (*dışlık*) and interior windows (*içlik*) were repaired. Broken bell jars were replaced.
- Wooden window frames and the door were preserved. The fumigation method was employed. A coat of flexible vapor-permeable finish was applied.

In summary, the archival records of Muradiye Tombs show that a few in situ investigations were conducted to understand the reasons of material deterioration and to visualize the type of deteriorations. However, except the latest survey report and drawings, there is impossible to gain knowledge about exposure, weathering forms, weathering intensity, how weathering advances, and vulnerable areas in a section of a facade.

To conclude, in Muradiye Complex, the buildings have been subject to many remedial activities in different scale and in different dates. However, except the latest restoration projects, in the archives of Bursa – CNHPRB, Bursa Regional Directorate of Foundations, the Metropolitan Municipality of Bursa and General Directorate for Foundations in Ankara, documentation of materials via field surveys, results of the laboratory analysis for the identification of material characteristics and causes of deterioration in original materials belonging to different periods of the buildings for conservation interventions could not be found. The available documents were reorganized according the chronological order of events and the findings were evaluated and used to make comparisons with the findings of the following chapters.

CHAPTER 6

RESULTS AND DISCUSSION: ASSESSMENT OF POTENTIAL IMPACTS IN BURSA

Tangible heritage is a fragile and non-renewable resource – once lost it cannot be replaced; unfortunately, much of this heritage is under threat from the impacts of global climate change. As Turkey has complex climate ranging from hot and dry to cold and humid, consequences of the anticipated impacts of climate change vary on different parts of Turkey, and likewise on tangible heritage in these parts. This situation gives rise to the question of selecting the most appropriate region that would prove to be informative as a case study in terms of understanding and adapting to different impacts of climate change. Therefore, the following issues gain importance:

- to understand the link between changing patterns of deterioration mechanisms and the stock of historic buildings in Turkey by creating overlay maps;
- to determine the city that can be used as the case study by producing overlay maps;
- to examine the statistical distribution of tangible heritage in Bursa by producing heritage maps;
- to understand changes in the selected climate parameters in Bursa by conducting trend analyses;
- to understand the link between traditional materials of construction and the deterioration processes, which may be accelerated or decelerated due to changes in climate in Bursa by producing heritage-climate risk map overlays.

6.1. Overlay Maps of Deteriorations in Building Materials due to Climate Change

It is expected that several deterioration mechanisms may be accelerated or worsened by future changes in climate whereas others are likely to retard. Therefore, the overlay maps were prepared to understand the link between changing patterns of deterioration mechanisms and the stock of historic buildings in Turkey. As a result, the case study area came to the forefront. The findings are presented according to different building materials and deterioration mechanisms in the following paragraphs.

6.1.1. Stone and Brick Deterioration

The regions in Turkey where stones and bricks are under the influence of several deterioration mechanisms, whose patterns may vary with climate change, are given as overlay maps in the following sections.

(i) Salt Crystallization: As it is described in the Building Research Establishment document, salt crystallization test, which is mainly intended for use on limestone or sandstone, stone samples are subjected to at least 15 test cycles to assess durability of porous building stones (see Section 2.3 and for full details of the test procedure see Ross and Butlin, 1989). From this point of view, the classes, which cover the number of humidity cycle events (below and above 75.5 %) in a year greater than 15 and the classes, which are over standard deviation in the map of historic buildings were used to produce the overlay map for humidity cycles and tangible heritage locations in Turkey (Figure 6.1).

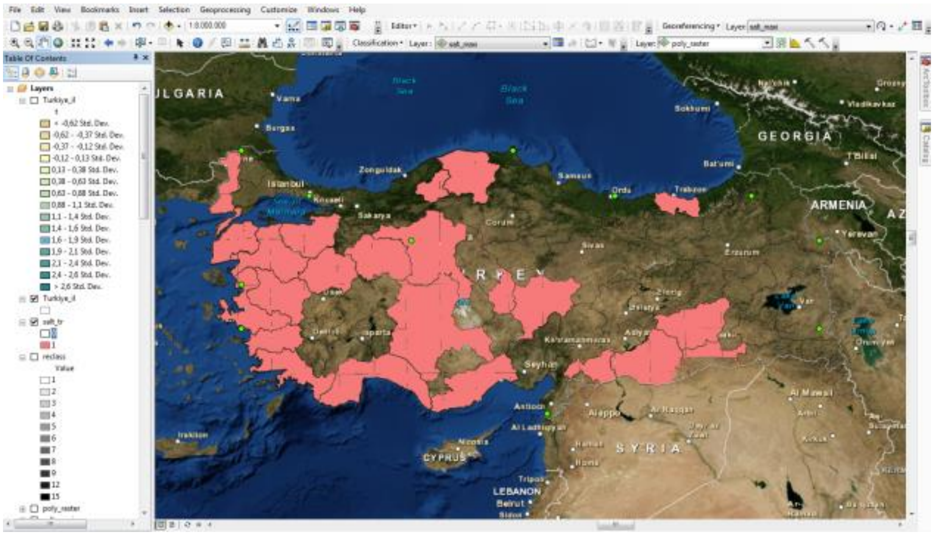


Figure 6.1. The map shows the intersection of the number of humidity cycle events equal or greater than 15 per year and the map of areas by distribution of historic buildings (pink = intersected regions) (prepared by the author).

In order to limit the study area, it is also necessary to examine maps, which present change from recent past to near future, and change from recent past to far future (according to section 2.3). As it is deduced from these maps, the biggest change in the annual frequency of salt crystallization events is expected to be in the far future in Trabzon; and the cities below the Marmara Sea such as Bursa, Balıkesir, Kütahya, Manisa.

(ii) Frost damage: There are numerous different methodologies used to determine the number of cycles run in durability tests. The condition of samples is assessed throughout the cycles, and any defects noted (crack formation, loss in mass, and appropriateness, changes in strength). In some weak limestone, which may show cracking or spalling after as few as five cycles of freezing and thawing whereas more dense and less porous limestone can pass the test visually unaffected[21]. From this point of view, when the number of freezing events per year is greater than 5 the data was included in the calculation; thus areas under risk area were delineated on the output map.

Both the map, which shows the number of freeze-thaw cycles (events / year), and the map, which shows wet-frost index (events/year) for far future indicate that due to rising temperatures there is likely to be a reduction in freezing across Turkey. This will lower the potential for frost damage to porous building materials. Therefore, frost damage is excluded while preparing the final overlay map.

(iii) Thermal stress: It is stated that the major impact is expected when the number of thermal stress events exceed 200 per year, internal tension in the materials greater than 20 MPa is forecast. Therefore, the number of events equal or greater than 200 events per year was included in the calculation for determining the risk areas (Figure 6.2).

[21] Miglio and Willmott (1997)

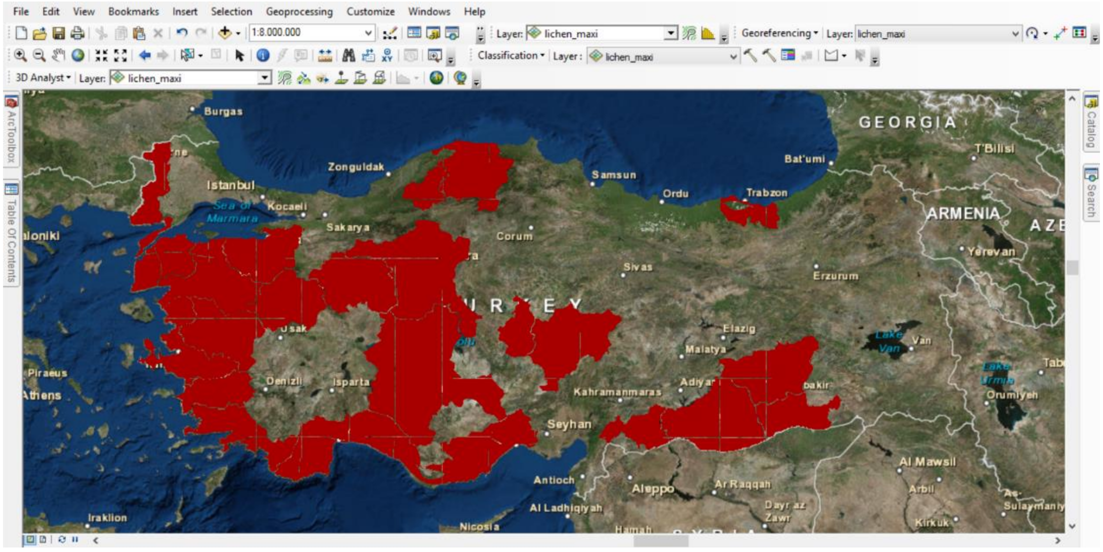


Figure 6.2. The map shows intersection of the number of thermoclastism events equal or greater than 200 events / year and the map of areas by distribution of historic buildings (red = intersected regions) (prepared by the author).

As it is understood from the maps, which present change from recent past to near future, and change from recent past to far future, it is expected that the number of thermoclastism events may increase for almost the whole of Turkey, in the far future. When it is evaluated in terms of the stock of heritage buildings per city, Western and Southern coast cities, Southeastern Region, some cities in Central Anatolia, Karabük and Trabzon from Black Sea Region come to the forefront.

(iv) Surface Recession: It is stated that if a threshold value for surface recession i.e. 8 µm / year is exceeded, buildings, monuments, statues and carved decorative elements, *etc.* made of carbonate stones can be under the risk of surface recession. Therefore, surface recession values greater than 10 µm /year were included in the calculation of risk areas.

It is expected that the biggest change towards uptrend in surface recession rates of low porosity carbonate stone is likely to be in the northern region of Turkey from Marmara Region to the east border in the far future according to changes maps. Besides, in the intersection map, the cities below Marmara Sea, several areas from the South, and the cities from the coast of the Black Sea are pointed (Figure 6.3).

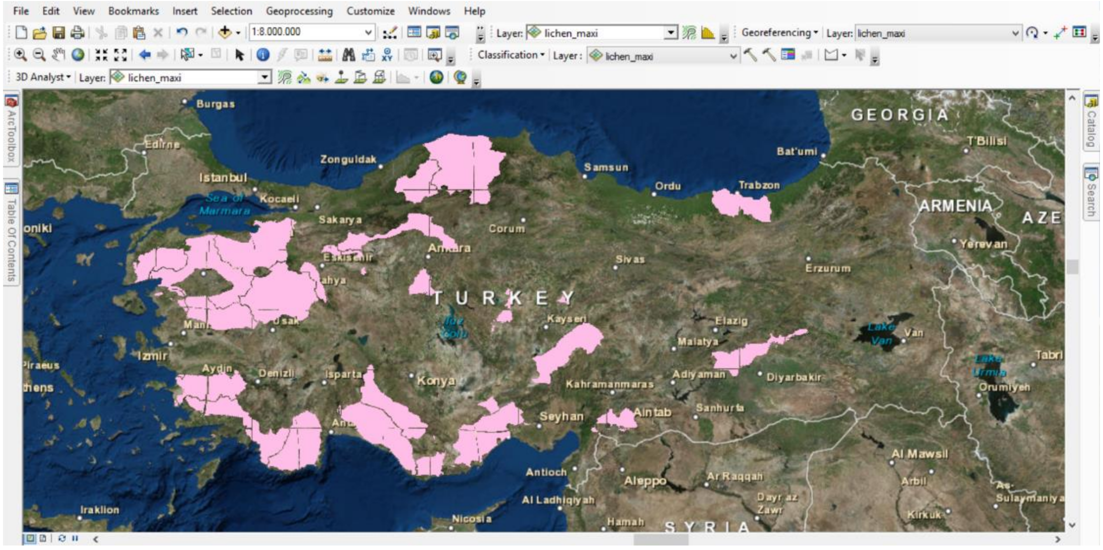


Figure 6.3. The map shows intersection of the surface recession rate values equal or greater than 10 µm / year and the map of areas by distribution of historic buildings (light pink= intersected regions).

When the maps in Figures 6.1, 6.2 and 6.3 were superimposed and evaluated, the cities, below the Marmara Sea, Bursa, Balıkesir, Kütahya, Manisa may be the under the risks of salt crystallization, surface recession and thermal stress. The cities, at the coast of Aegean Sea and Mediterranean Sea, Aydın, Muğla, Antalya and Mersin will also be under the risk of salt crystallization, surface recession, and thermal stress. The cities from the coast of the Black Sea -Karabük, Kastamonu and Trabzon –will also be under the risks mentioned above (Figure 6.4).

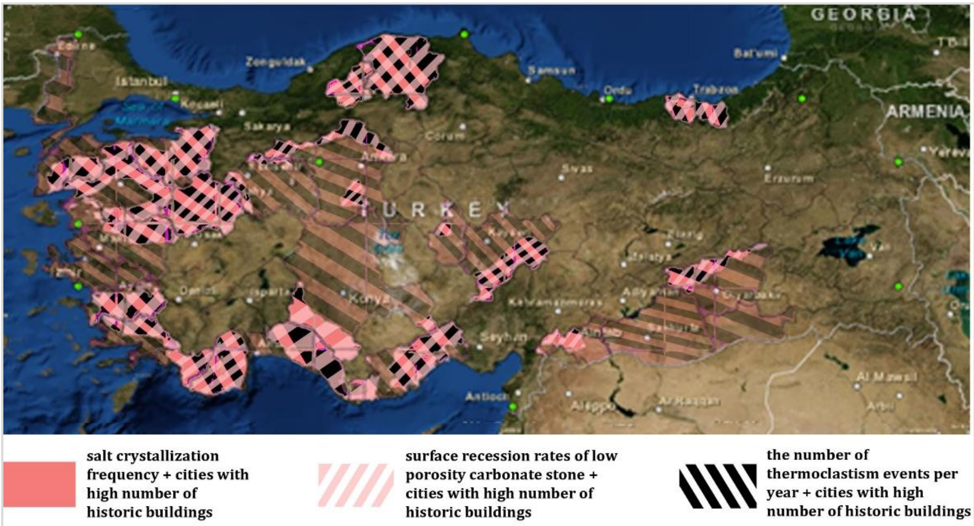


Figure 6.4. The figure shows the superimposed map of the intersected regions of the deterioration mechanisms, such as salt crystallization frequency, surface recession rates, and thermoclastism events, and cities with high number of historic buildings.

(v) Biodeterioration: As there have not been found any threshold for total biomass either from the project or the literature yet, the values greater than the first precisely defined number were selected to produce the map of intersection (Figure 6.5).

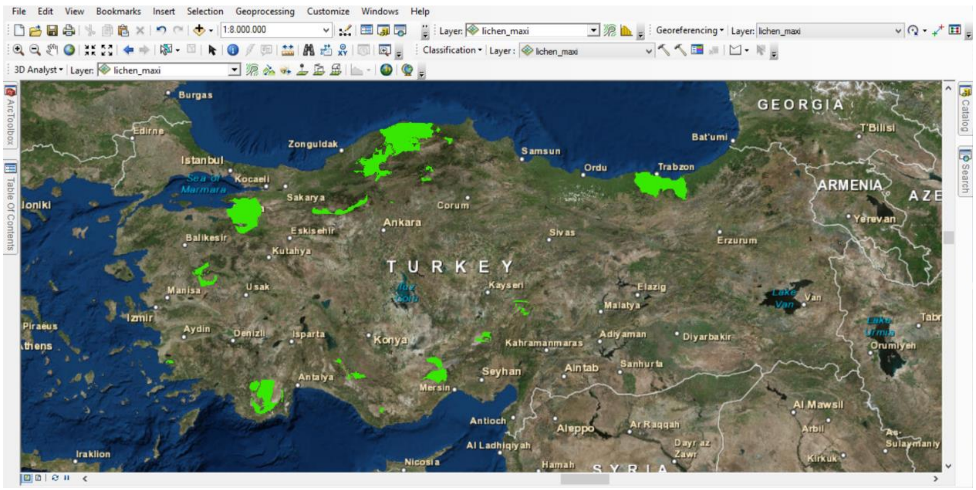


Figure 6.5. The map shows the intersection of the total biomass values equal or greater than 5 mg/cm^2 and the map of areas by distribution of historic buildings (green= intersected regions) (prepared by the author).

When the maps of changes in total biomass are evaluated, it is deduced that although climate change does not seem to affect excessively the biomass stock on stone monuments in Turkey in the near future, a decrease is predicted in most parts of Turkey in the far future. During this change in the pattern of total biomass, Bursa, Trabzon, Kastamonu, Karabük and western part of Antalya are likely to be under the risk of biodeterioration more than other cities.

(vi) Blackening: The values greater than the first precisely defined number were selected to produce the map of intersection (Figure 6.6).

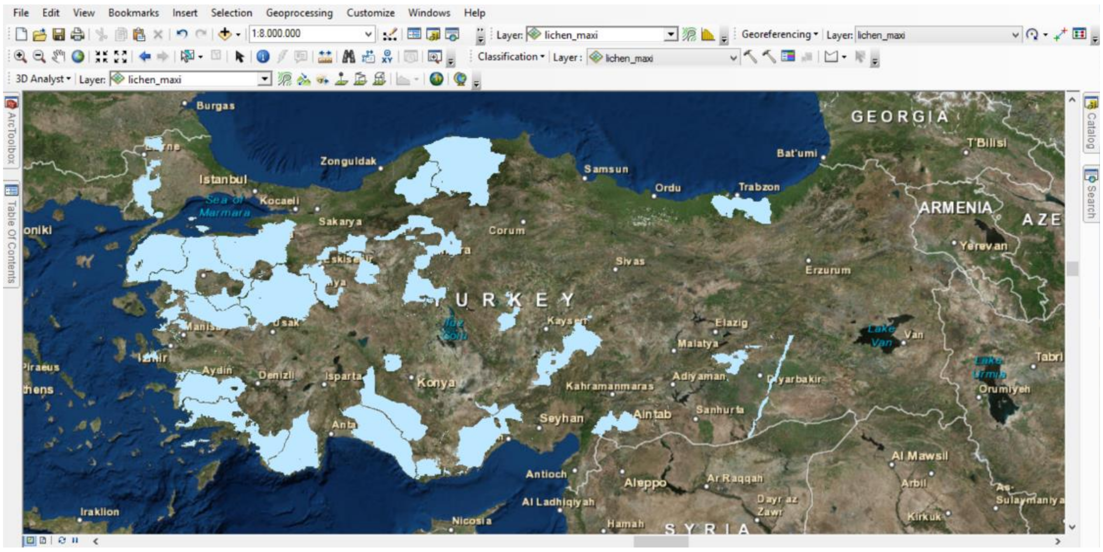


Figure 6.6. The map of mean-wind-driven rain index and the map of areas by distribution of listed buildings (blue= intersected regions) (prepared by the author).

In the intersection map, it is expected that the possibility of experiencing rain-washing in the cities where wind-driven rain may be dominant is likely to be in coastal areas more than the rest of Turkey. As the acceptance of blackening depends on the level of reflectivity and distribution pattern, wind-driven rain leads to change in blackening pattern.

When the overlay tool is conducted for all the maps mentioned above, the output is the following map (Figure 6.7). Some parts of Bursa, Karabük, Kastomonu, Trabzon, and Antalya are likely to be under the risk of various deterioration mechanisms affecting building materials especially porous calcareous stones.

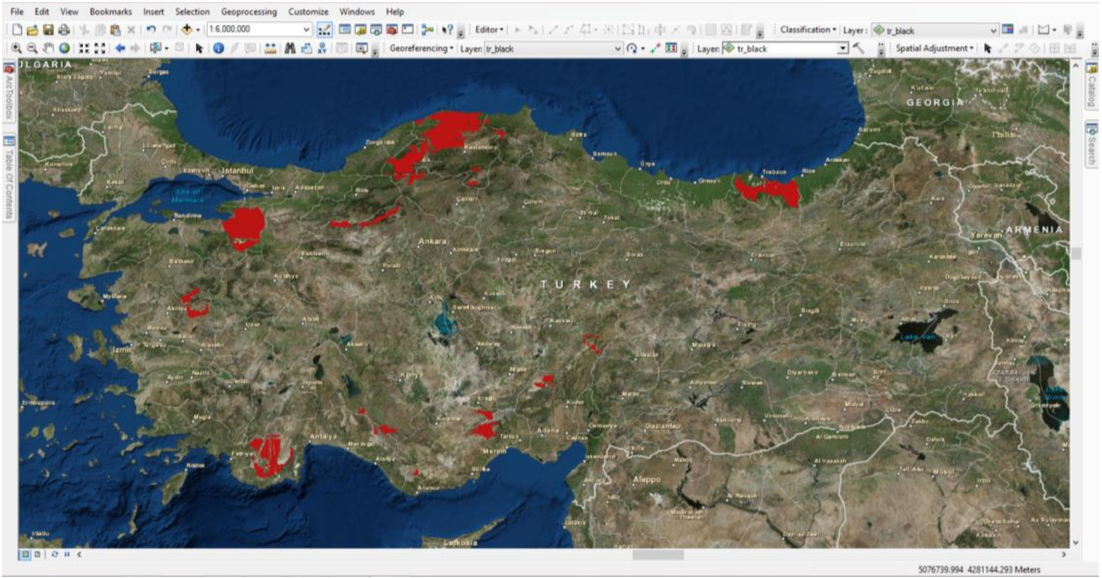


Figure 6.7. The weighted overlay tool was employed to intersect overlay maps of salt crystallization, thermal stress, surface recession, total biomass, and blackening (prepared by the author).

6.1.2. Timber Deterioration

The overlay maps were presented to understand two principal damage mechanisms by which historic wooden structures and objects deteriorate:

- mechanical damage due to climatic variations, mainly of ambient relative humidity,
- attack by wood-degrading fungi

As relative humidity variations which exceed 30% over 2 consecutive days have the potential to considerable damage according to laboratory measurements and numerical simulations, the number of events equal or greater than 1 humidity shock(s) events per quarter was included to the calculation of risk areas (Figure 6.8).

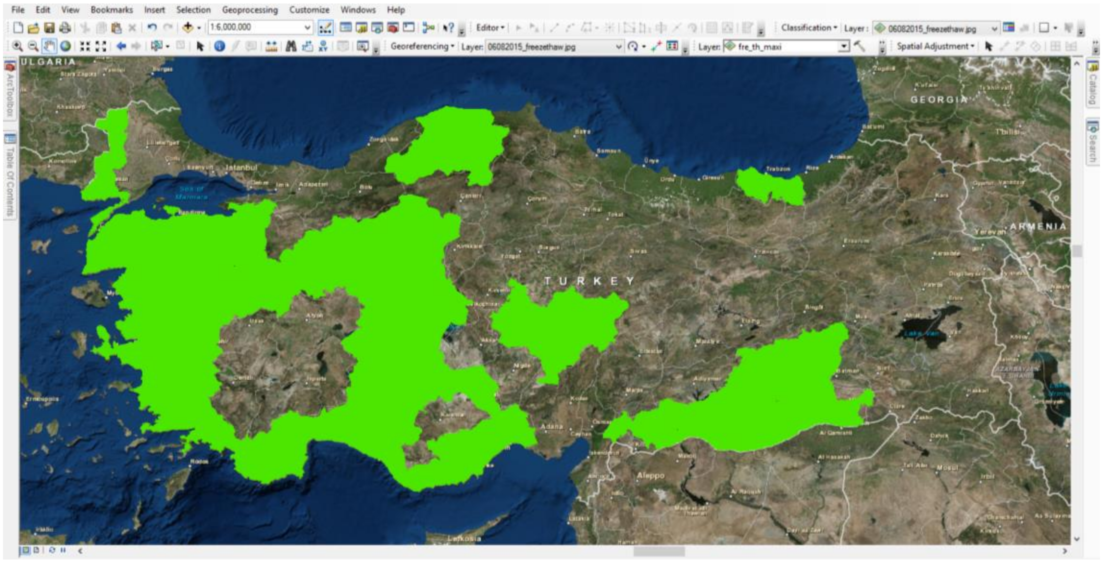


Figure 6.8. The map shows intersection of the values equal or greater than 1 humidity shock(s) events per quarter and the map of areas by distribution of listed buildings (light green= intersected regions) (prepared by the author).

As it is understood from the changes maps in humidity shocks events, the number of damaging humidity variations will increase in almost all Turkey in the far future. The biggest change in humidity variations is observed in the northwest and northeast regions of Turkey. During these changes, Trabzon, Kastamonu, Karabük, and coastal cities are likely to be under the risk of mechanical damage due to humidity variations more than other cities. Although the Southeastern Region is appeared in the overlay map, the maps of changes indicate that a decrease trend is expected.

In order to determine areas, which are under the risk of the fungal attack on outdoor wooden parts of buildings, the values greater than the first precisely defined number are selected. The output map is given below (Figure 6.9).

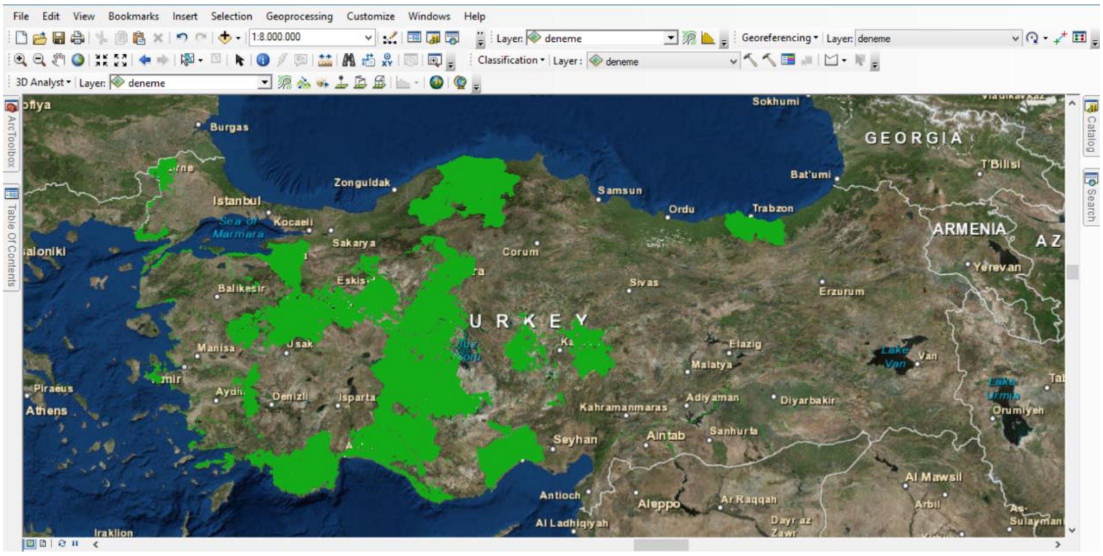


Figure 6.9. The map shows intersection of the risk index of climate induced decay of outdoor wooden structures by fungal growth equals or greater than 200 m.0C.day and the map of areas by distribution of historic buildings (green= intersected regions) (prepared by the author).

When the maps of changes in total biomass are evaluated, although decay rate of outdoor wooden structures by fungal growth is likely to decrease in almost all Turkey in the far future, it may be influential especially in the Central Anatolia.

6.1.3. Metals Deterioration

The intersection maps, which are presented below, were prepared by taking into account the threshold values defined in the Noah's Ark Project. It is stated that the corrosion threshold value that should not be exceeded for carbon steel is 20 µm per year, while the value that should not be exceeded for zinc is 1.1 µm per year.

(i) The combined effect of temperature and SO2 pollution, illustrated for carbon steel but indicative also of bronze corrosion: The maps of changes point a decreasing trend in western and southern regions and an inclining trend in northeastern region of Turkey in the far future. According to the map of intersection (Figure 6.10), Bursa and most part of Kütahya will be under the risk of the corrosion of steel, iron and bronze apart from Trabzon, Kastamonu and Karabük in the north of Turkey.

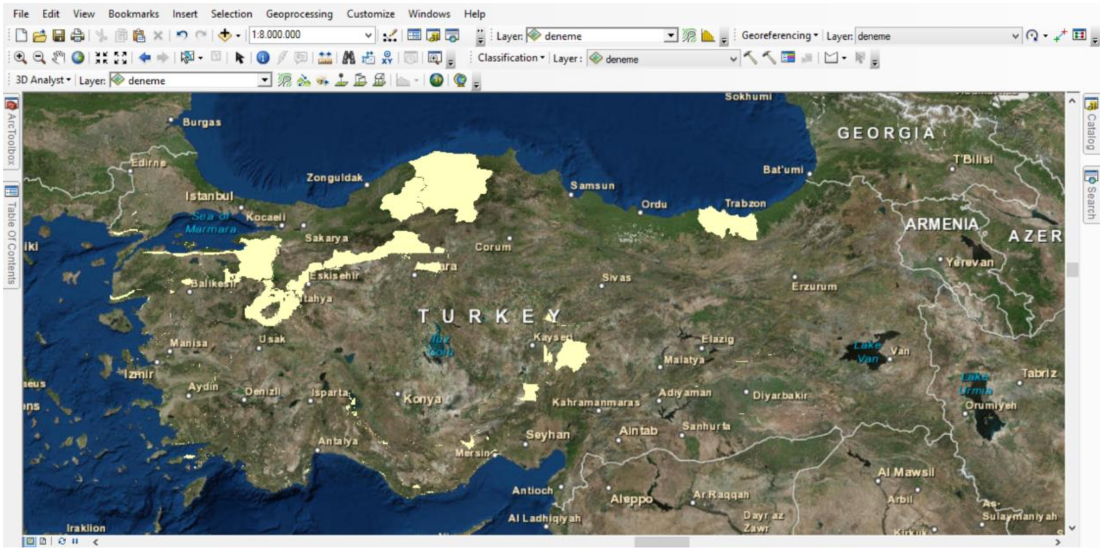


Figure 6.10. The map shows intersection of the values, which are equal or greater than 20 μm per year, of the corrosion of steel, iron and bronze caused by acidifying pollutants in urban areas and the map of areas by distribution of historic buildings (yellow= intersected regions) (prepared by the author).

(ii) The combined effect of temperature and chloride deposition, including information on windborne sea salt aerosol, illustrated for zinc but indicative also of lead and steady state copper corrosion: The maps of changes indicate that the corrosion of zinc is expected to increase almost in the whole Turkey. It is seen from the map of intersection that the cities on the west and south coasts of Turkey, the south coast of Marmara Sea, Southeastern Anatolia, Trabzon, Kastamonu, Karabük, and several cities in Central Anatolia come to the forefront with their above average number of the historic buildings (Figure 6.11).

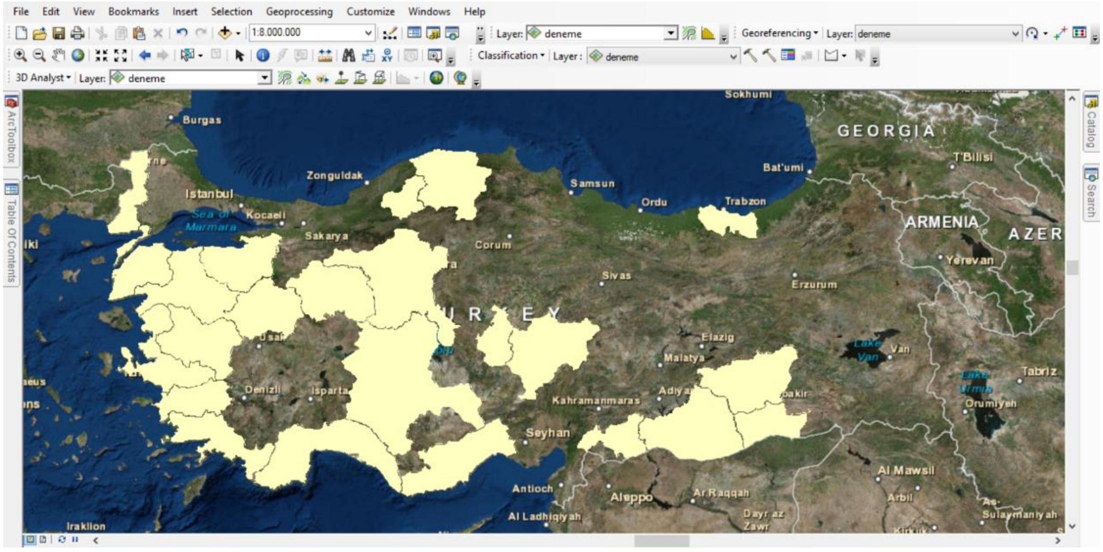


Figure 6.11. The map shows intersection of the values, which are equal or greater than 1 μm per year, of the corrosion of zinc copper and lead caused by high chloride deposition and the map of areas by distribution of historic buildings (yellow= intersected regions) (prepared by the author).

To sum up, among the regions, which has appeared in the overlay maps, Bursa was selected as the case study area in terms of being under the accelerated effects of the various deterioration mechanism in the future; being rich in tangible heritage; having WH sites; and being an important city during the early period of the Ottoman Empire. In the following sections were organized and presented from the perspective of Bursa.

6.2. Trend Analysis

The climate data series for temperature (the monthly maximum, minimum, and mean temperatures) and precipitation (the monthly number of rainy days with precipitation of greater than or equal to 0.1 mm, and the monthly-accumulated precipitation) from 1965 to 2014, were reorganized. Then, the annual values were calculated in Excel, and Mann-Kendall Trend Test was employed to understand trends in temperature and precipitation in the given period. The findings are presented in the following paragraphs.

a) Temperature: On running the Mann-Kendall Trend Test on annual maximum, minimum, and mean temperature data, the following results in Table 6.1 were obtained. If the p value is less than the significance level α (alpha) = 0.05, H_0 is rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant.

Table 6.1. Results of the Mann-Kendall Trend Test for temperature data

Mann-Kendall Trend Test			
Temperature / Values	p-value (Two-tailed)	alpha	Test Interpretation
T_{max} (^{0}C)	0.004	0.05	Reject H0
T_{min} (^{0}C)	< 0.0001	0.05	Reject H0
T_{mean} (^{0}C)	0.001	0.05	Reject H0

On plotting the linear trend line, the following results for the annual minimum and maximum temperatures in Figure 6.12 were obtained.

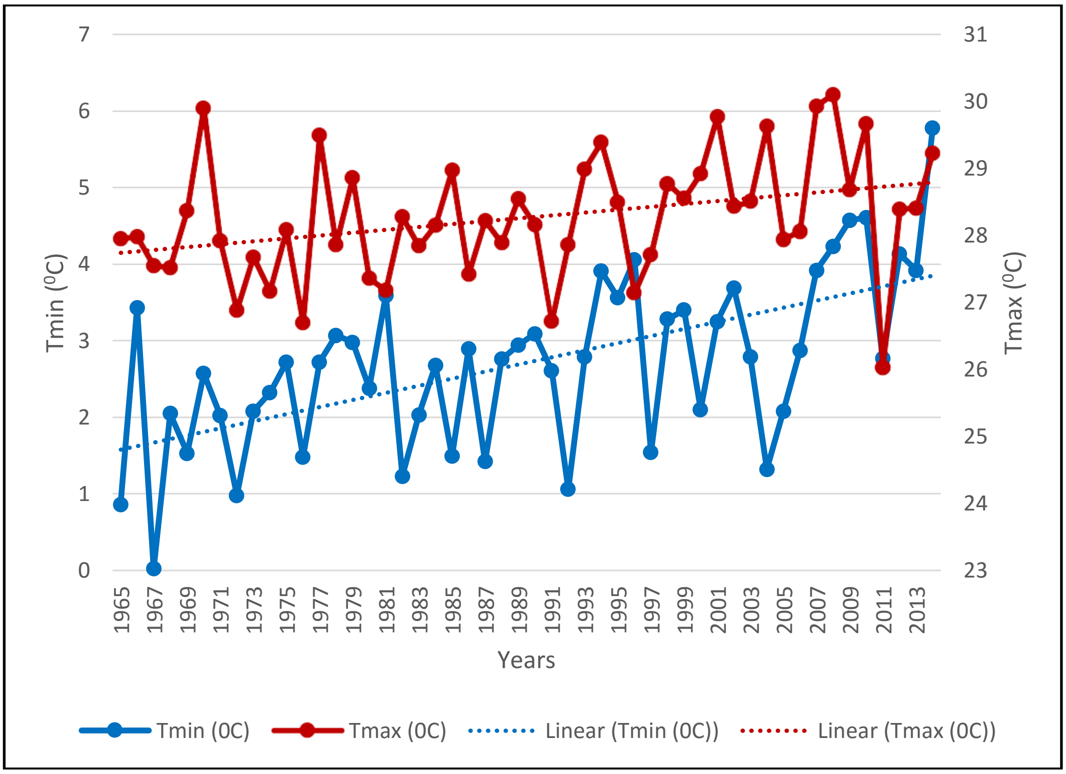


Figure 6.12. The graph shows the annual mean Tmax, and Tmin trends between 1965 and 2014. The warming trend is obvious in both Tmax and Tmin (prepared by the author).

Although the increasing trends are seen in both the annual minimum and maximum temperatures in Bursa in the period of 1965-2014, the increase in the annual minimum is higher than the maximum one.

b) Precipitation: The Mann-Kendall test was run on the annual number of days with precipitation ≥ 0.1 mm data. This threshold value represents the occurrence of precipitation since it is the minimal measurable amount. The results in Table 6.2 were obtained. The p value is less than the significance level α (alpha) = 0.05. There is a declining precipitation trend in the time series. The result is said to be statistically significant.

Table 6.2. Results of the Mann-Kendall Trend Test for the annual number of days with precipitation ≥ 0.1 mm data

Mann-Kendall Trend Test			
Precipitation / Values	p-value (Two-tailed)	alpha	Test Interpretation
Sum >=0.1 mm	0.028	0.05	Reject H0

Figure 6.13 represents the annual number of rainy days for 50 years with maximum number of days in which rainfall occurred in the year 2010 with 139 days and minimum number of days in which rainfall occurred in the year 2007 with 79 days.

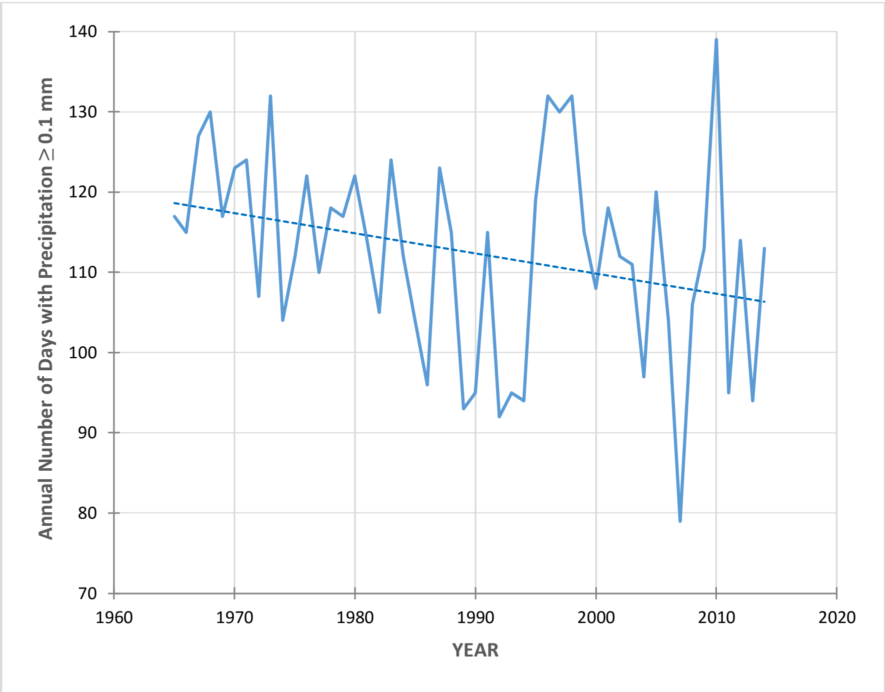


Figure 6.13. The graph shows the annual number of rainy days, which has a negative trend (prepared by the author).

In addition to test the occurrence of precipitation, the trend of the annually accumulated precipitation was also calculated by using Mann-Kendall Trend Test. The results in Table 6.3 were obtained.

Table 6.3. Results of the Mann-Kendall Trend Test for the annually accumulated precipitation data from 1965 to 2014.

Mann-Kendall Trend Test			
Precipitation / Values	p-value (Two-tailed)	alpha	Test Interpretation
Annually (mm)	0.482	0.05	Accept H0

As the computed p-value is greater than the significance level alpha, which is equal to 0.05, the null hypothesis H0 is accepted, i.e. there is no trend in the series (Figure 6.14).

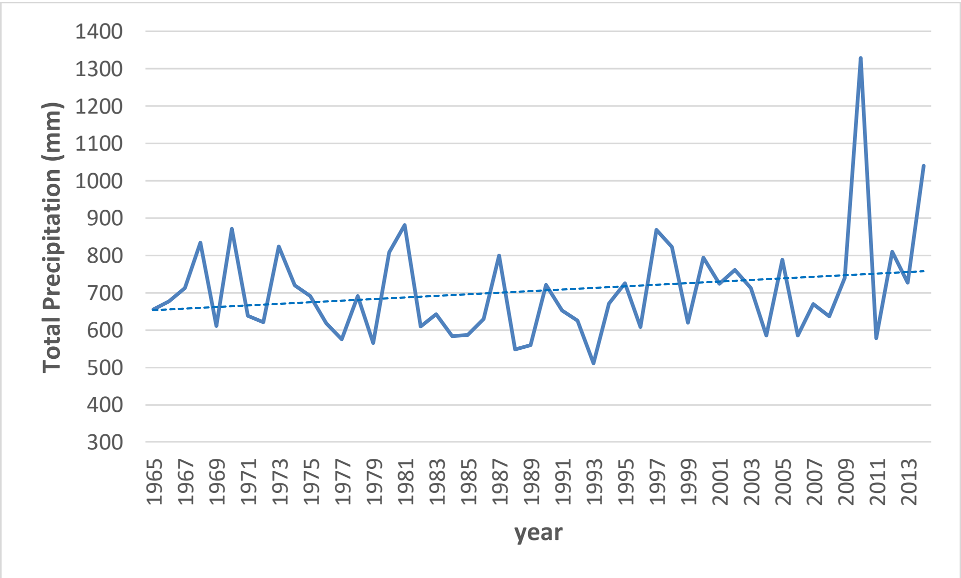


Figure 6.14. The graph shows no trend in the annually accumulated precipitation data from 1965 to 2014 (prepared by the author).

To sum up, the previous studies show that Bursa has experienced Heat Urban Island effect due to significant land cover changes because of rapid urbanization and industrialization. As built surfaces warm faster during daytime and keep air temperature high during nighttime in urbanized areas relative to temperatures in less urbanized areas. This is parallel with the increasing trend in monthly minimum temperatures in Bursa in the period of 1965-2014. Additionally, the results show that there are changes in the pattern of precipitation. Therefore, the changes in minimum and maximum temperatures, and humidity cycles should be evaluated in terms of deterioration mechanisms, such as wet-forest and salt crystallization, which base on quite small changes. Relatively small changes in temperature and/or humidity that may cause phase changes and significant damage to historic buildings.

Although there is no significant increasing or decreasing trend in annually accumulated precipitation, the declining trend is seen in the annual number of rainy days. This may be evaluated in terms of the sign of significant changes in the pattern of the spells of dry days, which is based on the number of days without precipitation. Additionally, the changes in the rainfall intensity defined as the ratio of the total accumulated rain falling during a given period may lead to changes in the pattern of flash floods, which is the combined effects of intense rainfalls, high coverage of impervious surfaces, and inadequate drainage. Therefore, historic buildings in Bursa will be prone to the likelihood of flash flooding, which causes serious damage and disruption on both the structural integrity of these buildings and materials of construction.

6.3. Heritage-Climate Risk Maps

It is necessary to create specific combinations of climatic parameters, which are not specific for a single material, to evaluate the various degradation mechanisms for different materials. Therefore, in this section, a general way to combine climatic parameters, which is useful for understanding effects of climate on cultural heritage, is presented. This information can be used to both understand the reasons of the current conditions and predict future effects of climate by evaluating it with the projected climate maps. Within this perspective, site-specific analysis should be conducted for further studies.

The data used in the following maps includes climate data (annually number of days with maximum temperatures ≥ 30 °C, and minimum / maximum RH) and the selected number of historic buildings in Bursa. The results are given in the following sub-sections.

6.3.1. Stone and Brick Deterioration

The temperature and RH induced stress, and the possible consequences of changes in temperature and RH on other decay mechanisms within a stone were taken into account to predict possible damage-related processes. To this end, the days with maximum temperatures ≥30 °C for the period of 1985-2014 in terms of thermal stress and biological processes, and the number of events when RH falls below and rises above 75% in a year in terms of salt crystallization frequency for the period of 1985-2006 were mapped.

The annual number of days with maximum temperatures ≥30 °C was graphed according to stations in Bursa and its surrounding cities (Figure 6.15). Although the fluctuations were observed within the selected period, as of 2014, it is higher than the ones in 1980s in all weather stations.

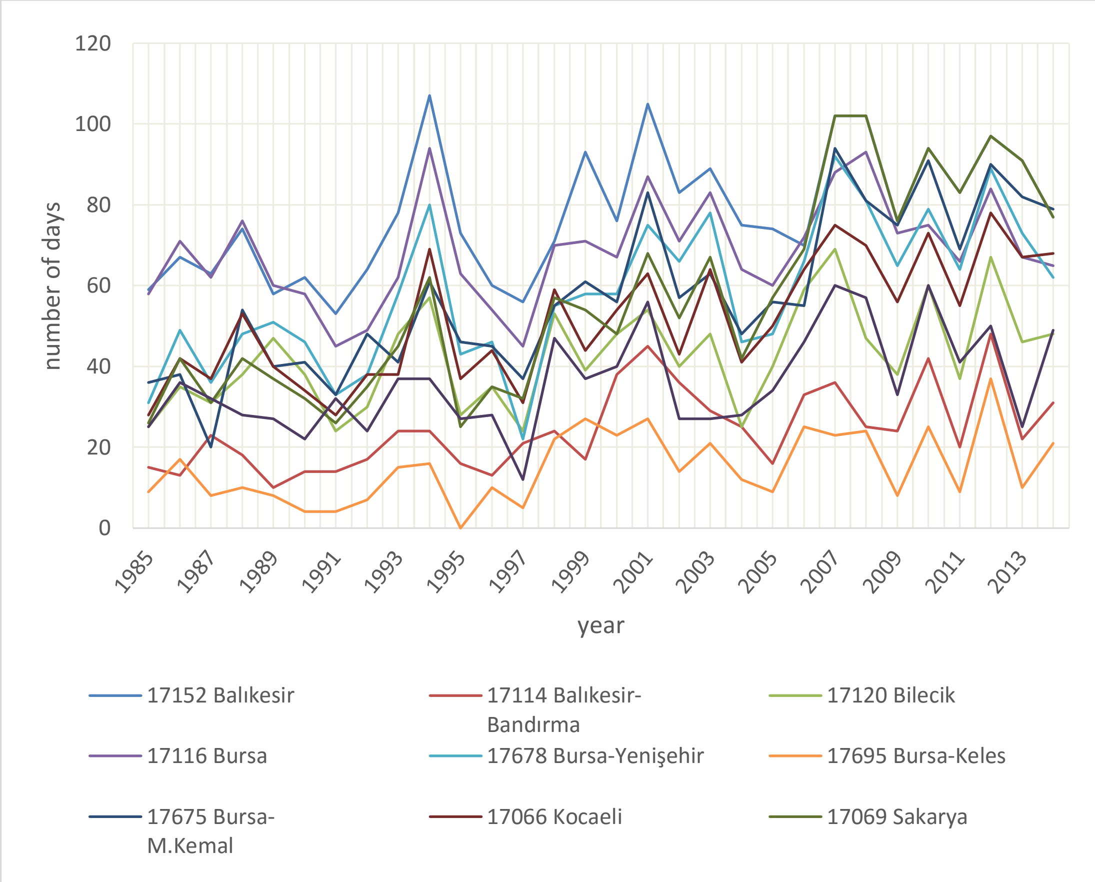


Figure 6.15. The graph showing the annual number of days with maximum temperatures ≥30 °C within the period of 1985-2014 for selected weather stations (prepared by the author).

The graph mentioned above was mapped as shown in Figure 6.16. The highest risk area on the map is around the Bursa station number 17116, which is in the city center, whereas the rural region of Bursa is under the lowest risk. The highest density of cultural heritage assets is also in the center of Bursa, which is under the weather-related risks.

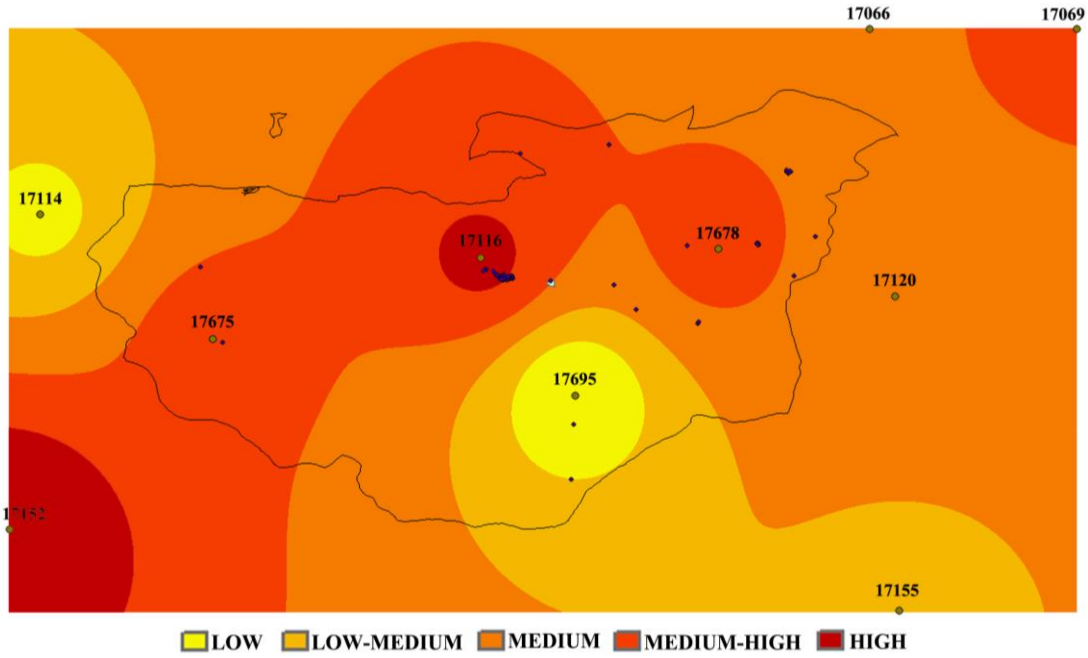


Figure 6.16. The map showing the different risk areas in terms of thermal stress (prepared by the author).

The annual number of events when RH falls below and rises above 75 % was graphed according to stations in Bursa and its surrounding cities within the period of 1985-2006 (Figure 6.17). Bursa-Yenişehir station number 17678 has the highest result, exceeding 6000 events, whereas Bursa-Keleş station number 17695 has the lowest result 3661.

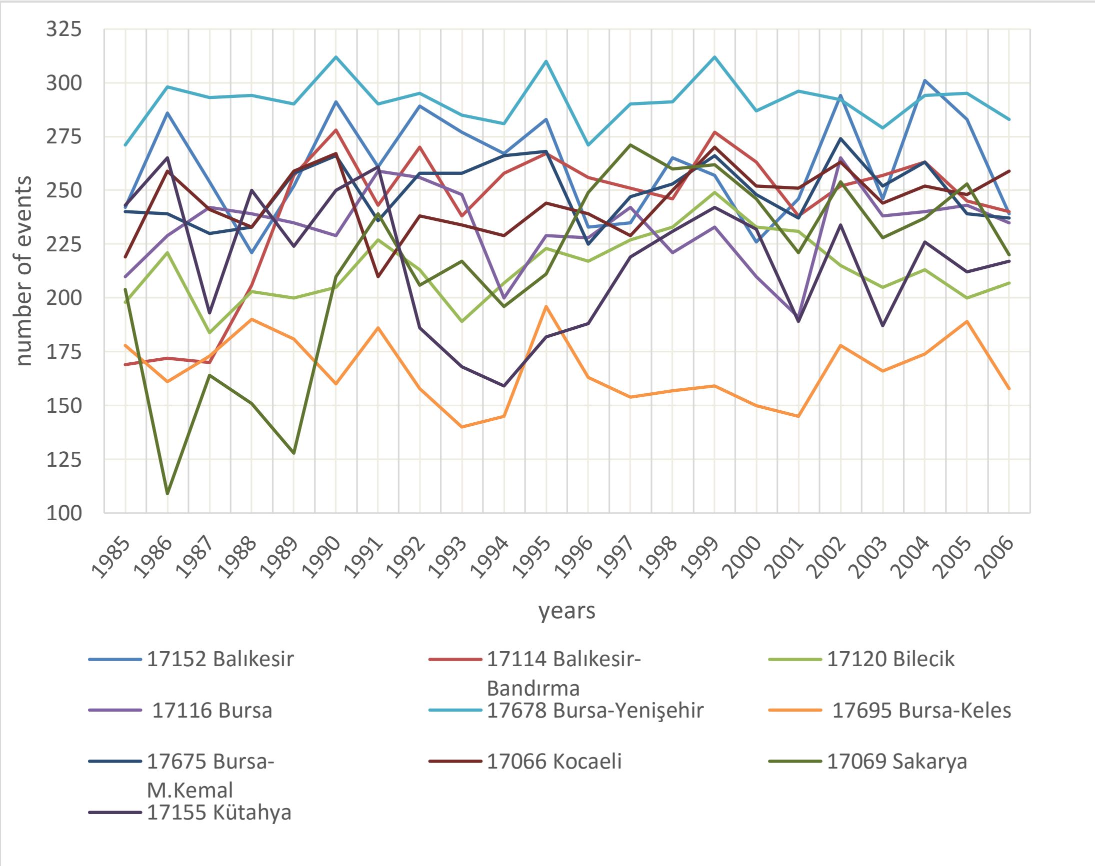


Figure 6.17. The graph showing the annual number of events when RH falls below and rises above 75 % within the period of 1985-2006 for selected weather stations (prepared by the author).

The graph was mapped as shown in Figure 6.18. The map indicates that the highest risk area is around the Bursa-Yenişehir station number 17678, whereas the rural region of Bursa is under the lowest risk in terms of salt crystallization. The highest density of cultural heritage assets is in the center of Bursa, which is under the medium risk.

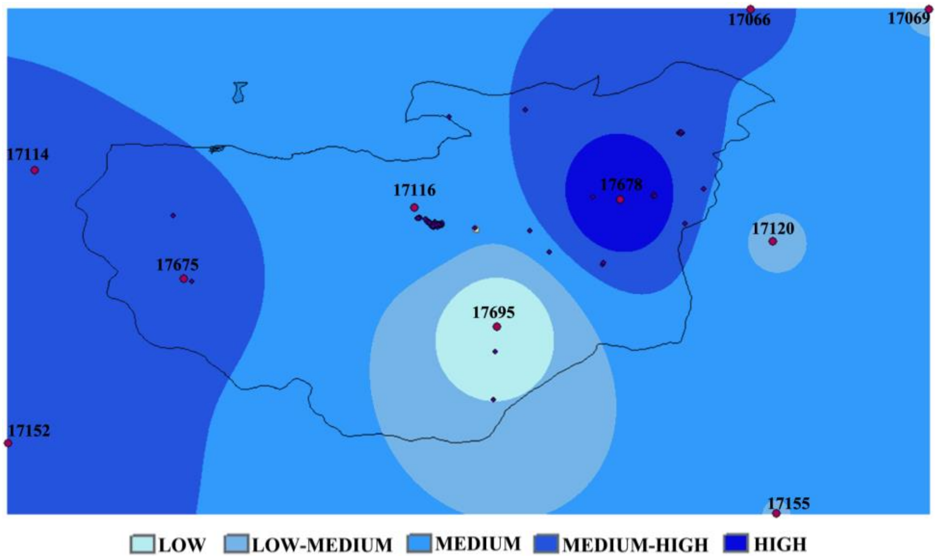


Figure 6.18. The map showing the different risk areas in terms of salt crystallization frequency (prepared by the author).

The overlay analysis was performed for the maps of thermal stress and salt crystallization frequency to determine the areas where both deterioration mechanisms are effective in which risk levels (Figure 6.19).

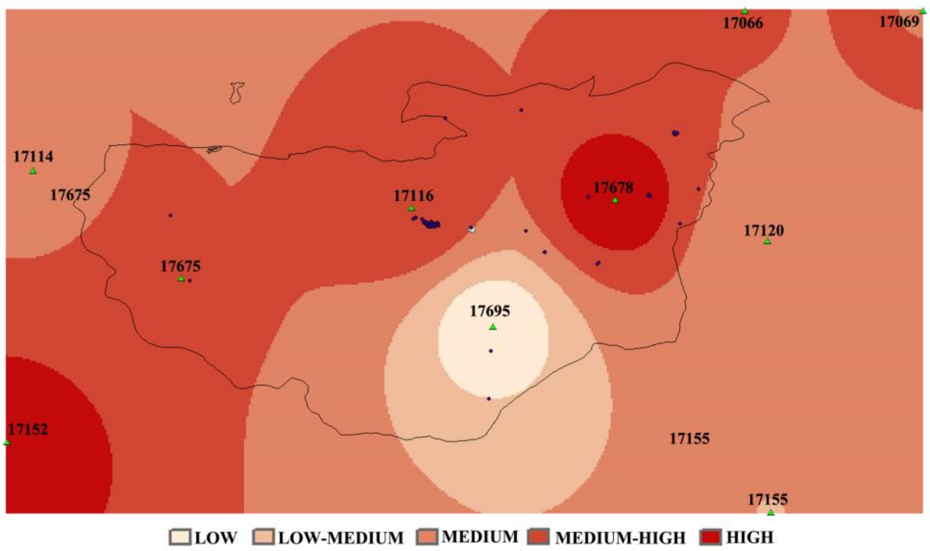


Figure 6.19. The map showing the different risk areas where both thermal stress and salt crystallization are prevalent (prepared by the author).

Since development of micro-cracking in and exfoliation of materials with different mineralogical composition, such as mortars, and with almost entirely same composition, such as marble, are the results of thermal shock from intense solar radiation, materials used in the historic buildings in Bursa, such as marble, limestone and lime mortars are under the risk of thermal stress. Along with thermal stress, salt crystallization is also a cause of degradation leading to complete chipping off. It is predicted that its frequency will increase over the next century. When the climate projections are evaluated, increased trend in temperatures, especially in the city center, and salt crystallization frequency, it is obvious that the influence of climate change on the degradation mechanisms should be taken into account while elaborating risk preparedness concept and management strategies.

6.3.2. Timber Deterioration

As RH variations have the potential to considerable damage, the annual number of RH variations exceeding 30% over two consecutive days was graphed by using the climate date recorded by the stations in Bursa and its surrounding cities within the period of 1985-2006 (Figure 6.20).

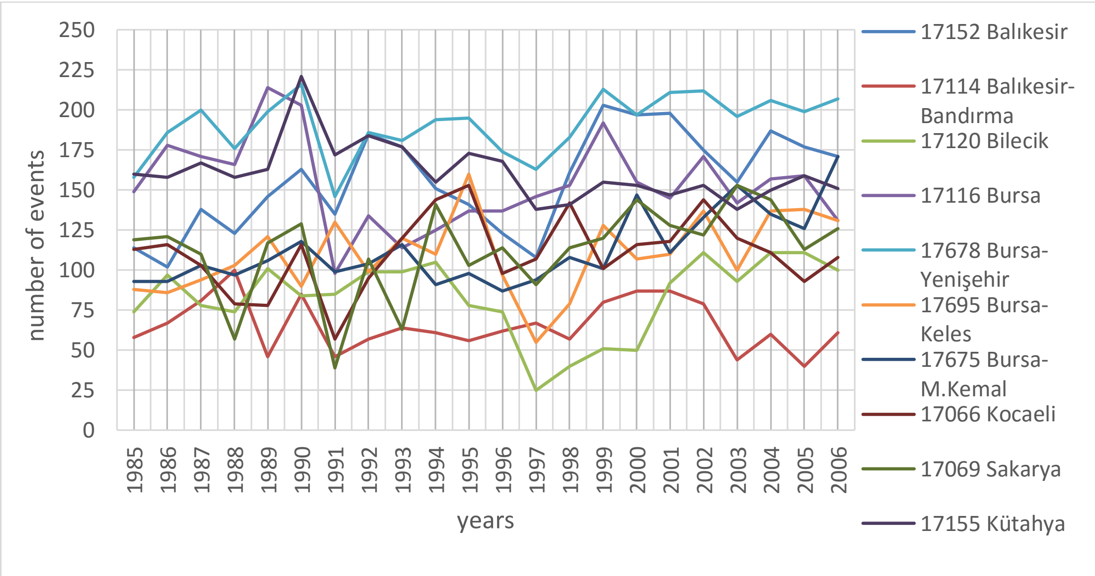


Figure 6.20. The graph showing the annual number of RH variations exceeding 30% over two consecutive days within the period of 1985-2006 (prepared by the author).

At the beginning of the 90s, the decrease was observed in all selected weather stations. In spite of the decrease in the 90s at Bursa station number 17116, which had recorded 3377 events totally within the selected period, approximately more than 150 events per year had recorded. Bursa-Yenişehir station number 17678 has the highest result, exceeding 4000 events, whereas Balıkesir-Bandırma station number 17114 has the lowest events, 1445, in 22 years.

The graph mentioned above was mapped as shown in Figure 6.21. The map indicates that the highest risk area is around the Bursa-Yenişehir station number 17678, whereas the rural region of Bursa is under the low-medium risk area in terms of mechanical damage due to RH variations. As the highest density of listed cultural heritage assets is close to the Bursa station number 17116, which is under the medium-high risk, historic wooden structures and objects have been under the risk of mechanical damage due to humidity variations.

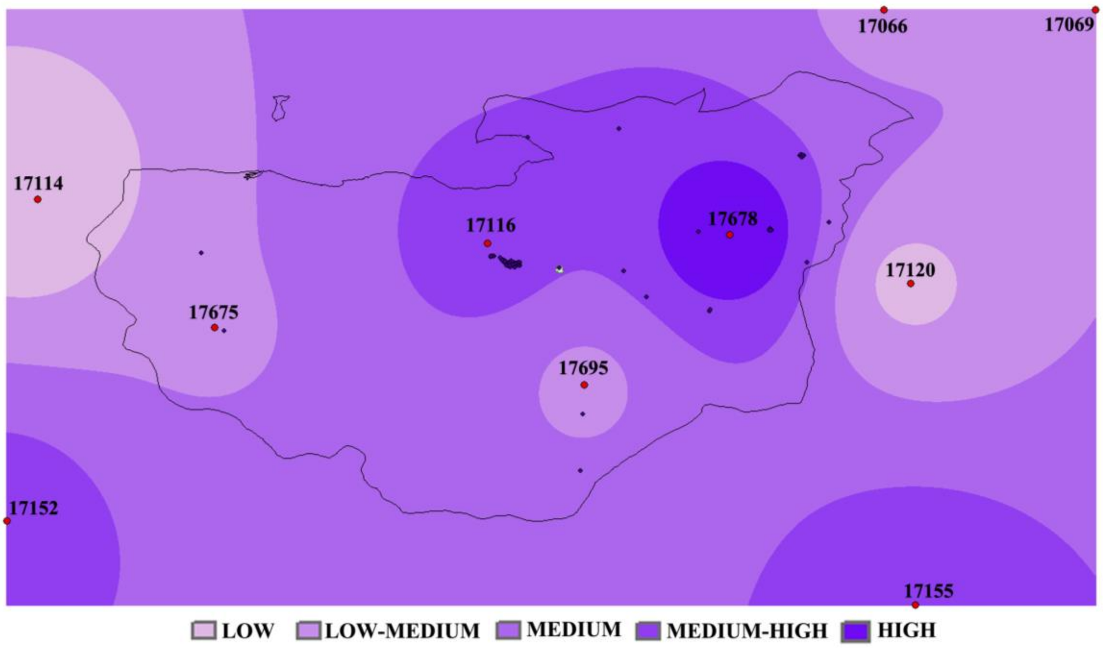


Figure 6.21. The map showing the different risk areas, where mechanical damage may occur due to RH variations exceeding 30% (prepared by the author).

Since the physiochemical nature of timber makes it responsive to variations in RH fluctuations in moisture levels that cause increased stresses, tightly restrained wooden elements may be at risk due to the possibility of cracks occurring around the fixing points. Moreover, painted timber elements may be at risk because the timber substrate and the paint layer have different responsive capacities to fluctuations in RH. This difference leads to a failure of adhesion, and the delamination and flaking of the paint layer. For instance, the timber elements of the buildings in Muradiye Complex had suffered from decay occurring due to RH variations (Figure 6.22).

(a) (b)

Figure 6.22. The photos showing (a) the cracks in the bonding timber of the tomb of Gülbahar Hatun, and (b) adhesion of the paint layer in patches on the timber door of Hüma Hatun (taken by the author).

6.3.3. Metals Deterioration

In traditional masonry structures, in order to avoid displacement of stones and secure their structural integrity, metal dowels and cramps were often used. Corrosion of these embedded metals is the leading cause of deterioration in stone. When corrosion in metals embedded in stone occurs, the resulting rust occupies a greater volume than the metal. The expanding rust creates tensile stresses in the stone that can cause spalling cracking and delamination. As temperature and RH play an important role in corrosion, the combined threshold at which corrosion is expected to commence is when conditions greater than 0ºC and 80% RH.[22]

To this end, the number of events when daily maximum RH > 80% and daily minimum temperature exceeds 0ºC for the period of 1985-2006 were calculated and graphed according to stations in Bursa and its surrounding cities (Figure 6.23). Sakarya station number 17069 has the highest result, exceeding 6100 events, whereas Bursa-Keleş station number 17695 has the lowest result 2482. Although the fluctuations were observed at Bursa station number 17116, which had recorded 4366 events totally within the selected period, approximately 200 events per year had recorded.

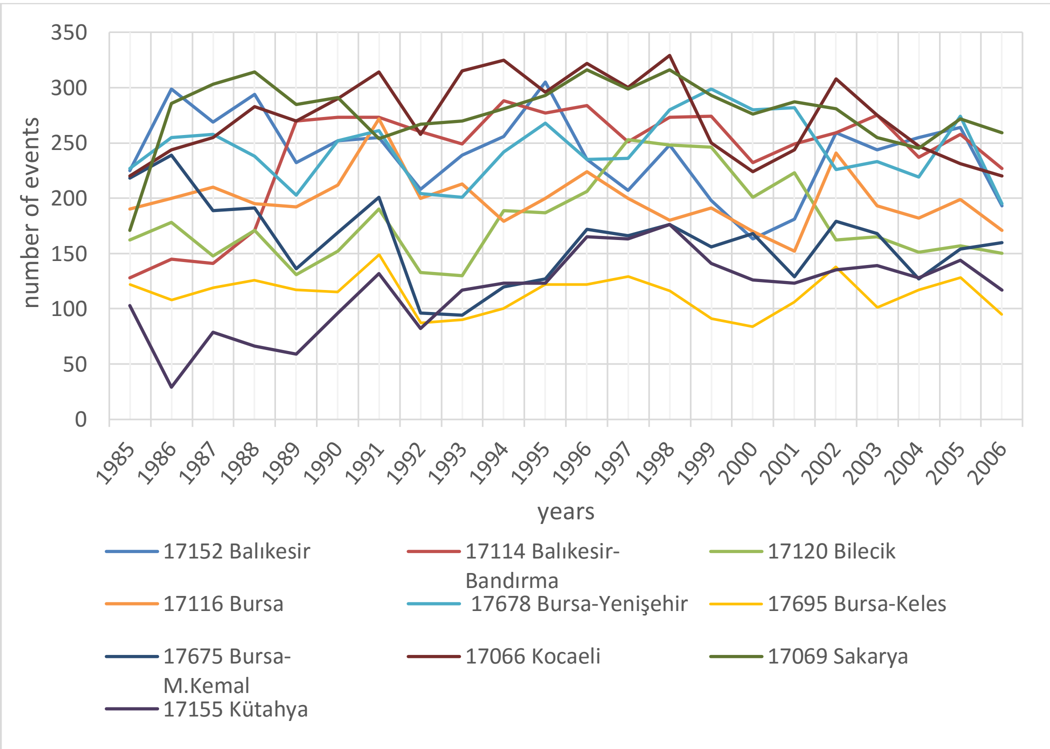


Figure 6.23. The graph showing the annual number of events when daily maximum RH exceeding 80% and daily minimum temperature exceeding 0ºC within the period of 1985-2006 for selected weather stations (prepared by the author).

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[22] For more information see Rose, Pearson, Mensinga and Straube, 2014.

The graph given above was mapped as shown in Figure 6.24. The highest risk area on the map is around the Kocaeli and Sakarya stations numbers 17066 and 17069, respectively, whereas the rural region of Bursa is under the lowest risk. The highest density of listed cultural heritage assets is in the center of Bursa, which is classified as medium risk area in terms of being under the risk of embedded metals corrosion.

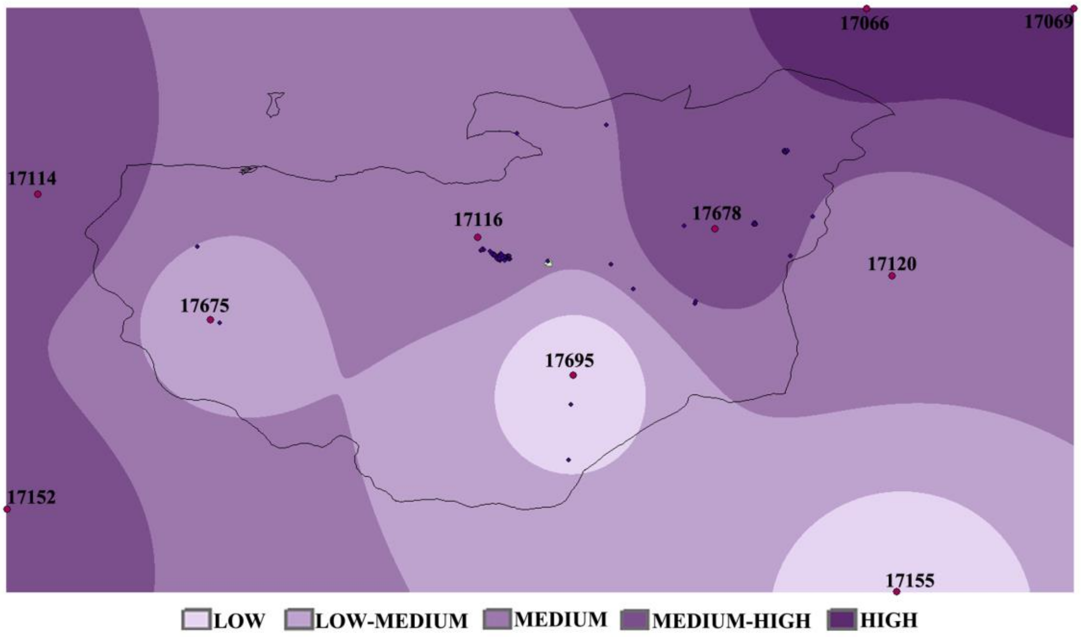


Figure 6.24. The map showing the different risk areas, where corrosion of embedded metals may cause deterioration in stone (prepared by the author).

In conclusion, identifying thresholds at which deterioration commences is useful to evaluate climate data. When past climate data were mapped according to defined thresholds, it is useful to evaluate which deterioration mechanisms affected prevalently in which areas. Combined assessment of the heritage-climate risk maps and future climate projections can be used while determining if a building is at increasing risk for specific types of deterioration. The results can be included in the management plans to minimize the risk of reaching these thresholds.

6.4. Before and After Remedial Activities - Field Observations

Before the restoration project, the decay mapping had been carried out at Muradiye Complex by the architectural firm. Classification of decay features into a limited number of significant categories, such as carbon accumulation, disintegration, recessed mortar, surface erosion, dampness, biological growth, soiling, corrosion, lead decay, was based on field observations of the firm. As it is possible to see how much of a facade is affected by certain weathering forms with this approach, a better understanding of the processes and an informed assessment of material condition are gained and decisions including possible remedial activities can be made.

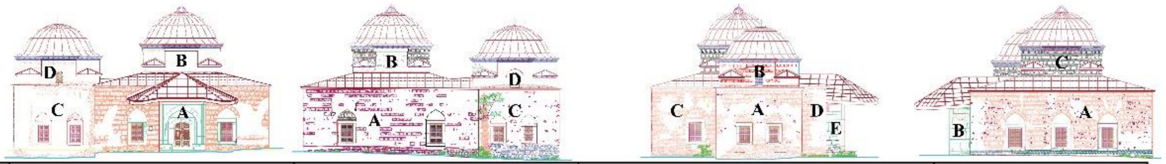
The surface areas of the various types of deteriorations affecting the selected buildings were calculated from the graphic representation of the photogrammetric survey of the tombs showing the state of decay forms and presented in the following paragraphs.

The percentages of overall decay forms on the facades of the tomb of Murad the Second were calculated (Table 6.4). Taking the A and B parts of the front facade as a whole, carbon accumulation affected almost 43%, while it affected 22% of the C and D parts of the front facade. As regard the A part of the right facade, it affected 56% of the surface. When all facades are considered, it was understood that carbon accumulation was very common and dominant.

The percentage of the biomass accumulation and disintegration on the rear facade, A and B parts, was 7.2% and 12.5%, respectively. Besides, it affected 5.2% of the A part of the right facade.

On the rear facade, the percentage of disintegration was 15% whereas it was not significant in other facades.

Table 6.4. The graphic representation of the photogrammetric survey of the Tomb of Murad the Second [and Şehzade (Prince) Alaaddin] showing the state of decay forms and the surface areas of the various types of deteriorations (prepared by the author).



	FACADE	FRONT FACADE				REAR FACADE				LEFT FACADE					RIGHT FACADE		
	PART	A	B	C	D	A	B	C	D	A	B	C	D	E	A	B	C
CALCULATION OF FACADE AREAS	SURFACE AREA (m2)	78.38	8.40	46.45	10.04	91.62	8.27	45.39	10.94	49.44	9.77	36.98	13.75	7.34	85.69	7.19	8.47
	WINDOW AREA + CASING (m2)	4.19 3.98	-	3.14 3.05	-	3.96 4.00	-	2.54 2.69	-	2.96 2.87	-	4.12	-	-	3.94 4.07 4.08	-	-
	WINDOW AREA (m2)	1.93 1.89	-	1.38 1.41	0.73	1.94 1.94	-	1.26 1.21	1.11	1.31 1.31	0.79	1.96	-	-	1.89 1.92 1.93	-	-
	DOOR AREA+ PORTAL (m2)	18.74	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DOOR AREA (m2)	3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TYPES OF DETERIORATIONS	CARBON ACCUMULATION (m2)	32.89	0.65	10.13	2.46	0.09	0.42	3.66	0.71	20.18	2.29 / 0.189 (window)	19.01	6.61	-	38.56	2.57	-
	DISINTEGRATION (m2)	-	-	-	-	12.51	-	0.15	-	0.08	-	-	0.03	-	-	-	-
	INTERVENTION IN PLASTER & MORTAR (m2)	-	0.65	-	-	0.79	0.78	-	0.52	0.0171 (window)	0.73	1.61	N/A	0.04	-	-	0.80
	DAMPEN/ ROTTNESS (m2)	-	-	-	-	-	-	-	-	-	-	-	-	0.28	-	-	-
	BIOLOGICAL GROWTH (m2)	-	-	-	-	7.20	-	-	-	-	-	-	-	-	3.86	-	-
	SOILING (m2)	-	-	-	-	-	-	9.64	-	-	-	-	-	-	0.33	-	-
	SOILING (MARBLE) (m2)	0.03 (door) 0.42 (widow)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

The percentages of overall decay forms on the facades of the Tomb of Ebe Hatun were calculated and presented in Table 6.5. The surface area of the carbon accumulation was almost 33 % of the front facade, while soiling affected 21.6 %, detachment in the form of material loss 22.8 % and intervention with cement based plaster and mortar 7.5%.

The rear facade was dominated by cement based repair that affected 22.4% of the surface of the facade.

The surface area of the carbon accumulation of the left facade was 45% while it was almost 38 % of the right facade.

Table 6.5. The graphic representation of the photogrammetric survey of the Tomb of Ebe Hatun showing the state of decay forms and the surface areas of the various types of deteriorations (prepared by the author).

	FACADE	FRONT FACADE	REAR FACADE	LEFT FACADE	RIGHT FACADE	A-A SECTION	A'-A' SECTION	B-B SECTION	B'-B' SECTION	GROUND FLOOR
	SURFACE AREA (m2)	14.88	26.81	15.31	15.42	7.64	7.66	7.31	7.31	17.53
TYPES OF DETERIORATIONS	CARBON ACCUMULATION (m2)	4.91	0.77	6.90	5.85	1.58	0.78	1.58	1.68	-
	DETACHMENT (m2)	0.22	-	-	-	0.95	0.99	0.60	0.46	0.17
	DETACHMENT (KÜFEKİ STONE) (m2)	3.18	0.90	1.41	0.33	0.04	-	-	-	1.67
	RECESSED MORTAR (m2)	0.60	0.15	0.77	1.06	-	-	-	-	-
	DAMP/ ROTTNESS (m2)	-	-	-	-	-	-	-	0.30	-
	BIOLOGICAL GROWTH (m2)	0.50	0.33	0.12	0.01	-	-	-	-	0.05
	SOILING(m2)	3.22	2.93	2.77	3.35	-	-	2.35	1.84	13.62
	SOILING (MARBLE) (m2)	0.50	0.44	0.87	0.30	-	-	-	-	-
	LEAD DECAY (m2)	0.72	0.72	0.69	0.72	-	-	-	-	0.0042
	WORM/DAMP (TIMBER) (m2)	0.37	0.11	0.02	-	-	-	0.04	0.38	-
	CRACKS IN MARBLE	0.02	0.02	0.01	-	-	-	-	-	-
	CRACKS	-	-	-	-	0.0004	0.0197	0.03	0.01	-

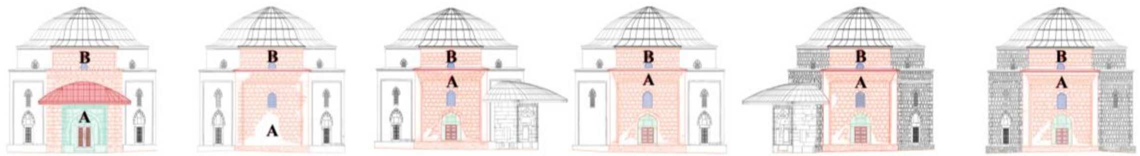
The percentages of overall decay forms on the facades of the Tomb of Cem Sultan were calculated and presented in Table 6.6. The carbon accumulation was significant on all the facades. Taking the part A of the rear facade, carbon accumulation affected 63.5% of the surface, while it affected 82.6% of the part B.

Blackening was mapped especially on the gypsum framed exterior windows (*dışlık*) and the places where the roof and the masonry meet. It dominated the whole left facade number 1, 88.37% of the part A and almost 97% of the part B.

The percentages of overall decay forms on the facades of the tomb of Gülruh Hatun were calculated and presented in Table 6.7. The percentage of decay due to carbon accumulation on the part A of the front facade was 31.1% while on the part C it was 62.9%. Taking the facade section as a whole, carbon accumulation was 30.25%, while detachment in the form of material lost affects 11.05%.

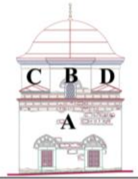
In brief, the most significant and common decay forms, which were mapped, are carbon accumulation, detachment in the form of both surface erosion and material loss, soiling especially due to lead decay. Black streaks were also mapped in the pattern of rainwater wash under the eaves.

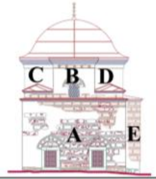
Table 6.6. The graphic representation of the photogrammetric survey of the Tomb of Cem Sultan showing the state of decay forms and the surface areas of the various types of deteriorations (prepared by the author).



	FACADE	FRONT FACADE		REAR FACADE		LEFT FACADE 1		LEFT FACADE 2		RIGHT FACADE 1		RIGHT FACADE 2	
CALCULATION OF FACADE AREAS	PART	A	B	A	B	A	B	A	B	A	B	A	B
	SURFACE AREA (m2)	42.90	10.70	50.69	10.37	53.18	10.39	53.23	10.34	52.27	10.24	52.09	10.37
	WINDOW AREA + CASING (m2)	-	-	-	-	5.01 -	-	4.92 -	-	5.40 -	-	5.4 -	-
	WINDOW AREA (m2)	-	0.32	1.20	0.22	1.62 1.18	0.32	1.62 1.18	0.33	1.76 1.18	0.32	1.76 1.18	0.35
	DOOR AREA+ PORTAL (m2)	19.69	-	-	-	-	-	-	-	-	-	-	-
	DOOR AREA (m2)	3.02	-	-	-	-	-	-	-	-	-	-	-
TYPES OF DETERIORATIONS	CARBON ACCUMULATION (m2)	2.14	8.41	31.45	8.39	34.06	7.46	35.61	7.46	32.05	7.46	32.71	7.40
	SOILING (m2)	-	0.32 (window)	7.25	0.36 (window)	1.18 (window)	0.32 (window)	1.18 (window)	0.33 (window)	1.18 (window)	0.32 (window)	1.18 (window)	0.35 (window)
		2.26 (wall)	1.28 (wall)		-	47 (wall)	10.07 (wall)	-	-	1.3 (wall)	-	7.25 (wall)	-
	SOILING (MARBLE) (m2)	16.44	-	-	-	3.39	-	3.39	-	3.64	-	-	-
	LEAD DECAY (m2)		-	0.66	-	0.67	-	0.68	-	0.67	-	-	-
	CORROSION	0.25	-	-	-	-	-	-	-	-	-	-	-
	LEAD DECAY (ROOF) (m2)	58.84											

Table 6.7. The graphic representation of the photogrammetric survey of the Tomb of Gülruh Hatun showing the state of decay forms and the surface areas of the various types of deteriorations (prepared by the author).





	FACADE	FRONT FACADE						REAR FACADE				LEFT FACADE					RIGHT FACADE				
	PART	A	B	C	D	E	F	A	B	C	D	A	B	C	D	E	A	B	C	D	E
	SURFACE AREA (m2)	18.43	13.03	13.25	9.12	5.29	5.38	43.48	10.25	5.38	5.38	42.57	10.27	5.50	5.50	6.13	44.74	10.27	5.50	5.50	6.29
CALCULATION OF FACADE AREAS	WINDOW AREA + CASING (m2)	-	2.42	2.44	-	-	-	2.40 2.46	-	-	-	2.40 2.40	-	-	-	-	2.40 2.40	-	-	-	-
	WINDOW AREA (m2)	-	1.25	1.25	0.65	-	-	1.25 1.29	0.99	-	-	1.29 1.25	0.99	-	-	-	1.25 1.29	0.99	-	-	-
	DOOR AREA+ PORTAL (m2)	4.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DOOR AREA (m2)	2.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TYPES OF DETERIORATIONS	CARBON ACCUMULATION (m2)	4.38	2.41	6.01	2.51	0.60	0.62	8.02	3.14	-	-	8.48	2.27	-	-	4.50	6.91	2.68	-	-	1.05
	DETACHMENT (m2)	4.12	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	0.1548 (SÖVE)	-	-	-	-
	DETACHMENT (KÜFEKİ STONE) (m2)	-	0.35	0.63	0.34	-	-	0.89	-	-	-	2.15	-	-	-	-	1.15	0.22	-	-	-
	RECESSED MORTAR (m2)	0.40	-	1.00	2.51	0.60	0.62	-	-	-	-	-	-	-	-	-	0.08	-	-	-	0.51
	BIOLOGICAL GROWTH (m2)	-	-	-	-	-	-	0.44	-	-	-	0.17	-	-	-	0.25	0.35	-	-	-	0.28
	SOILING (m2)	-	-	-	0.65	-	-	-	0.99	-	-	-	0.75	-	-	-	-	-	-	-	-
	SOILING (MARBLE) (m2)	0.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	LEAD DECAY (m2)	0.30	0.19	0.19	0.86	0.37	0.37	0.69	0.80	0.46	0.46	0.69	1.14	0.47	0.46	0.09	0.69	0.92	-	-	-
	WORM/DAMP (TIMBER) (m2)	0.0191 (Door)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CRACKS IN MARBLE (m2)	-	0.01	0.003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

After understanding decay forms from the survey drawings, decay forms, which have occurred / prolonged after remedial activities, were investigated during the field observations, which were made on August 23, 2014 and on November 29, 2014. The details of the visual observations based on detailed photo documentation of the buildings within the frame of field observations are presented in the following sections.

6.4.1. Muradiye Mosque

The photos taken in the summer and fall seasons display the difference of biological growth and dampness' presence during the dry and wet seasons (Figures 6.25 and 6.26). The presence of biological growth on buildings is a useful indicator to detect excess moisture. Besides, a thorough investigation of the nature and extent of growth can highlight defects and their causes in the fabric.

Signs of rising damp can be seen at the base of the external walls in Figures 6.26 and 6.27. During the restoration activities, around the mosque, open and closed subsurface drainage systems were constructed. Although the level of rising damp has decreased, the sign of rising damp can be still observed especially in the wet season. The defective open and/or close subsurface drainage and/or the combined factors of drainage system failure and lack of drainage slopes around the building can cause water to accumulate in the foundation. Moreover, rainwater splashing up from the paved area next to the walls can dampen the exterior surfaces. The combination of different sources of water makes damp problem more critical.

(a) (b)

Figure 6.25. (a) The faint green stains and the line of dampness on the west facade of the mosque in August 2014; and (b) the open drainage system (taken by the author).

(a) (b)

Figure 6.26. Damp and green areas are more significant in both photos (a) and (b) taken in November 2014 (taken by the author).

On the eastern facade of the mosque, wet areas were also observed on the base of the external walls. Besides, fine, white, and powdery deposit of water-soluble salts, i.e. efflorescence, left on the surface of masonry as the moisture evaporated (Figure 6.27). Since sufficient moisture in the wall causes phase changes, i.e. salts dissolve in water, moisture levels and placement of moisture, at heights and at depth within the wall, should be carefully monitored. The salt crystallization cycles may repeat for months or years. The intensity of the efflorescence should also be monitored to understand whether it decreases or increases.

Figure 6.27. Wet areas and deposit of water-soluble salts on the lower parts of the masonry are similar to the condition before restoration on the east facade (taken by the author).

Apart from rising damp problem, the survey report prepared before the restoration activities indicates that the mosque had suffered from the flow of water over the surface that causes a gradual deterioration (Figure 6.28). As well as giving special attention to detailing that convey rainwater from roof drains in order to prevent high volumes of water discharging over specific areas of the wall, changing environmental conditions should be monitored. As water penetration of a masonry wall surface under specific water flow rate and air pressure conditions can increase, the issues of prolonged time of wetness and deep wetness become significant. That affects a range of decay mechanisms through making surface algal soiling and deep-seated salt penetration possible. Therefore, the risk of wetting drying, freeze-thaw, and salt crystallization cycles at the surface and at depth should be evaluated within the framework of changing climatic parameters including ambient temperature, surface temperature, solar radiation, rainfall, relative humidity, wind speed and direction *etc*. at the site.

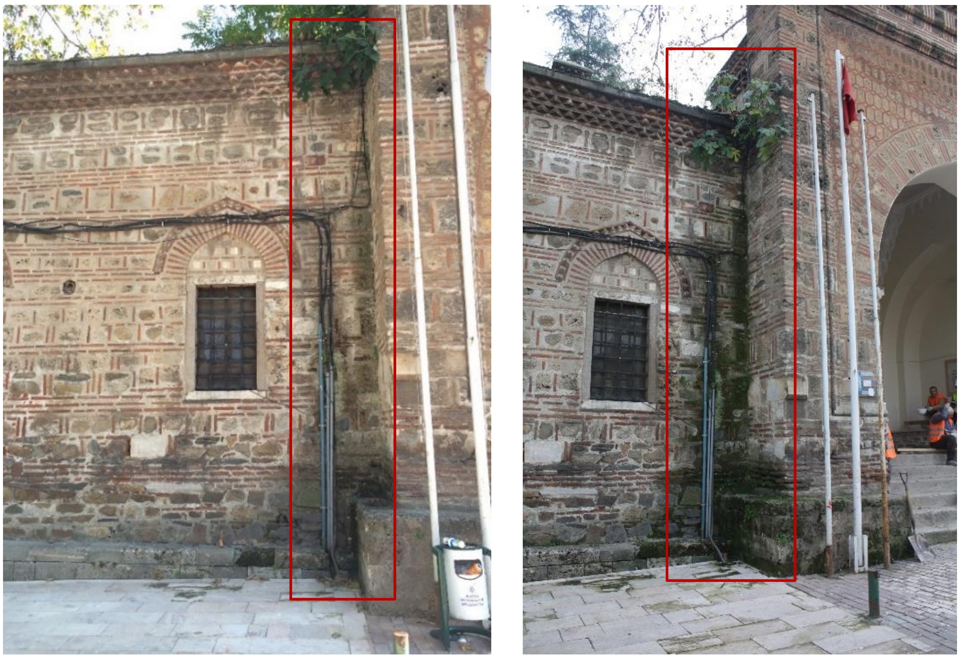
(a) (b)

Figure 6.28. Occurring of dampness and biological growth on the facades due to the flow of water over the specific area after the restoration project (taken by the author in November 2014)

6.4.2. Muradiye Madrasa

When the site was visited in August 2014, remedial activities had not been started yet. They were started in November 2014 but the madrasah was not a part of the restoration project of the tombs.

The link between algal colonization on stone surfaces and moisture regimes was observed during the study visits in August and November (Figure 6.29). As moisture availability occurring due to different reasons is often a problem even if buildings are restored/maintained, investigating links between wetness and climatic parameters in future is necessary in terms of both surface and deep-seated wetness of the masonry.



(a) (b)

Figure 6.29. The difference between (a) August (dry season) and (b) November (wet season) in terms of the intensity of greening on the surface (taken by the author).

One of the possible reasons of the observed greening of stone surfaces, which indicates an increase in moisture availability and associated time of wetness, is the flow of water over the surface (Figure 6.30).

Black streaks, i.e. accumulated dirt and pollutants, were also observed on the facades that may be linked to changes in pollution regime in urban locations. Automotive emissions generating atmospheric particles and corrosive gases in contact with climate parameters may also be effective in formation of black streaks (Figure 6.30).

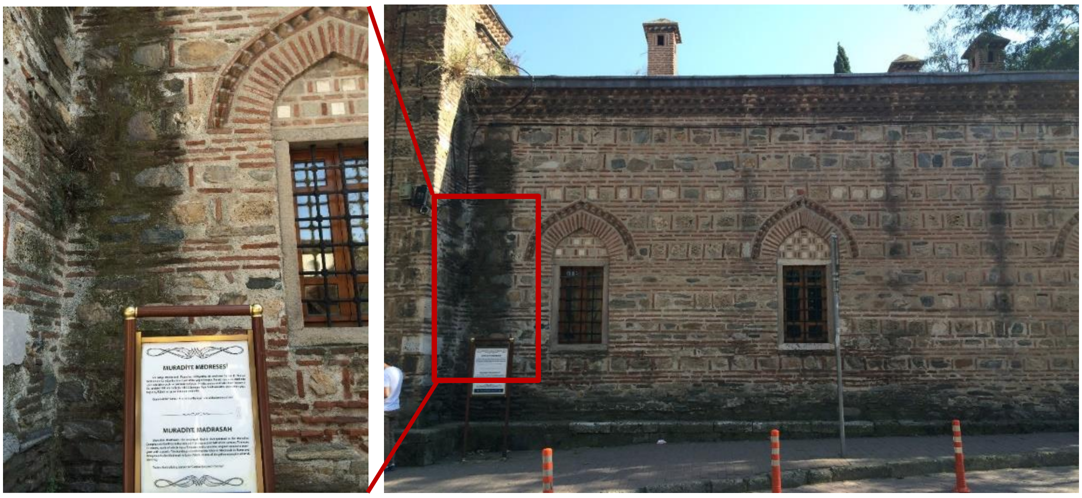


Figure 6.30. The greening of stone and black streaks were dominant on the facade (taken by the author in August 2014).

Biological growth is unavoidable at varying locations of building exteriors. Many types of biological colonization are harmless, and the presence of them may indicate other problems that affect a structure whereas some growths can damage underlying building materials like stone and mortar. In Figure 6.31, in the wet season rapid growing of algae on the surface may lead to damage during the wetting-drying cycles with producing excessive amounts of slime that may expand and contract. Therefore, it may cause flaking or spalling of stone surfaces. Moreover, the algal layer creates a medium within the mortar joints between the stones and bricks that promotes the development of small plants bushes and grasses and/or woody plants, which may also damage to the masonry.

(a) (b)

Figure 6.31. Both (a) and (b) showing different kinds of biological matters, which were more dominant than dry season, on wet areas in November 2014 (taken by the author).

Another reason of wetness is rising damp whose signs were observed in both August and November (Figure 6.32).

(a) (b)

Figure 6.32. The photos taken in August (a) and November (b) showing the signs of rising damp on facades (taken by the author).

6.4.3. Muradiye Hammam

The hammam was restored in 2010, however it was observed that dampness, blackening and biological growth problems have repeated at the same spots after implementation of remedial works (Figures 6.33 and 6.34).

As it is seen that the junctions in the roof, which are potential trouble spots, have defective sections causing stains and encouraging the establishment of biological growth that follow water penetration. Moreover, rising damp problem with a tidemark on surfaces is readily observed on the plinth. Damp streaks also repeat themselves at the same places on the facade.

Figure 6.33. The red circles indicating the different areas suffering from dampness, blackening and biological growth (taken by the author).

As in Figure 6.34, where woody root growth has established itself in the masonry, the damage may have occurred within the wall in various ways, including root action on walls, shading of surfaces that affect time of wetness, and penetrating into walls that dislodge the stonework, *etc*. Moreover, the growth has also seen at high levels of the building, such as the places where the roof and the masonry meet or where the defective masonry saturates. When woody root growth is seen, it is essential to be dealt with them preferably by removing. In the hammam, the problem of the growth has repeated itself at the same spot over the years, as it is understood from the photos of the hammam taken decades ago (Appendix D). Therefore, reason(s) of the re-growth should be carefully investigated and eliminated.

Figure 6.34. The re-growth of the woody root plant at the junction of the walls (taken by the author).

Other hot spots where excessive moisture and biological growth have been observed in the hammam are around of the gutter with a spout and on the base of the walls. The gutter designed to convey water away from the facade causes saturating the wall, which paves the way for biological growth. The defective sidewalks, which normally slope downward from the building and direct water to drains on the roads, and rainwater splashing back on the walls may lead to dampness and biological growth on the base of the walls (Figure 6.35).

(a) (b)

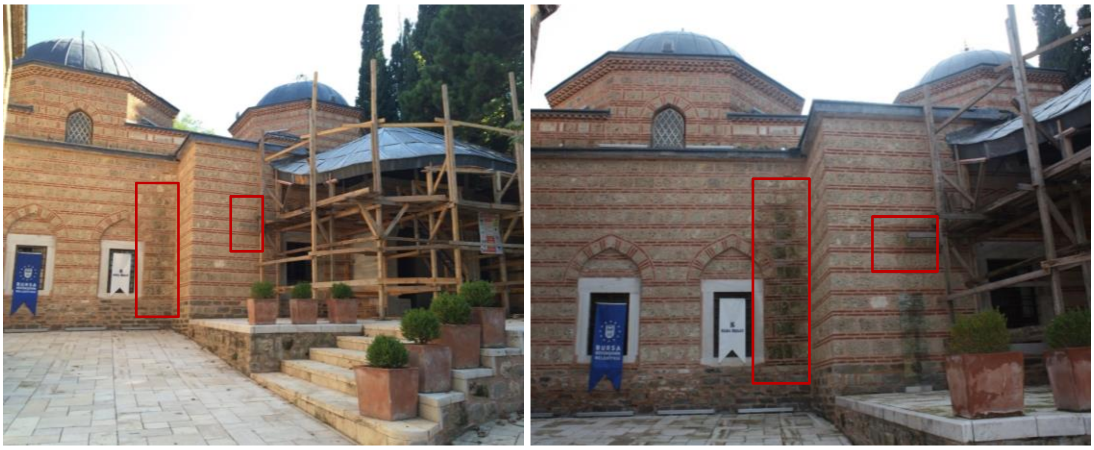
Figure 6.35. (a) The gutter with a spout and (b) the defective sidewalk may lead to biological growth and dampness (taken by the author).

6.4.4. Muradiye Tombs

Study visit in August 2014: As the site was closed to visitors due to ongoing restoration, some of tombs were photographed from a distance. It was determined that work program about outside of the tomb such as removing cement based mortars; facade cleaning; remove dirt and stains; consolidation of stones and bricks; construction of drainage system; changing the lead boards, *etc.* were completed.

Study visit in November 2014: After the permission was obtained, the tombs were photographed. It was observed that dampness and biological growth problems have been continuing at the same areas of the facades, which had suffered before the remedial activities. The photographs of the tombs are presented in this section.

Tomb of Murad the Second [and Şehzade (Prince) Alaaddin]: The specific areas on the front facade of the tomb have suffered from biological growth due to excessive moisture (Figure 6.36). Before the remedial activities, same problems were observed on these areas.



(a) (b)

Figure 6.36. The photos taken in (a) August and (b) November showing the damp areas and the formation of algae, which have increased on the walls within three months (taken by the author).

Apart from the photos taken by the author, the following photo taken in May 2015 displays the areas mentioned above. The darker color of these areas indicates the possibility of dirt and/or carbon accumulation on them over the months (Figure 6.37).

Figure 6.37. The problematic areas are darker in May 2015 (taken by Şeyma İpekel).

The greening indicating excess moisture has also been observed on the back facade (south) of the tomb (Figure 6.38). Since biological growth attract moisture to the masonry and hold it there, investigation of the source and extent of growth can point detects. The low levels of sun exposure and low evaporation rates in combination with the prevailing winds contribute to damp problems as well as defects or failures of roofing materials or of water shedding.

Figure 6.38. The biological growth has found on the back facade of the tomb after removal of plant material during the remedial activities (taken by the author).

Since the building had had a rising damp problem, open and closed subsurface drainage systems were constructed during the remedial activities. The greening has been found on the base of the walls after the restoration (Figure 6.39).

Figure 6.39. Biological growth has been obvious on the plinth in November (taken by the author).

Tomb of Şehzade (Prince) Ahmet: In August 2014, although the work program about outside of the tomb was completed, it was observed that there were some problems about lead sheets of the portico's roof. Additionally, biological growth has prolonged (Figure 6.40).

(a) (b)

Figure 6.40. The photos showing (a) the deformed lead sheets covering the roof; and (b) biological growth on the plinth in August 2014 (taken by the author).

In November 2014, it was observed that dampness and biological growth (algae, moss, lichen *etc*.) problems have been continuing on the stairs in front of the portico and on the plinth (Figure 6.41). These areas may receive water from deep-seated wetting, and/or flow water on surfaces and splash-back from the ground.

Figure 6.41. The photos show the dampness and biological growth problems on *küfeki* stones of the stairs in front of the portico and the plinth (taken by the author).

The deformed lead sheets, discoloration and blackening were also observed in November (Figures 6.42 and 6.43).

Figure 6.42. The photo displaying the deformed lead sheets, especially from seams; greening on the marble parts of the portico; and the woody roots plant penetrating the materials (taken by the author).

(a) (b)

Figure 6.43. The photos showing blackening and soiling on the moldings and the decorated parts of the facades below the moldings. Discoloration has been seen in patches (taken by the author).

Since ***the rest of the tombs*** in the complex had also had a rising damp problem, subsurface drainage systems were constructed around them during the remedial activities. The high-tide-like stain on the walls, which shows the limit of rising damp, has lowered after restoration. However, dampness and greening on stones can be still seen on the base of walls due to rising damp and/or splash-back rainwater as the most commonly encountered problems (Figures 6.44, 6.45 and 6.46).

(a) (b)

Figure 6.44. (a) Greening on the lower surfaces of the Tomb of Şehzade (Prince) Mustafa indicating the presence of excessive moisture; and (b) darker patches on the lower level of the walls of Gülruh Sultan Tomb corresponding to areas of persistent damp (taken by the author).

(a) (b)

Figure 6.45. (a) The level of dampness in the Tomb of Gülbahar *Hatun* (Ebe - Obstetrician Lady), and (b) Greening on the stone surfaces and darker patches in the Tomb of Şirin *Hatun* indicating the presence of dampness (taken by the author).

(a) (b)

Figure 6.46. The photos displaying the level of damp and greening on the surfaces of the Tomb of *Şehzade* (Prince) Mahmut (taken by the author).

The details from the portal of the Tomb of Mükrime *Hatun* indicate areas of persistent damp, which exhibits itself as darker patches and colonization (Figure 6.47). When new or enhanced colonization is observed, inspect the building to identify whether it is a symptom of a maintenance problem.

(a) (b)

Figure 6.47. The photos displaying the colonization on damp areas of the lower levels of the walls in the Tomb of Mükrime *Hatun* (taken by the author).

Damage types, which have been determined by getting information from the archive records, the survey drawings and the field observations, the complex interaction with the decreasing and increasing climate change parameters over the century in Bursa are given in the following table based on the document prepared at the World Heritage Committee's 30th session (Table 6.8).

Table 6.8. Damage types detected in the buildings of the Muradiye Complex and their interaction with the climate parameters and changing climate.

CLIMATE INDICATOR	CLIMATE CHANGE RISK	FACTOR	EFFECT	DAMAGE TYPE
Atmospheric Moisture Change	Intense rainfall	Relative humidity cycles	More organic growths Crystallization and dissolution of salts	Corrosion of metals Shock causing splitting, cracking, flaking and dusting of materials and surfaces
Temperature Change	Diurnal, seasonal, extreme events (heat waves, snow loading)	Decreasing freeze-thaw weathering Decreasing in wet frost Increasing thermal stress	The bonds of the mortar among the binding aggregates are dissolved Deterioration of facades	Leads to the dissolution of the mortar
Climate and Pollution acting together	- pH precipitation - Changes in deposition of pollutants	Acidic waters (with CO_2, SO_2) that come with rain or snow water Anionic salt crystals i.e. chlorides, sulfates and nitrates are formed	Increased chemical weathering More organic growths	* Stone recession by dissolution of carbonates * Dissolve the carbonates of lime binder * Adhesion and cohesion features of the mortar are decreased * Aggregates are decomposed * Blackening of materials * Corrosion of metals * Decomposition of the mortar, deep cracks and draping of the mortar are observed * Biological decay, coloring of the mortar and dissolution

Apart from damage types derived from environmental conditions mentioned above, the defects due to remedial activities in the Muradiye Complex are presented in the Table 6.9.

Table 6.9. The destructive effects of the remedial works

FACTOR	EFFECT	DAMAGE TYPE
Using more cement than lime	Formation of highly stiff mortar, cracking	Shrinkage cracks and diffusion of water through cracks, draping due to different work
Salts that may come from the cement	Efflorescence on the surface of the mortar	The salts cause the efflorescence and lead to internal stresses

As a part of remedial activities, cleaning treatments were applied on facades. However, cleaning procedures, which sometimes involve some risk of damage, may end with unpredictable and ineffective results. Although the stone cleaning decrease the appearance of biological growth, spores of some species may survive and they may re-establish on the cleaned surfaces within a matter of months. After any cleaning treatments, stone surfaces have more favorable conditions for biological growth than before because of increasing surface roughness. Besides, remedial activities may not involve comprehensive studies to determine the sources of the problem and /or not be enough to find appropriate solutions. Inappropriate repairs and poor workmanship hasten the occurrence of decay and may lead to longer-term problems resulting in very high repair costs.

In any case, it is necessary to monitor biological growths over time to determine whether the growths are a symptom of a maintenance problem or they responds to changes in the environment. Since humidity and temperature have a definite effect on a range of mechanisms that have a potential to deteriorate materials through allowing surface algal soiling, and deep-seated salt penetration, the asynchronous wetting/drying behaviors at the surface and at depth *etc*., the impacts of anticipated changes in climate should be investigated to guide management strategies.

6.5. Concluding Remarks

The investigation of the complex interaction between the buildings and the local climate requires understanding the physical, chemical and biological mechanisms, which induce changes both in compositional and structural characteristics of materials. This situation gives rise to the question of how to assess different impacts of climate change on tangible cultural heritage. In this regard, proposed steps mentioned in previous sections in detail are given as a model composing five stages (Figure 6.48):

- The first stage is composed of gathering actual historic building stock data from sources such as databases of ministries and climate change projection maps to manage in the next stage.
- These different types of data are store, analyze and present in GIS to produce overlay maps, which help to determine the region / city, which is under the risk of changing patterns of deterioration mechanisms derived from climate change and rich in tangible cultural heritage.
- After determining the region / city, at the third stage, reviewing the archives in terms of past climate data and records of selected buildings. Trend analyses are conducted to understand changing trends in climate parameters, and the past remedial works are used to calculate surface areas of various types of deteriorations.
- At the fourth stage, geographic locations of the selected buildings and common materials of construction, which are obtained in the previous stage, and processed climate data according to thresholds of climate parameters that affect materials are uploaded to GIS to be mapped. The heritage maps and heritage-climate risk maps are obtained.
- At the fifth stage, field surveys are conducted in different times to make visual observations, take photos and mapping.

The findings of the third, fourth and fifth stages are evaluated together to guide management initiatives and future studies.

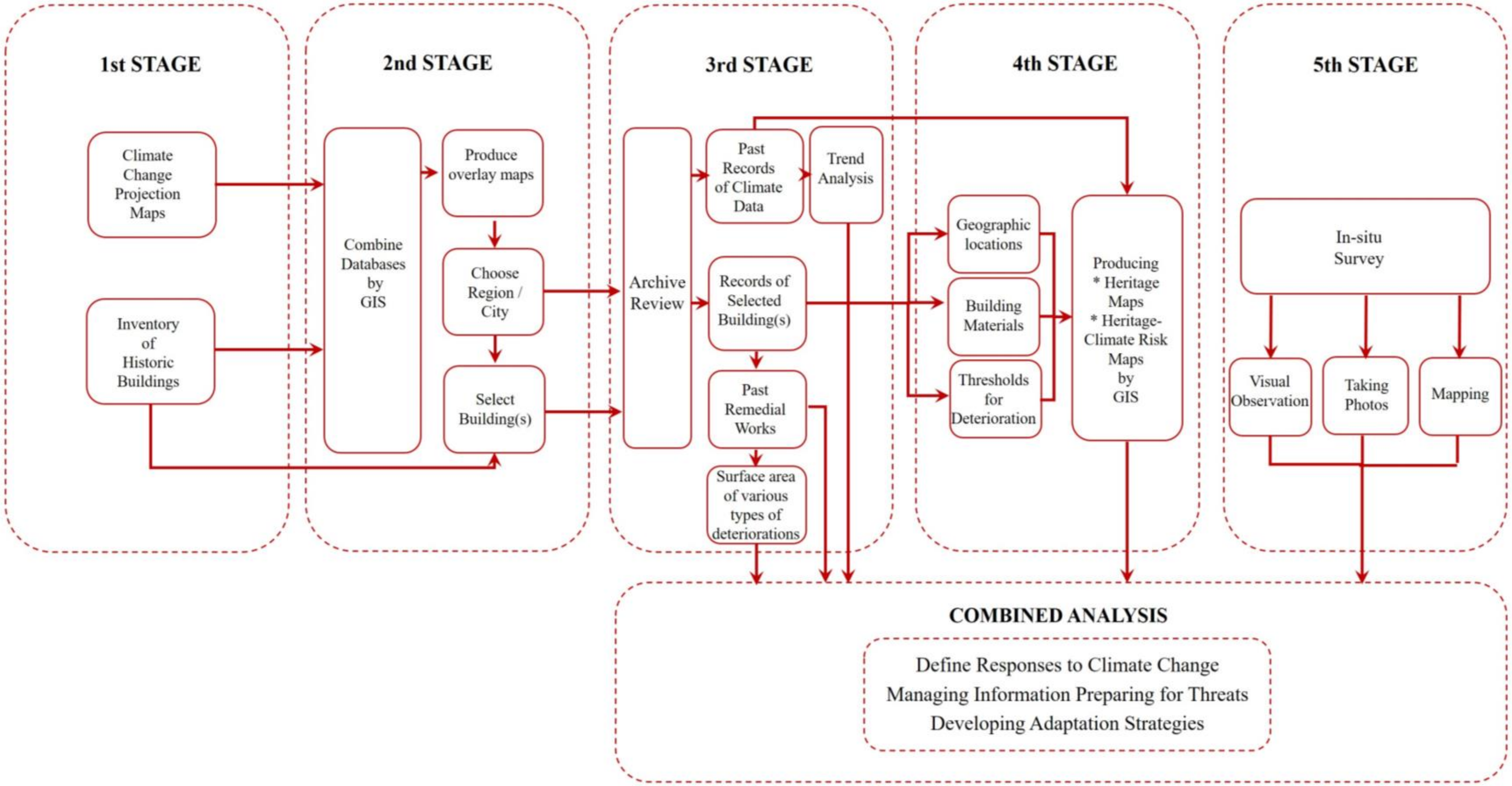


Figure 6.48. A model to understand the impacts of climate change on tangible cultural heritage

CHAPTER 7

CONCLUSION

This conclusion chapter begins with a review of the purpose and structure of the study, which includes casting light on the conceptual framework, methodology and evaluation of the case study into the general principles, and, concludes with the possible implications of the study in further studies.

Cultural Heritage, expressed as either intangible or tangible, includes all evidence of human creativity and expression, which are inherited from past generations, kept in a condition of good repair in the present and passed on to future generations for their benefit. However, cultural heritage is not only a set of buildings, objects or traditions taken over from the past but also is the result of a decision-making process to choose what is worthy of being preserved in view of considerable social, environmental and economic repressions, which threaten cultural heritage. The threats including human induced factors can be listed as illegal trafficking of artifacts and cultural objects, plundering of archaeological sites, destruction of historical buildings and monuments, the accelerating pace of urbanization, management mistakes, lack of legislation and pollution etc. Additionally, natural factors, such as earthquakes, floods, landslides, hurricanes etc. cause irreparable damage to the cultural heritage of a country. Among these threats, climate change is showing its increasing impacts on cultural heritage by both triggering the climate related disasters and affecting deterioration mechanisms, which depend on climatic parameters.

Unfortunately, the responsiveness and inherent adaptive capacity of cultural heritage assets to changes in climate is uncertain. There is also uncertainty as to the capacity of management systems to facilitate the adaptation of cultural heritage assets and their specific values in the face of both abrupt and gradual impacts of climate change. Hence, difficulties will be faced in the protection of heritage and cultural diversity of any particular place or region. There will be losses and these losses will be magnified if appropriate strategies are not put in places in the immediate future. The importance of sustainable management in heritage studies within a framework of internationally recognized and appropriately applied standards comes to the forefront. However, much research and therefore a lot of time is required to establish guidelines for mitigation of climate change impacts on cultural heritage. This study can be considered as a first step in this regard by producing risk and vulnerability maps for cultural heritage assets, which overlay climatic data and heritage site locations so that an overview of the risks to different aspects of cultural heritage can be identified within the risk preparedness concept.

The study started with investigation the scope of cultural heritage and climate change, and the interplay between them to understand the anticipated consequences. Both abrupt and gradual impacts of climate change were investigated and the extreme climatic events that can have significant impacts on both natural and human systems were highlighted. Moreover, climatic projections indicate that an increase of a few degrees in temperatures and / or small percentages in precipitation can have significant impact on historic buildings due to the sensibility of phase changes occurring at certain temperatures, such as freeze-thaw and wet-frost cycles. As it is important to know how changes in climate parameters are shaping the different mechanisms of deterioration in terms of protecting cultural heritage, the outputs of different climate change models were investigated from the regions of Turkey, and the effects of climate change on a selected city and cultural heritage site in Turkey were examined.

7.1. Climate Change Estimations and Hierarchical Maps

The starting point of this study is the results achieved within the project Noah's Ark on 'Global Climate Change Impact on Built Heritage and Cultural Landscapes' funded by the European Union under its sixth Framework Programme. The outputs maps of this project were reevaluated by employing ArcGIS 10 and using statistical data of historic buildings to define risk areas in Turkey in terms of deterioration mechanisms that affect the materials of construction. Since Turkey has varied geographical conditions, the impacts of climate change result in significant differences in climatic conditions from one region to the other, i.e. different regions are experiencing these impacts in different ways. Significant changes in the climate of Turkey have already been observed over recent decades, and they are expected to continue and intensify in the future.

Based on these maps, it is revealed that the historic environment and so the cultural heritage of Turkey have been facing particular threats. The coastal cities and several cities in Central Anatolia are especially pointed in these maps as risk areas in terms of different types of threats derived from climate change. For instance, the highest level of risk for the thermal stress will be experienced in the Aegean and Mediterranean coasts of Turkey while surface recession is particularly noticeable in the mountainous areas getting high rainfall, such as the eastern Black Sea Region. Furthermore, porous stone, which is typically used in the monuments in Turkey, may be less vulnerable to freeze-thaw processes in the future. Therefore, management strategies should be reviewed in terms of changing patterns of deterioration mechanisms and more attention should be paid to damage factors with an increasing trend.

7.2. Impacts on the Case Study Area- Bursa

In view of such future scenarios and the complexity of deterioration mechanisms involving a mixture of chemical, physical, and biological processes, the necessity of the site-specific analysis comes to the forefront. The overlays of risk scenario maps were evaluated for certain periods of architecture in Turkey. Then, the study was limited to the early Ottoman architecture in Bursa, which was highlighted in the overlays maps as having higher risks. Consequently, the local climate trends and site specific conditions of the case study area were examined.

The analyses, specific to Bursa, have been conducted on climate data series for temperature (the daily maximum and minimum temperatures), Relative Humidity (RH) (the daily maximum and minimum) and precipitation (the monthly accumulated precipitation) from 1965 to 2014. It is revealed that increasing trends in minimum and maximum temperatures and the fluctuation pattern of precipitation are in parallel with the previous studies. When the climate data between 1985 and 2014 were mapped by taking account to specific combinations of climatic parameters, which generate the deterioration mechanisms, it was indicated that which deterioration mechanism has been prevalent in a specific region at which level. For instance, the highest risk area in terms of thermal shock has been the city center of Bursa where the number of listed buildings is the highest whereas the rural region of Bursa has been determined as being under the lowest risk. As the climate projections indicate an increase in temperature in Bursa, the development of micro-cracking in and exfoliation of various types of stone with different mineralogical composition may increase over the century. This increasing trend in temperature in the center of Bursa accelerated by the help of urban heat island effect that was highlighted in the previous studies, authorities about conservation and management issues should include protective approaches against decay forms derived from thermal shock.

As stone can undergo severe deterioration due to various decay agents, one of these agents is salt crystallization. Around Yenişehir has been the highest risk area whereas the rural region of Bursa has been under the lowest risk in terms of salt crystallization. The historic center of Bursa has been under medium risk. Moreover, based on the archival survey and the field survey in Muradiye Complex, it is understood that the buildings in the complex have been suffering from several problems due to salt crystallization during their life time. The problems repeated after every remedial activity. As the climate change projections indicate that drier summers may increase salt weathering of stone, the presence of blistering and flaking of the outer few millimeters of stonework may be more prevalent. Therefore, despite the difficulty of treatments, it is important to remove salts and prevention through stopping penetration of salt at source.

Since the variation of RH causes mechanical damage to timber structures and objects, Yenişehir has been under the highest risk whereas the rural region of Bursa has been under the low-medium risk area. The highest density of listed buildings is in the city center, which has been under the medium-high risk of mechanical damage due to humidity variations. The findings in the archival survey point out the decay of timber members of the buildings in the complex. For instance, cracks occurred around the joints. Delamination and flaking of paint layers (such as painted wooden doors) were also recorded. Since the number of damaging humidity variations will increase over the century, investigations to understand RH levels and fluctuations should be included in the remedial activities and management strategies.

One of the causes of stone decay is the corrosion of the embedded metals that occurs when conditions are greater than 0ºC and 80% RH. According to the heritage-climate maps, Bursa has been under the risk that ranges from low to medium-high. Since the historic center has been under the medium risk, the combined threshold of temperature and humidity cycles should also be analyzed in accordance with climate projections on the deterioration process. Besides, spalling, cracking and delamination of stone should be observed by taking account the possibility of the expanding rust and tensile stresses in the stone.

Apart from the heritage-climate maps, the archival and field studies point the repeated and prolonged biological growth, such as algae, moss and vascular plants, at the same locations of the buildings. The growth of algae is the indicators of other problems such as water penetration, and may lead to colonization by vascular plants as well as encouraging particulate soiling. In the case of Muradiye Complex, there are many examples where previous inappropriate treatments have made things worse, and the current remedial activities have not treated the symptoms. Although the problems derive from different reasons, the effects of changes in temperatures and humidity cycles may worsen the existing problems.

To sum up, based on the field survey in Muradiye Complex and archival resources, it is understood that the buildings in the complex have been suffering different types of deterioration processes during their life time. The problems due to salt crystallization, thermal stress, atmospheric pollution agents, and biological growth were common, and repeated after every remedial activity. It was photographed that some of the problems mentioned in the survey report have redeveloped in a very short time after the latest remedial action. As well as the risk of inappropriate, unnecessary and uncontrolled remedial treatments to historic buildings, the accelerated or decelerated risks due to changing conditions in climate system are projected to affect the pattern of deterioration mechanisms and worsen the existing problems. Predicting the impacts of anticipated effects of climate change is a highly difficult task. Statistically downscaling climate projections are being prepared periodically, however they are not capable of making decision specific to a historic site / building. Therefore, site-specific analyses should be carried out and the results should be involved in a management plan. The short, medium and long-term management strategies should be defined according to the impacts of climate change on the complex mixture of physical, chemical, and biological deterioration mechanisms. Defining the management strategies by taking account the anticipated impacts of climate change leads to regular based maintenance, which can stop decay before it is widespread. Over time, the cost of maintenance may be substantially less than the replacement of damaged historic features.

7.3. Recommendations for Further Studies

It is widely accepted that changes in climate system likely to alter the magnitude and the seasonal variations of temperature and precipitation patterns. Although the conflicts over the causes and consequences of climate change make the efforts of developing strategies complicated, actions are being taken to address the impacts of both recent and predicted climate change for different sectors. In Turkey, however, very small have been taking to face the challenges of climate change for a few selected sectors without giving enough attention to acknowledge the need for the preservation of tangible cultural heritage. As changes in climate systems will influence the conservation conditions for tangible cultural heritage, and make the sustainability of tangible cultural heritage more difficult, identifying and addressing gaps including the scientific studies, and climate projections *etc.* between the climate change and the protection of cultural heritage is important. Further studies should be directed to develop detailed risk preparedness concept and management strategies. The management strategies should also provide a balanced assessment of the different levels of competing risks provided by the various aspects of climate change on historic buildings, such as air pollution and natural hazards. Since the study was able to identify some of the anticipated impacts of climate change in Bursa within the framework of Muradiye Complex, this study reflected only limited aspects of the impacts, which has complex causes and consequences.

Policy makers at national and local levels may face uncertainty about how to adapt to predicted changes because the uncertainty about local impacts and timing of particular extreme weather events. As regional and local studies, which are related to assess the impacts of climate change, are important to develop mitigation and adaptation strategies, high-resolution climate simulations capable of resolving finer details are needed to reduce uncertainties and forecast extreme weather events. In the case of Bursa, there are still gaps in climate change studies. Further projections in particular to downscale information to a local level are needed. Within this perspective, site-specific analysis should be conducted as further studies. The effects of changes in temperatures and humidity cycles should be analyzed by taking into account historic buildings in a specific location in accordance with climate projections on the deterioration processes, which are induced by phase changes, such as wet-frost and salt crystallization. Due to the complexity of the linking climate change and cultural heritage studies, a group of cultural heritage professionals coming from different disciplines, such as architecture, art history, conservation, restoration, engineering, chemistry, physics, biology, heritage administration and law *etc.*, should come together while monitoring changes, especially on decadal time scales, developing tools to manage cultural heritage in a changing climate and preventing damage by developing short, medium and long term strategies.

During the research process, it is also revealed that as heritage inventories and statutory lists are critical tools for managing cultural heritage. More studies should be devoted in establishing fully digitized and searchable heritage inventory, which covers the inventory forms, survey reports, maps, photographs, sketches, all relevant geographic, geologic, architectural, and building material properties of historical buildings, previous damages from natural disasters, structural and architectural drawing information and other relevant documents. They are invaluable for a variety of users including property owners, cultural resource consultants, researchers, planners, architects, historian and/or art historian, engineers, restoration specialists and government agencies. In Turkey, a website of the MoCT, which includes cultural heritage inventory, has been prepared by entering data on listed buildings in the boundaries of each provincial organization of the Ministry. The database including six categories that are “identity, state of conservation, properties, state of usage, detailed definition, and images”, has been created. However, these categories have not been filled properly yet by many provincial organizations. There are still missing data and the data whose accuracy of content is in question. As the preservation of the cultural heritage assets is one of the main issues, a digitized open-source heritage inventory of and management system for cultural heritage in Turkey are vitally needed to be completed as soon as possible for the efficient conservation interventions. Additionally, in Turkey, there are several organizations that are involved individually in the documentation and preservation of cultural heritage and there is no coordination amongst them. Hence, it has not been possible to collect all the information into a common database.

As the digitization of inventories is necessary, results of the literature review and the data processing chapter of this study have pointed out that development of a database based on the GIS to compile, homogenize, organize and process a large number of data can be the main infrastructure component for the central and local authorities responsible for cultural heritage. Besides, a GIS platform will provide a framework for an automated monitoring system that will eventually help researchers to detect changes in conditions due to both natural and human induced factors, such as surface recession, *etc*. It will be useful to build spatially correlated data system on weathering features and deterioration rates. Therefore, in Turkey, the centralized web-based GIS system called "National Immovable Cultural Heritage Inventory System" (Tescilli Kültür Varlıkları Taşınmaz Ulusal Envanter Sistemi / TUES), which is under construction, should not only include information on monuments and listed historical buildings, Conservation Council decisions and million pages of archival documents, but also be an instrument in evaluating (assessing, measuring, mapping, and linking) the nature and scale of the risks posed to cultural heritage assets arising specifically from climate change as well as urbanization, development of new tourism and industrial areas *etc.* Moreover, GIS and spatial data should be promote to utilize as decision support tools by providing accurate identification of the place itself and its boundaries, appropriate, and well-researched information.

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APPENDICES

APPENDIX A: HIERARCHICAL MAPS

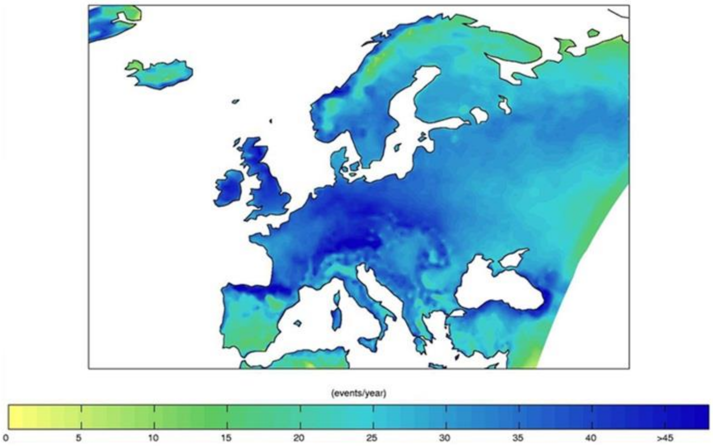


Figure A.1. The map shows salt crystallization frequency for far future. (Source. Sabbioni *et al.*, 2010)

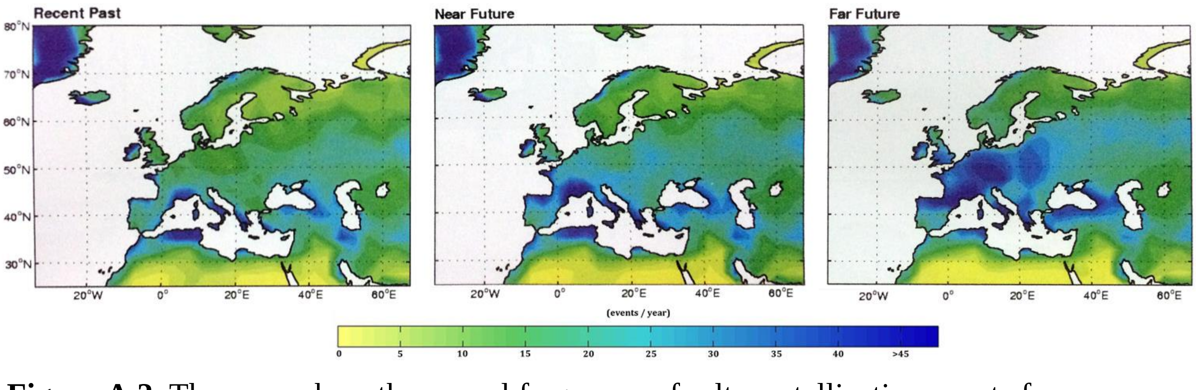


Figure A.2. The maps show the annual frequency of salt crystallization events for recent past (1961-1990), near future (2010-2039), and far future (2070-2099). (Source. Sabbioni *et al.*, 2010)

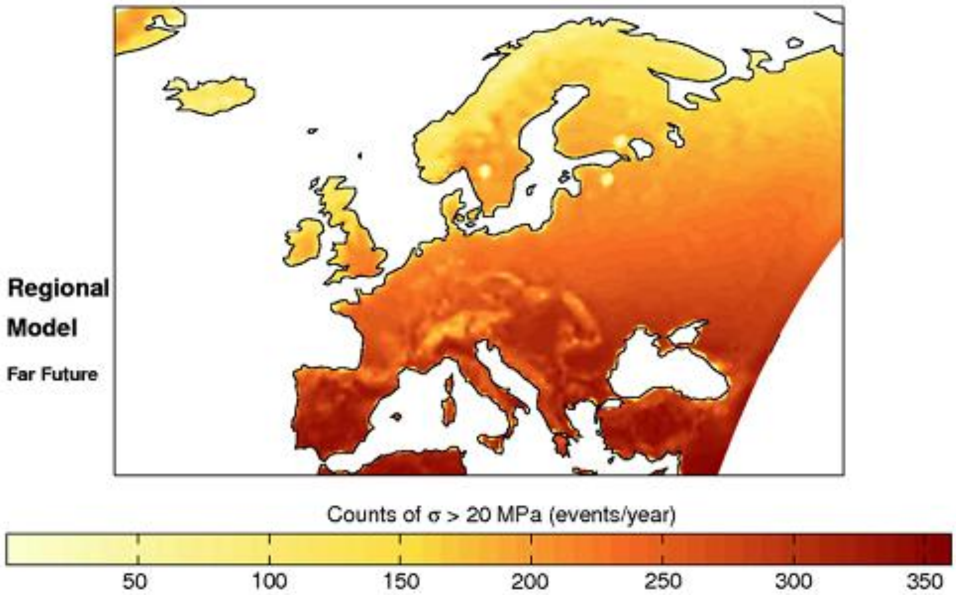


Figure A.3. Estimated thermal stress risk on Carrara marble for 2070-2099 under the A2 scenario derived from HadRM3 output
(Source. Bonazza *et al.*, 2009)

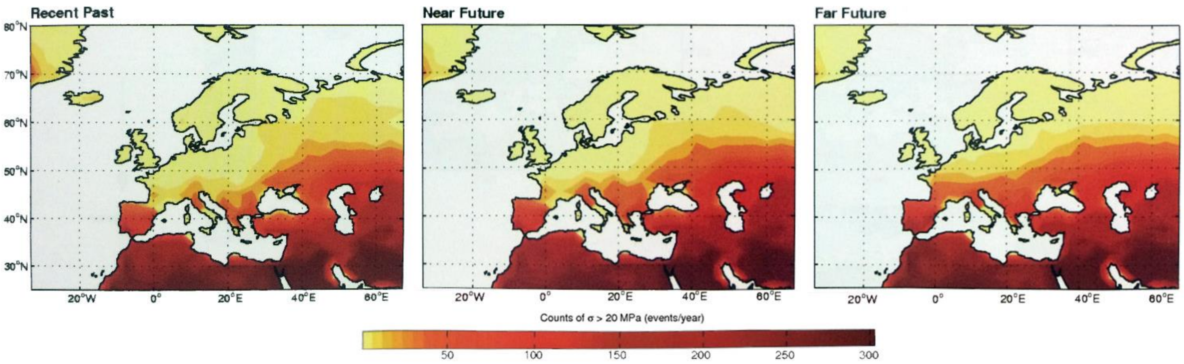


Figure A.4. The maps show the number of events per year in which thermoclastism will cause internal tension (σ) greater than 20 MPa for recent past (1961-1990), near future (2010-2039), and far future (2070-2099).
(Source. Bonazza *et al.*, 2009)

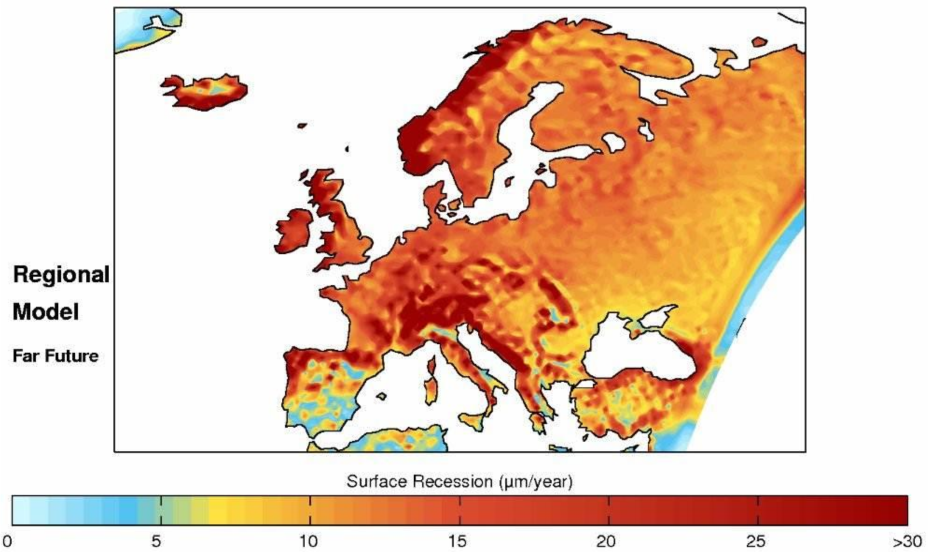


Figure A.5. The map shows surface recession rates of low porosity carbonate stone for far future (2070-2099)
(Source. Bonazza *et al.*, 2008)

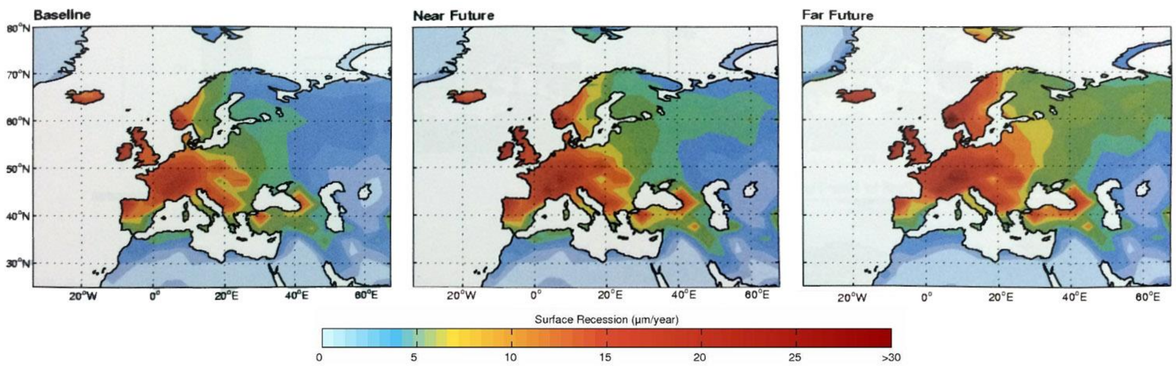


Figure A.6. The maps show the surface recession rates of low porosity carbonate stone for recent past (1961-1990), near future (2010-2039), and far future (2070-2099).
(Source. Sabbioni *et al.*, 2010)

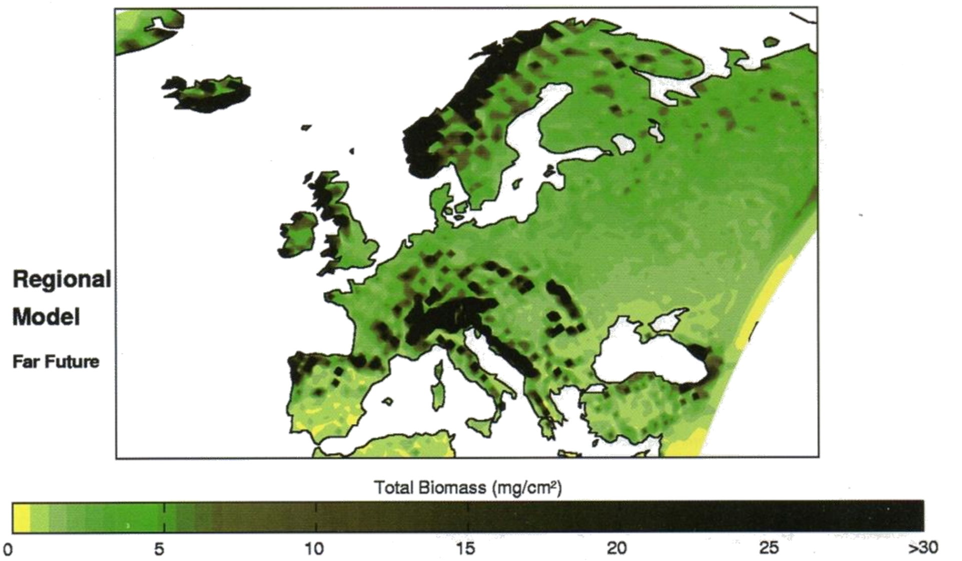


Figure A.7. The maps shows that the total biomass will increase all over Europe. (Source. Sabbioni, 2008)

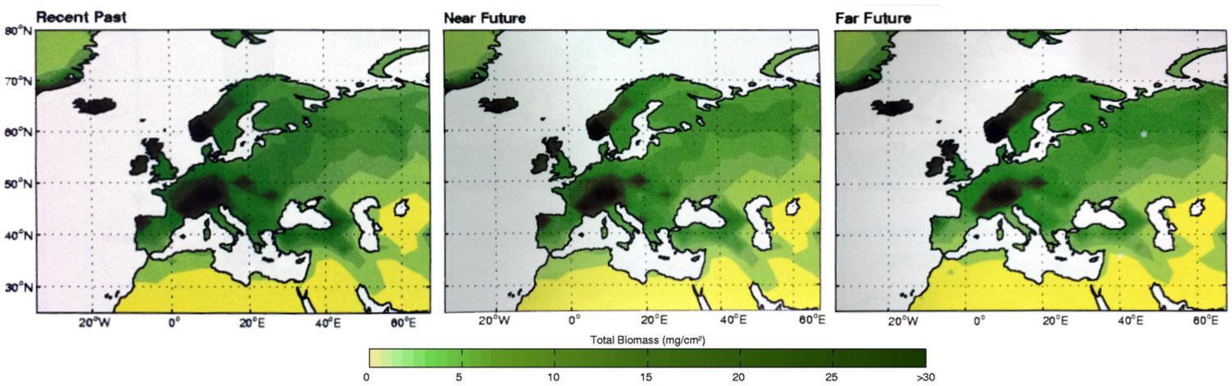


Figure A.8. The maps show total biomass accumulation on monuments for recent past (1961-1990), near future (2010-2039), and far future (2070-2099). (Source. Sabbioni *et al.*, 2010)

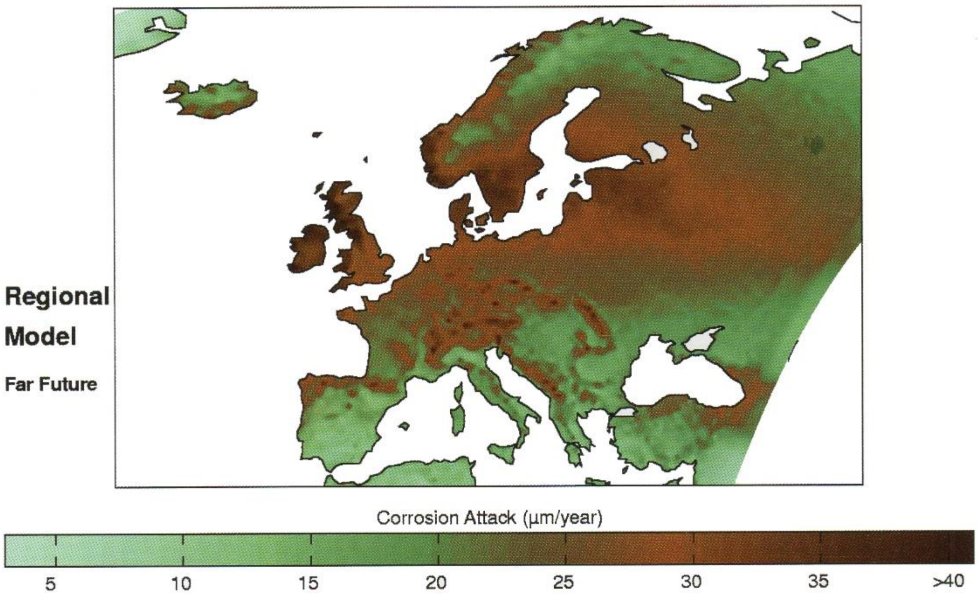


Figure A.9. The maps shows the corrosion of steel-iron and bronze caused by acidifying pollutants for far future (2070-2099)
(Source. Sabbioni *et al.*, 2010)

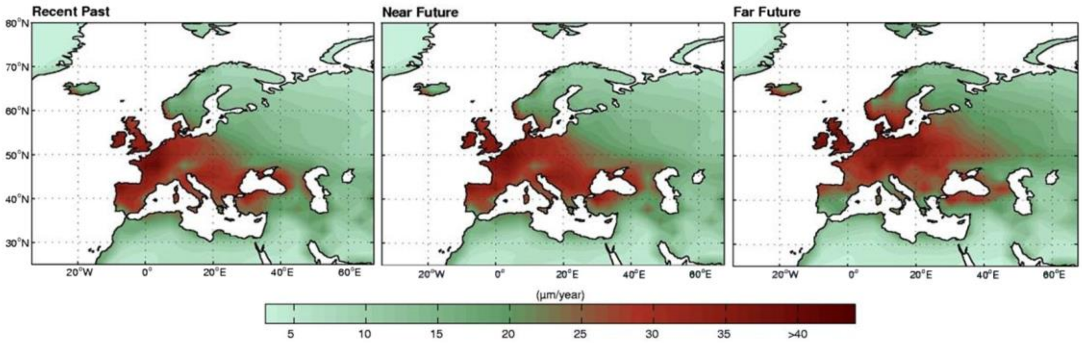


Figure A.10. The maps show the corrosion of steel-iron and bronze caused by acidifying pollutants for recent past (1961-1990), near future (2010-2039), and far future (2070-2099).
(Source. Sabbioni *et al.*, 2010)

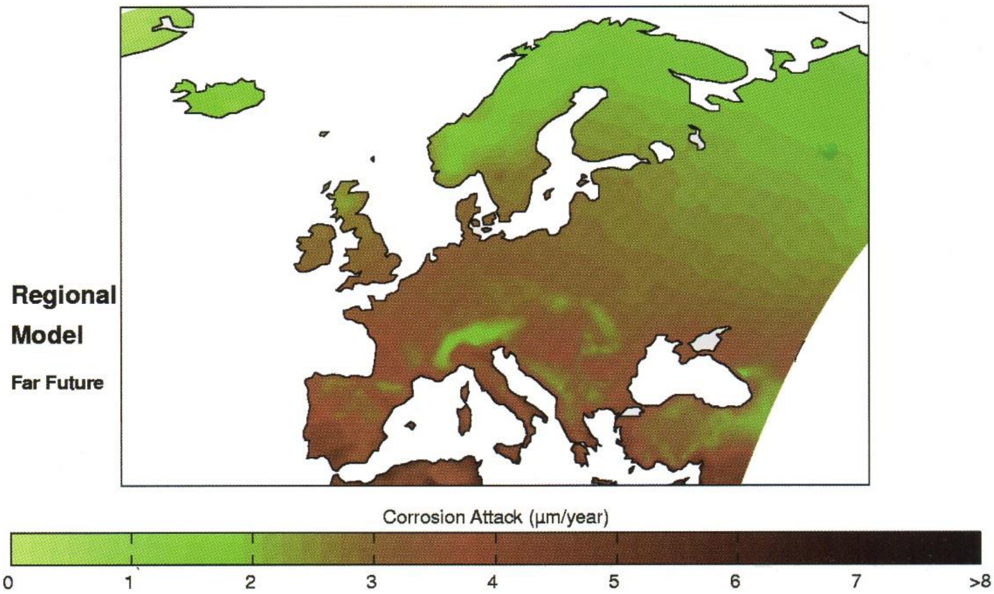


Figure A.11. The maps shows the corrosion of zinc, copper and lead due to high chloride for far future (2070-2099).
(Source. Sabbioni *et al.*, 2010)

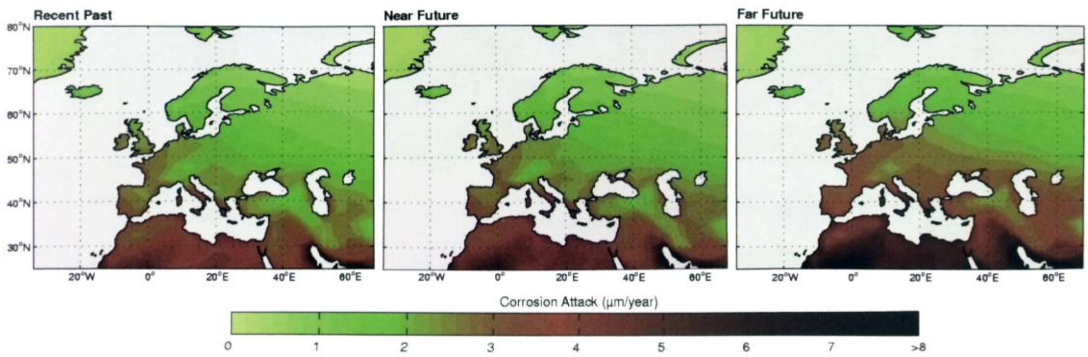


Figure A.12. The maps show the corrosion of zinc, copper and lead caused by high chloride for recent past (1961-1990), near future (2010-2039), and far future (2070-2099).
(Source. Sabbioni *et al.*, 2010)

APPENDIX B : SELECTED TANGIBLE HERITAGE ASSETS AND THEIR GEOGRAPHICAL LOCATIONS

Table B.1. Selected tangible heritage assets in Bursa with their geographic latitude and longitude components.

DISTRICT	NAME OF THE PROPERTY	Y-Latitude	X-Longitude
Cumalıkızık	Early Ottoman Rural Settlement	40.175098	29.171567
Osmangazi	I. Murad MOSQUE (HUDAVENDIGAR COMPLEX)	40.202208	29.021175
Osmangazi	I. MURAD TOMB (HUDAVENDIGAR COMPLEX)	40.202176	29.020993
Osmangazi	I. MURAD SOUP KITCHEN (HUDAVENDIGAR COMPLEX)	40.202631	29.020693
Osmangazi	Cık Cık (Gir Çık) HAMMAM (HUDAVENDIGAR COMPLEX)	40.202508	29.021518
Osmangazi	OLD THERMAL BATH (HUDAVENDIGAR COMPLEX)	40.202099	29.023456
Osmangazi	LAMİ ÇELEBİ MOSQUE (HUDAVENDIGAR COMPLEX)	40.201839	29.02327
Osmangazi	II. MURAD MOSQUE (MURADIYE COMPLEX)	40.190981	29.046517
Osmangazi	II. MURAD MADRASA	40.190898	29.045654
Osmangazi	II. MURAD SOUP KITCHEN (MURADIYE COMPLEX)	40.191271	29.047021
Osmangazi	II. MURAD TOMB (MURADIYE COMPLEX)	40.190533	29.046036
Osmangazi	II. MURAD HAMMAM (MURADIYE COMPLEX)	40.190922	29.044961
Osmangazi	HÜMA HATUN TOMB (MURADIYE COMPLEX)	40.190783	29.046981
Osmangazi	SARAYLILAR TOMB (MURADIYE COMPLEX)	40.190874	29.046961
Osmangazi	GÜLRUH SULTAN TOMB (MURADIYE COMPLEX)	40.190626	29.045381
Osmangazi	ŞİRİN HATUN TOMB (MURADIYE COMPLEX)	40.190731	29.045386
Osmangazi	ŞEHZADE MAHMUD TOMB (MURADIYE COMPLEX)	40.190422	29.045436
Osmangazi	MÜKRİME HATUN TOMB (MURADIYE COMPLEX)	40.190308	29.045478

Table B.1 cont'd

Osmangazi	GÜLŞAH HATUN TOMB (MURADIYE COMPLEX)	40.190233	29.045597
Osmangazi	ŞEHZADE MUSTAFA TOMB (MURADIYE COMPLEX)	40.190369	29.045781
Osmangazi	CEM SULTAN VE ŞEHZADE MUSTAFA ÇELEBİ TOMB (MURADIYE COMPLEX)	40.190522	29.0456
Osmangazi	ŞEHZADE AHMED TOMB (MURADIYE COMPLEX)	40.190658	29.046236
Osmangazi	EBE (GÜLBAHAR) HATUN TOMB (MURADIYE COMPLEX)	40.19055	29.045406
Osmangazi	BEŞİKÇİLER (SİNAN DEDE) MOSQUE (MURADİYE COMPLEX)	40.192108	29.044836
Osmangazi	ŞAİR AHMED PAŞA MADRASA (MURADİYE COMPLEX)	40.191833	29.045828
Osmangazi	ŞAİR AHMED PAŞA TOMB (MURADİYE COMPLEX)	40.191753	29.045997
Osmangazi	BAHRİ BABA MASJİD (MURADİYE COMPLEX)	40.190256	29.048561
Osmangazi	AZEB BEY MOSQUE (MURADİYE COMPLEX)	40.188608	29.045014
Osmangazi	AZEB BEY TOMB (MURADİYE COMPLEX)	40.188608	29.044897
Osmangazi	KARŞI DURAN SÜLEYMAN TOMB	40.190358	29.045222
Yıldırım	YEŞİL MOSQUE (YEŞİL COMPLEX)	40.182164	29.074614
Yıldırım	YEŞİL TÜRBE (YEŞİL COMPLEX)	40.181381	29.074875
Yıldırım	YEŞİL MEDRESE (YEŞİL COMPLEX)	40.181528	29.073353
Yıldırım	YEŞİ İMARETİ (YEŞİL COMPLEX)	40.181839	29.075125
Yıldırım	HAMAM (YEŞİL HAMMAM) (YEŞİL COMPLEX)	40.181478	29.074128
Yıldırım	BEDRETTİN MOSQUE (YEŞİL COMPLEX)	40.183331	29.071617
Yıldırım	BEDRETTİNMOSQUEÇEŞMESİ (YEŞİL COMPLEX)	40.183344	29.071595
Yıldırım	SELÇUK HATUN MOSQUE (YEŞİL COMPLEX)	40.182281	29.069972
Yıldırım	IRGANDI BRIDGE (YEŞİL COMPLEX)	40.181939	29.070792

Table B.1 cont'd

Yıldırım	BOYACIKULLUĞU BRIDGE (YEŞİL COMPLEX)	40.182928	29.072211
Yıldırım	HACI BABA MASJİD HAZİRESİ (YEŞİL COMPLEX)	40.180072	29.072675
Yıldırım	YILDIRIM MOSQUE(YILDIRIM COMPLEX)	40.18745	29.082414
Yıldırım	YILDIRIM MADRASA(YILDIRIM COMPLEX)	40.18785	29.081894
Yıldırım	YILDIRIM BAYEZİD TOMB (YILDIRIM COMPLEX)	40.188006	29.082383
Yıldırım	YILDIRIM HAMMAM (YILDIRIM COMPLEX)	40.186942	29.081419
Yıldırım	YILDIRIM MOSQUE FOUNTAIN(YILDIRIM COMPLEX)	40.187742	29.082375
Yıldırım	MOLLA YEGAN MADRASA (YILDIRIM COMPLEX)	40.187564	29.079628
Yıldırım	MÜFTÜ ÖNÜ MOSQUE	40.179177	29.072754
Yıldırım	YILDIRIM HOSPITAL	40.18804	29.082385
Yıldırım	FEYZULLAH PAŞA MASJİD	40.182204	29.079273
Yıldırım	ZEYNİLER MOSQUE	40.180887	29.083646
Yıldırım	EMİR SULTAN HAMMAM	40.180751	29.081542
Yıldırım	BAZEYID PAŞA MEDRESESİ	40.183872	29.074811
Yıldırım	BAZEYID PAŞA MOSQUE	40.181671	29.076904
Yıldırım	MES'UD MAKRAMEVİ (Hasırcılar) MASJID	40.179458	29.074498
Yıldırım	UMUR BEY MOSQUE	40.177654	29.071289
Yıldırım	UMUR BEY HAMMAM	40.177378	29.071851
Osmangazi	ORHAN GAZİ MOSQUE	40.184037	29.063843
Osmangazi	ORHAN HAMMAM	40.184573	29.062906
Osmangazi	EMİR HAN	40.184543	29.062275
Osmangazi	KAPAN HAN	40.183937	29.060617
Osmangazi	ULU MOSQUE	40.183987	29.061512
Osmangazi	BEDESTEN	40.185146	29.062052
Osmangazi	VAİZİYE (MAHKEME) MADRASA	40.184459	29.061148
Osmangazi	ŞENGÜL HAMMAM	40.184463	29.061562
Osmangazi	BAKIRCILAR MARKET	40.184448	29.060007
Osmangazi	İPEK HAN	40.185361	29.061168
Osmangazi	İVAZPAŞA MARKET (İVAZPAŞA, GELİNCİK, SİPAHİ)	40.185644	29.062167
Osmangazi	GEYVE HAN	40.185163	29.062966

Table B.1 cont'd

Osmangazi	İVAZ PAŞA MOSQUE	40.185656	29.061334
Osmangazi	MEYHANELİ (TAVUK PAZARI) HAMMAM	40.185891	29.060834
Osmangazi	PİRİNÇ HAN	40.185719	29.060202
Osmangazi	ERTUĞRUL BEY MOSQUE	40.185824	29.062926
Osmangazi	FİDAN HAN	40.184854	29.063741
Osmangazi	KOZAHAN - İÇKOZAHAN	40.184241	29.06395
Osmangazi	OSMANGAZİ TOMB	40.186777	29.057284
Osmangazi	ORHANGAZİ TOMB	40.186745	29.057677
Osmangazi	OKÇU BABA TOMB	40.185358	29.058437
Osmangazi	BALİBEY HAN	40.184952	29.058602
Osmangazi	ÇAKIR HAMAM	40.18396	29.059192
Osmangazi	MECNUN DEDE MOSQUE	40.183253	29.059754
Osmangazi	AHŞAP HAN	40.183042	29.059537
Osmangazi	AHŞAP HAN	40.1828	29.059468
Osmangazi	HACI SEVİNÇMOSQUE	40.182703	29.059314
Osmangazi	VELED-İ VEZİRİ MOSQUE	40.182061	29.058319
Osmangazi	FIŞKIRIK (DUHTER-İ ŞERİF) MOSQUE	40.181784	29.059916
Osmangazi	İNEBEY MADRASA	40.182667	29.06096
Osmangazi	İNEBEY HAMMAM	40.182688	29.06082
Osmangazi	TAHTAKALE HANI	40.183146	29.060263
Osmangazi	TAHTAKALE BUILDING	40.183146	29.060263
Osmangazi	GÜNGÖRMEZMOSQUE	40.183489	29.060425
Osmangazi	ŞEKER HOCAMOSQUE	40.182912	29.061889
Osmangazi	ŞEKER HOCA TOMB	40.18283	29.06188
Osmangazi	NALBANTOĞLU MOSQUE	40.182331	29.063814
Osmangazi	KARAŞEYH MOSQUE	40.182722	29.065422
Osmangazi	TARİHİ BELEDİYE BİNASI (1867)	40.18383	29.064555
Osmangazi	SİMKEŞMOSQUE	40.183692	29.065384
Osmangazi	NALICILAR HAMMAM	40.184438	29.066733
Osmangazi	KÜTAHYA HAN (Çukur Han)	40.184799	29.066895
Osmangazi	ŞERAFEDDİN PAŞA MOSQUE	40.184262	29.067971
Osmangazi	KARA KADI MOSQUE	40.184876	29.067914
Osmangazi	TUZ HAN	40.184505	29.065752
Osmangazi	TUZ PAZARI MOSQUE	40.184945	29.06564
Osmangazi	HAYRETTİN PAŞAMOSQUE	40.18517	29.066835
Osmangazi	ALANYA – ALANYERİMOSQUE	40.185586	29.066062
Osmangazi	İSAMİL HAKKI BURSEVİ TEKKE VE MOSQUE	40.186176	29.065564
Osmangazi	YİĞİD CEDİDMOSQUE	40.185871	29.064489

Table B.1 cont'd

Osmangazi	PERŞEMBE HAMMAM	40.185989	29.062698
Osmangazi	YENİ BEZZAZMOSQUE	40.18665	29.063701
Osmangazi	VELED-İ ENBİYAMOSQUE	40.186552	29.062048
Osmangazi	REYHAN PAŞA HAMMAM	40.186922	29.06305
Osmangazi	MANTICI MOSQUE	40.187198	29.061605
Osmangazi	TAVUK PAZARI MASJİD	40.186459	29.060685
Osmangazi	MUDANYA (APOLYONT) HAN	40.186166	29.060177
Osmangazi	ABDAL MEHMETMOSQUE	40.186678	29.067911
Osmangazi	ABDAL MEHMED TOMB	40.186969	29.068228
Osmangazi	ABDAL DEPOSU	40.18643	29.067968
Osmangazi	HAYDAR HANE HAMMAM	40.178803	29.058078
Osmangazi	İBRAHİM PASHA HAMMAM	40.183688	29.056207
Osmangazi	KİREMİTÇİ SİNAN BEY MOSQUE	40.191786	29.063733
Osmangazi	KAYHAN MOSQUE	40.183697	29.070394
Orhangazi	ORHANGAZİ HAMMAM	40.491164	29.307218
Osmangazi	ÇIRAĞBEY MOSQUE	40.183959	29.055894
Osmangazi	HATİCE İSFENDİYARİ MOSQUE	40.185602	29.075198
Osmangazi	GÖKDERE MEDRESESİ	40.183861	29.071575
Osmangazi	SERVİNAZ HAMMAM	40.199631	29.016644
Osmangazi	YER KAPI MOSQUE	40.182718	29.056307
Osmangazi	KARA MUSTAFA KAPLICASI	40.198597	29.03859
Osmangazi	ALTIPARMAK MOSQUE	40.18932	29.050989
Osmangazi	KAVAKLI MOSQUE	40.184226	29.057193
Osmangazi	HAMZA BEY MOSQUE	40.192248	29.041975
Osmangazi	KEÇELİ HAMMAM	40.192248	29.041975
Osmangazi	BAŞÇI İBRAHİM HAMMAM	40.178482	29.06276
Osmangazi	MAKSEM (Düstürhan) MOSQUE	40.177226	29.062192
Osmangazi	SÜLEYMAN PAŞA TOMB	40.264159	29.651155
Osmangazi	ESKİ YENİ ÖRDEKLİ HAMMAM	40.187541	29.06789
Osmangazi	KEFEN SÜZEN MOSQUE	40.189206	29.064972
Osmangazi	NAKKER (Nakkaş) ALİ MASJİD	40.185496	29.052669
Osmangazi	ÇEKİRGE HAMMAM	40.201121	29.017661
Osmangazi	ALAADDİN PAŞA MOSQUE	40.185385	29.049967
Osmangazi	SOMUNCU BABA MOSQUE	40.177804	29.058873
Osmangazi	İMARET-İ İSABEY MOSQUE	40.187934	29.05256
Osmangazi	KANBERLER (SİTTİ) MOSQUE	40.185961	29.073096
Osmangazi	GÜLÇİÇEK HATUN (yahşi bey) TOMB	40.188884	29.04902
Osmangazi	PERŞEMBE HAMMAM	40.186166	29.060172
Osmangazi	AHMET DAİ MOSQUE	40.184769	29.07262
Osmangazi	HACI İVAZ PAŞA TOMB	40.179832	29.056195
Osmangazi	KÜKÜRTLÜ HAMMAM	40.198603	29.03856

Table B.1 cont'd

Osmangazi	NİLÜFER (HIDIRLIK) MOSQUE	40.179965	29.053489
Osmangazi	HACILAR MOSQUE	40.181867	29.066336
Osmangazi	ALİ PAŞA MEDRESESİ	40.179793	29.059335
İznik	HACI HAMZA HAMMAM (II. MURAD HAMMAM)	40.428309	29.720398
İznik	ÇANDARLI İBRAHİM PAŞA TOMB	40.4295	29.719
İznik	MAHMUT ÇELEBİ MOSQUE	40.428103	29.719741
İznik	I. MURAD HAMMAM	40.431017	29.720729
İznik	İSMAİL BEY HAMMAM	40.431336	29.721244
İznik	YAKUP ÇELEBİ MOSQUE VE TOMB	40.425836	29.723016
İznik	NİLÜFER HATUN SOUP KITCHEN	40.430299	29.726205
İznik	HACI ÖZBEK MOSQUE	40.429278	29.723083
İznik	YEŞİL MOSQUE	40.429658	29.727192
İznik	RÜSTEM PAŞA HAN	40.43217	29.719424
İznik	ÇANDARLI HAYRETTİN VE ALİ PAŞA TÜRBELERİ	40.427472	29.72176
İznik	ŞEYH KUBBETTİN MOSQUE AND TOMB	40.430894	29.726197
Yenişehir	REYHAN PAŞA GRAVE AND ZAWIYA	40.260693	29.649286
Yenişehir	ORHAN GAZİ MOSQUE	40.186736	29.734765
Yenişehir	AYDOĞDU BEY TOMB	40.257752	29.487719
Yenişehir	SİNAN PAŞA BAZAAR	40.260608	29.6539
Yenişehir	ÇİFTE HAMAM (ÇARŞI HAMMAM)	40.264351	29.650511
Yenişehir	SİNAN PAŞA MADRASA	40.260507	29.653648
Yenişehir	PUSTİNPUŞ BABA ZAWIYA	40.26059	29.652585
Yenişehir	KÖPRÜHİSAR KÖYÜ HAMMAM	40.279077	29.785184
Kestel	BABA SULTAN HAMMAM	40.109829	29.369883
Kestel	BABA SULTAN MOSQUE VE TOMB	40.109821	29.370277
Kestel	HOCA TURSUN HAN	40.167067	29.319099
Harmancık	MURAT ÇELEBİ MOSQUE	39.715098	29.220193
Karacabey	KÜMBETLİ MOSQUE	40.208292	28.360816
Gemlik	BÜYÜK HAMAM	40.471016	29.101061
İnegöl	KASIM EFENDİ MOSQUE	40.076888	29.512425
İnegöl	SALI HAMMAM	40.081291	29.514729
Keleş	KEMALİYE MOSQUE	39.843082	29.225379
Mustafa Kemal Paşa	LALA ŞAHİN PAŞA COMPLEX	40.032699	28.412159

APPENDIX C: SELECTED WEATHER STATIONS AND CLIMATE DATA

Table C.1. The selected stations and the monthly number of days with maximum temperatures of greater than or equal to 30 °C from 1985 to 2014 (prepared by the author).

YEAR / STATION	Balıkesir	Balıkesir-Bandırma	Bilecik	Bursa	Bursa - Yenişehir	Bursa-Keles	Bursa-M.Kemal	Kütahya	Kocaeli	Sakarya
	17152	17114	17120	17116	17678	17695	17675	17155	17066	17069
1985	59	15	25	58	31	9	36	25	28	26
1986	67	13	35	71	49	17	38	36	42	42
1987	63	23	31	62	36	8	20	32	37	31
1988	74	18	38	76	48	10	54	28	53	42
1989	58	10	47	60	51	8	40	27	40	37
1990	62	14	38	58	46	4	41	22	34	32
1991	53	14	24	45	33	4	33	32	28	26
1992	64	17	30	49	38	7	48	24	38	35
1993	78	24	48	62	58	15	41	37	38	45
1994	107	24	57	94	80	16	61	37	69	62
1995	73	16	28	63	43	0	46	27	37	25
1996	60	13	35	54	46	10	45	28	44	35
1997	56	21	24	45	22	5	37	12	31	32
1998	71	24	53	70	55	22	55	47	59	57
1999	93	17	39	71	58	27	61	37	44	54
2000	76	38	48	67	58	23	56	40	54	48
2001	105	45	54	87	75	27	83	56	63	68
2002	83	36	40	71	66	14	57	27	43	52
2003	89	29	48	83	78	21	63	27	64	67
2004	75	25	25	64	46	12	48	28	41	42
2005	74	16	40	60	48	9	56	34	50	57
2006	70	33	59	72	66	25	55	46	64	69
2007	102	36	69	88	92	23	94	60	75	102
2008	102	25	47	93	81	24	81	57	70	102
2009	76	24	38	73	65	8	75	33	56	76
2010	94	42	60	75	79	25	91	60	73	94
2011	83	20	37	66	64	9	69	41	55	83
2012	97	48	67	84	89	37	90	50	78	97
2013	91	22	46	67	73	10	82	25	67	91
2014	77	31	48	65	62	21	79	49	68	77

Table C.2. The selected stations and the annual number of events when RH falls below and rises above 75 % within the period of 1985-2006 (prepared by the author).

YEAR / STATION	Balıkesir	Balıkesir-Bandırma	Bilecik	Bursa	Bursa - Yenişehir	Bursa-Keles	Bursa-M.Kemal	Kütahya	Kocaeli	Sakarya
	17152	17114	17120	17116	17678-17118	17695	17675	17155	17066	17069
1985	242	169	198	210	271	178	240	243	219	204
1986	286	172	221	229	298	161	239	265	259	109
1987	254	170	184	242	293	173	230	193	241	164
1988	221	206	203	239	294	190	233	250	233	151
1989	252	257	200	235	290	181	258	224	259	128
1990	291	278	205	229	312	160	266	250	267	210
1991	261	243	227	259	290	186	236	261	210	239
1992	289	270	213	256	295	158	258	186	238	206
1993	277	238	189	248	285	140	258	168	234	217
1994	267	258	207	200	281	145	266	159	229	196
1995	283	267	223	229	310	196	268	182	244	211
1996	233	256	217	228	271	163	225	188	239	249
1997	235	251	227	242	290	154	247	219	229	271
1998	265	246	233	221	291	157	253	231	250	260
1999	257	277	249	233	312	159	266	242	270	262
2000	226	263	233	210	287	150	248	232	252	246
2001	246	238	231	191	296	145	237	189	251	221
2002	294	252	215	265	292	178	274	234	263	254
2003	246	257	205	238	279	166	252	187	244	228
2004	301	263	213	240	294	174	263	226	252	237
2005	283	245	200	243	295	189	239	212	248	253
2006	239	240	207	235	283	158	237	217	259	220

Table C.3. The selected stations and the annual number of RH variations exceeding 30% over two consecutive days within the period of 1985-2006 (prepared by the author).

YEAR / STATION	Balıkesir	Balıkesir-Bandırma	Bilecik	Bursa	Bursa - Yenişehir	Bursa-Keles	Bursa-M.Kemal	Kütahya	Kocaeli	Sakarya
	17152	17114	17120	17116	17678-17118	17695	17675	17155	17066	17069
1985	114	58	74	149	158	88	93	160	113	119
1986	102	67	97	178	186	86	93	158	116	121
1987	138	81	78	171	200	94	103	167	103	110
1988	123	100	74	166	176	103	97	158	79	57
1989	146	46	101	214	199	121	106	163	78	117
1990	163	85	84	203	216	90	118	221	116	129
1991	135	46	85	98	146	130	99	172	57	39
1992	185	57	99	134	186	99	104	184	95	107
1993	177	64	99	114	181	120	116	177	120	63
1994	151	61	105	125	194	110	91	155	144	141
1995	141	56	78	137	195	160	98	173	153	103
1996	123	62	74	137	174	97	87	168	98	114
1997	108	67	25	146	163	55	94	138	107	91
1998	161	57	40	153	183	79	108	141	142	114
1999	203	80	51	192	213	128	101	155	101	120
2000	197	87	50	155	197	107	147	153	116	144
2001	198	87	92	145	211	110	111	147	118	128
2002	175	79	111	171	212	137	133	153	144	122
2003	155	44	93	142	196	100	153	138	120	153
2004	187	60	111	157	206	137	135	150	111	144
2005	177	40	111	159	199	138	126	159	93	113
2006	171	61	100	131	207	131	171	151	108	126

Table C4. The selected stations and the annual number of events when daily maximum RH exceeding 80% and daily minimum temperature exceeding 0ºC within the period of 1985-2006 (prepared by the author).

YEAR / STATION	Balıkesir	Balıkesir-Bandırma	Bilecik	Bursa	Bursa - Yenişehir	Bursa-Keles	Bursa-M.Kemal	Kütahya	Kocaeli	Sakarya
	17152	17114	17120	17116	17678-17118	17695	17675	17155	17066	17069
1985	225	128	162	190	227	122	218	103	220	171
1986	299	145	178	200	255	108	239	29	244	286
1987	269	141	148	210	258	119	189	79	255	303
1988	294	171	171	195	238	126	191	66	283	314
1989	232	270	131	192	203	117	136	59	270	285
1990	252	273	152	212	252	115	169	96	290	291
1991	255	273	190	272	261	149	201	132	314	254
1992	208	260	133	200	204	87	96	82	258	267
1993	239	249	130	213	201	90	94	117	315	270
1994	256	288	189	179	242	100	120	123	325	281
1995	305	277	187	200	268	122	127	123	296	293
1996	235	284	206	224	235	122	172	165	322	316
1997	207	251	253	200	236	129	166	163	300	299
1998	248	273	248	180	280	116	176	176	329	316
1999	198	274	246	191	299	91	156	141	250	293
2000	163	232	201	170	280	84	168	126	224	276
2001	181	249	223	152	282	106	129	123	244	287
2002	259	259	162	241	226	138	179	135	308	281
2003	244	275	165	193	233	101	168	139	275	255
2004	255	237	151	182	219	117	127	128	247	245
2005	264	258	157	199	274	128	154	144	231	272
2006	193	227	150	171	195	95	160	117	220	259

APPENDIX D: PHOTOGRAPHS

1. Muradiye Mosque

Figure D.1. Muradiye Mosque in 1981
(Source. Beatrice St. Laurent / Courtesy Aga Khan Visual Archive, MIT Libraries – Dome)

2. Muradiye Madrasah

(a) (b)

Figure D.2. Muradiye Madrasa (unknown date)
(Source. Inventory of General Directorate for Foundations)

Figure D.3. Muradiye Madrasa (unknown date)
(Source. Governorship of Bursa)

Figure D.4. The entrance of Muuradiye Madrasa (unknown date-before 2012)
(Source. Governorship of Bursa)

3. Muradiye Hammam

Figure D.5. The wooden entrance door severely decayed. The stairs reached to the entrance door were completely demolished (unknown date).
(Source. Inventory of General Directorate for Foundations)

(a) (b)

Figure D.6. The entrance facade of the Muradiye Hammam in 1970.
(Source. Bursa-CNHPRB)

Figure D.7. The rear facade of the Muradiye Hammam in 1975.
(Source. Inventory of General Directorate for Foundations, 1975)

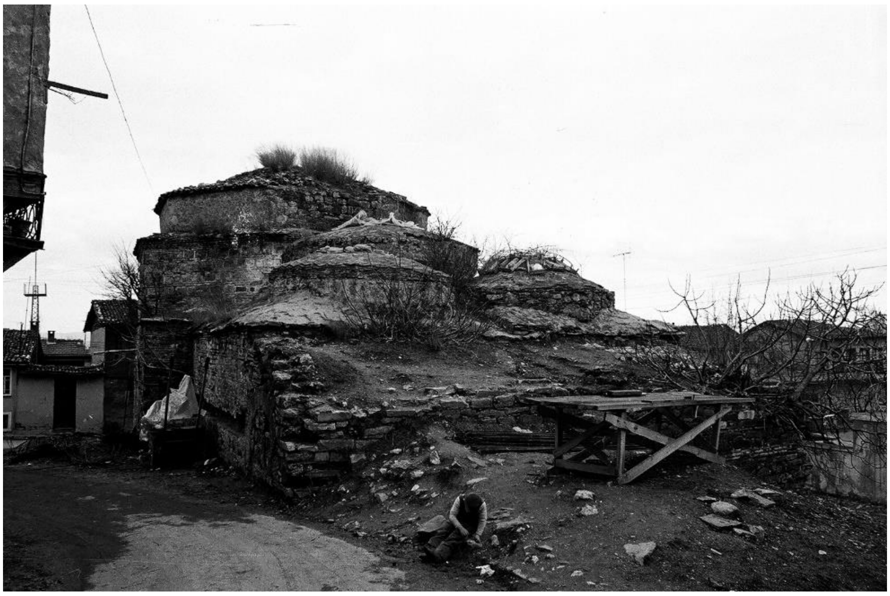


Figure D.8. The demolished boiler room of the Muradiye Hammam in 1975.
(Source. Inventory of General Directorate for Foundations, 1975)

Figure D.9. The entrance facade of the Muradiye Hammam in 2007.
(Source. Bursa-CNHPRB, 2007)

(a) (b)

Figure D.10. The appearance of the boiler room of the Muradiye Hammam in 2007.
(Source. Bursa-CNHPRB, 2007)

(a) (b)

Figure D.11. The appearance of the boiler room of the Muradiye Hammam in 2008.
(Source. Bursa-CNHPRB, 2008)

Figure D.12. The appearance of the boiler room of the Muradiye Hammam in 2014.
(taken by the author)

4. Muradiye Tombs

Figure D.13. View from tombs in the Muradiye Complex
(Source. Gabriel, 1958)

4.1. Tomb of Murad the Second

Figure D.14. View of the Tomb of Murad the Second tombs (unknown date)
(Source. Inventory of General Directorate for Foundations)

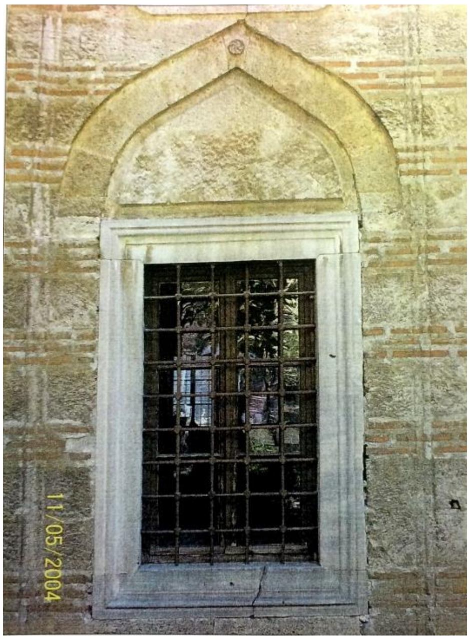
4.2. Tomb of *Şehzade* (Prince) Ahmet

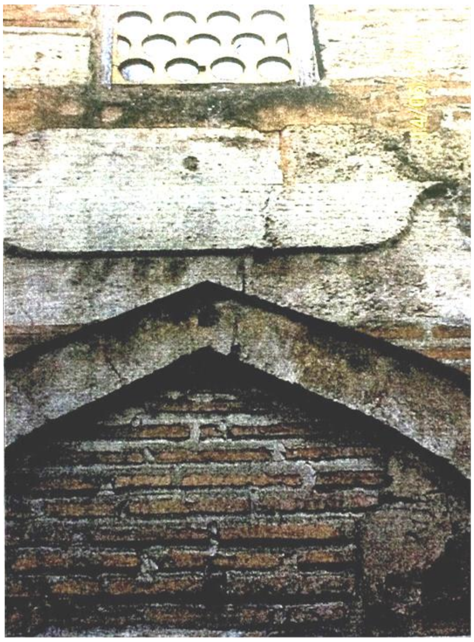
Figure D.15. The photo showing damp stain, soiling and blackening on the moulding and the facade
(Source. Bursa-CNHPRB, 2004)

(a) (b)

Figure D.16. Both (a) and (b) showing the wooden window shutter of the tomb.
(Source. D2 Tasarım Mimarlık, 2010)

4.3. Tomb of *Şehzade* (Prince) Mustafa





(a) (b)

Figure D.17. Both (a) and (b) show the cracks in different parts of the building, especially around the windows.
(Source. Bursa-CNHPRB, 2004)

Figure D.18. Material loss was seen in the arch pediment of the window.
(Source. D2 Tasarım Mimarlık, 2010)

4.4. Tomb of Cem Sultan

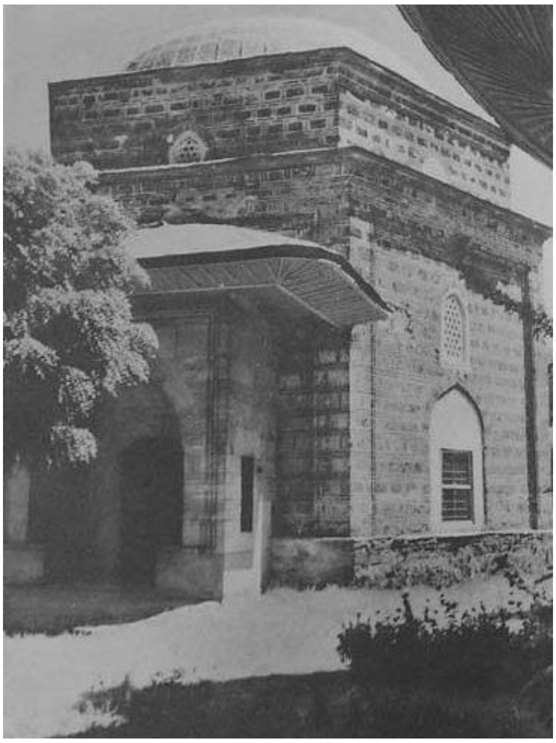


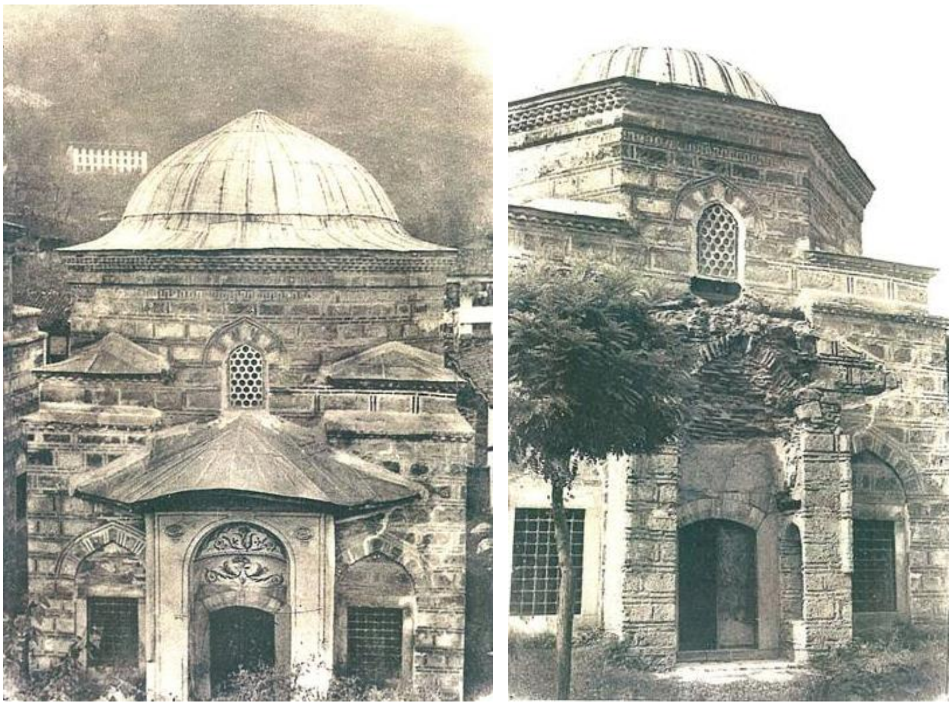
Figure D.19. The entrance facade of the tomb (unknown date).
(Source. D2 Tasarım Mimarlık – Restitution Report, 2010)

Figure D.20. The state of the entrance *iwan* and canopy in (a) 2004 and in (b) 2010.
(Source. (a) Bursa-CNHPRB, 2004 ; and D2 Tasarım Mimarlık, 2010)

Figure D.21. Material loss and installation of substitute materials leading to visual change in the wooden door.
(Source. Bursa-CNHPRB, 2004)

Figure D.22. Deformed lead sheets covering the entrance canopy.
(Source. D2 Tasarım Mimarlık, 2010)

4.5. Tomb of Şirin Hatun



(a) (b)

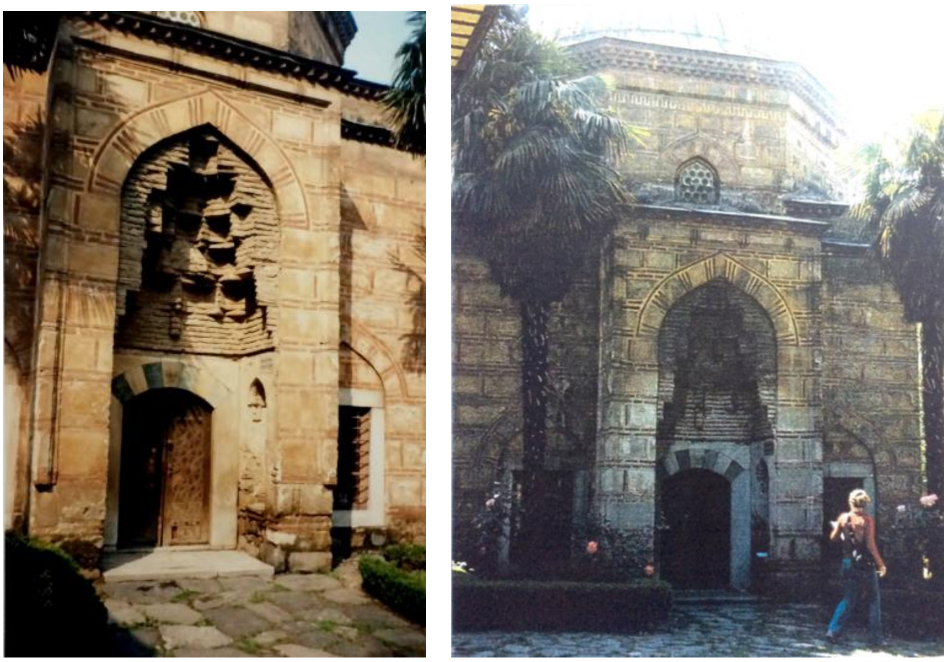
Figure D.23. (a) The state of the facade and the canopy, which was built in the Baroque style in the third quarter of the nineteenth century. (b) The canopy was removed and *iwan* were repaired (unknown date - before 1958)
(Source. D2 Tasarım Mimarlık - Restitution Report, 2010)

Figure D.24. The photo showing spalled plaster, blackening and deformed lead sheets over the eaves.
(Source. D2 Tasarım Mimarlık, 2010)

(a) (b)

Figure D.25. The photos showing the state of (a) the half-dome muqarnas hood (*kavsara*) and (b) the niche of the entrance portal.
(Source. D2 Tasarım Mimarlık, 2010)

4.6. Tomb of Gülruh *Sultan*



(a) (b)

Figure D.26. The photos showing the state of the entrance iwan in (a) 1996 and (b) 2004.
[Source. (a) Directorate of Bursa Museum, 1996; and Bursa-CNHPRB, 2004]

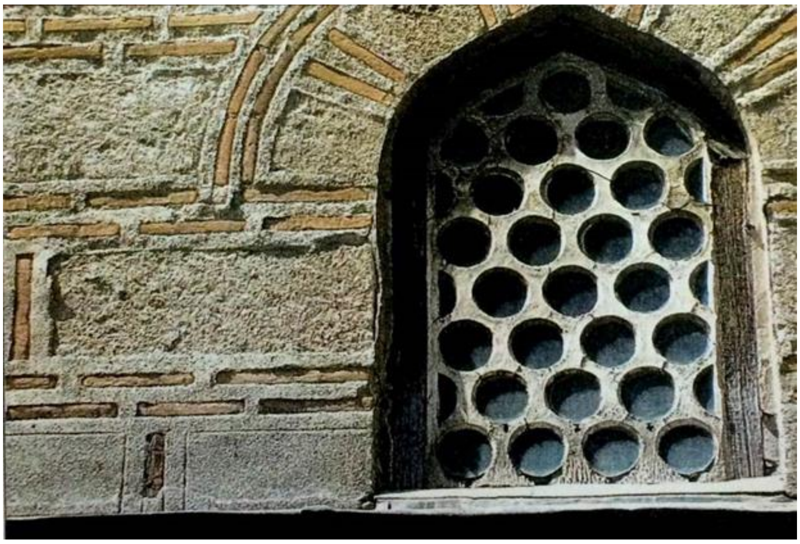


Figure D.27. The photo showing the poor repointing and the deformed gypsum-framed window *(dışlık)*.
(Source. Bursa-CNHPRB, 2004)

4.7. Tomb of Gülbahar *Hatun* (Ebe - Obstetrician Lady)

(a) (b)

Figure D.28. The photos showing (a) material losses in the arches and (b) deformed bonding timber in between arches.
(Source. D2 Tasarım Mimarlık - Survey Report, 2010)

4.8. Tomb of *Şehzade* (Prince) Mahmut

Figure D.29. The entrance portico of the Tomb of *Şehzade* (Prince) Mahmut (before 1950)
(Source. D2 Tasarım Mimarlık- Restitution Report, 2010)

4.9. Tomb of Mükrime *Hatun*

(a) (b) (c)

Figure D.30. (a) The state of the facade and the canopy, which was built in the Baroque style in the third quarter of the nineteenth century. (b) The canopy was removed (unknown date - before 1958). (c) The portal was repaired (unknown date- before 2012).
[Source. (a) and (b) D2 Tasarım Mimarlık - Restitution Report, 2010; (c) Governorship of Bursa]

(a) (b)

Figure D.31. The both photos showing the state of the facades: spalled plaster, blackening and deformed lead sheets.
(Source. Bursa-CNHPRB, 2004)

4.10. Tomb of Hüma *Hatun*

Figure D.32. The wooden door, which was embellished with rosettes, lost its original state due to being painted several times.
(Source. D2 Tasarım Mimarlık, 2010)

4.11. Tomb of *Saraylılar*

Figure D.33. The north facade of tomb showing the blackening (unkonown date-before 2012)
(Source. Governorship of Bursa)

Figure D.34. The photo showing the eroded brick and stone courses due to cement-based mortar and plaster, and the formation of fungi from bottom to the top of the piers due to dampness.
(Source. D2 Tasarım Mimarlık, 2010)

4.12. Tomb of Gülşah Hatun

Figure D.35. The photo showing the eroded brick and stone courses in the half-dome muqarnas hood (*kavsara*) of the portal.
(Source. D2 Tasarım Mimarlık, 2010)

Figure D.35. The wooden door, which was produced with *kündekari* technique, decayed excessively. Its lock / hinge rails and stiles were destroyed. Metal parts were lost.
(Source. D2 Tasarım Mimarlık, 2010)

CURRICULUM VITAE

PERSONAL INFORMATION

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EDUCATION

Degree	**Institution**	**Year of Graduation**
M.Sc. in Architecture	METU	2008
BArch in Architecture	METU	2005

PROFESSIONAL EXPERIENCE

Year	**Place**	**Enrollment**
2015-	TİKA	Deputy Coordinator
2013-2015	TİKA	Expert
2010-2013	Pamukkale University	Instructor
2007-2010	MoEU	Architect

PUBLICATIONS

International Conference Publications:

Başkan, E. G. and Elias-Ozkan, S.T. (2012). Adding the climate change dimension to the protection of tangible cultural heritage, "International Conference on Cultural Heritage Protection in Times of Risk: Challenges and Opportunities". Istanbul Yıldız Technical University- ICOMOS ICORP International Symposium, 15-17 November 2012.

Baskan, E. G. and Elias-Ozkan, S.T (2010) "The Role of Architectural Heritage in the Rural Built Environment: A Case Study in Kayseri", 1. International Graduate Research Symposium on the Built Environment, ODTÜ, ANKARA, 1.Cilt, pp. 143-148.

Baskan, E. G. (2007) "Approaches on Rural Planning in Turkey and an Experience: Village-City Project", The Accessibility and Attractiveness of Rural and Landlocked Areas: Sustainable Transport and Services of General Interest Conference, Council of Europe Conference of Ministers Responsible for Spatial/Regional Planning (CEMAT) High-Level Officers Committee, Andorra La Vella / Andorra, No:87, pp.117-123.

HONORS AND AWARDS

2014	Planning, Urban Management and Heritage (PUMAH) Project (EU - FP7- PEOPLE-2011-IRSES) – Scholarship
2012	DAAD (The German Academic Exchange Service) Scholarship International Summer Academy: Constructing Heritage in the Light of Sustainability (ISAC)- Cottbus/Germany
2005	Prosteel Steel Construction Plastic Art Gallery Student Competition - Encouragement Award
2005	METU High Honour Medal

CONFERENCES/WORKSHOPS ATTENDED

Nov 2012	International Conference on Cultural Heritage Protection in Times of Risk: Challenges and Opportunities
Feb 2012	1st International Green Building Summit, Istanbul
July 2012	International Summer Academy: Constructing Heritage in the Light of Sustainability (ISAC)- Cottbus/Germany
Oct 2010	1st International Graduate Research Symposium on the Built Environment
June 2010	EU FP7 Project: MonumentsLab – 206710 / Improvement of the METU-Research Laboratory for the Care and Conservation of Historic Monument Workshop II and Training Field Studies at Nemrut Mountain (UNESCO WHS) - Ankara – Adıyaman / Turkey
Sep 2009	European Cities and Global Climate Challenge Conference - Sweden / Stockholm - Delegate of the Ministry of Environment and Urbanization
April 2009	In-situ survey and round-table discussions on “Village Design Statements” and “Planning Approaches in UK” - United Kingdom / Gloucestershire - Delegate of the Ministry of Environment and Urbanization
Mar 2009	5th World Water Forum - Istanbul / Turkey - Delegate of the Ministry of Environment and Urbanization
Jan 2008	UN Third Regional Implementation Meeting on Sustainable Development and Africa (RIM-3) - Switzerland / Geneva - Delegate of the Ministry of Environment and Urbanization
2008	Workshop Series of Regional Environmental Center (REC) – Ankara / Turkey - Delegate of the Ministry of Environment and Urbanization
Nov 2007	Istanbul Launch of UNDP’s Global Human Development Report 2007-2008 “Fighting Climate Change: Human Solidarity in a Divided World” –Istanbul / Turkey - Delegate of the Ministry of Environment and Urbanization
Oct 2007	The Accessibility and Attractiveness of Rural and Landlocked Areas: Sustainable Transport and Services of General Interest Conference / Council of Europe Conference of Ministers Responsible for Spatial/Regional Planning (CEMAT) - Andorra / Andorra La Vella
Sep 2007	Landscape and Rural Heritage Conference / CEMAT- Romania / Sibiu - Delegate of the Ministry of Environment and Urbanization

Sep 2007 European Heritage Day Symposiums: "New Legal Arrangements and Improvements about Conservation of Cultural Heritage", "The Historical Memories of the People Living in the World Heritage City: Safranbolu", "Development of Conservation Process and New Approaches for Conservation" and "Life in Safranbolu"- Safranbolu / Karabuk- Turkey - Delegate of the Ministry of Environment and Urbanization

RESEARCH INTERESTS

Cultural Heritage, Climate Change, Cultural Heritage Management, World Heritage, Cultural Heritage Conservation