PREPARATION OPPORTUNITIES OF SMART CITIES AGAINST DEADLY HEATWAVES

by

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ABSTRACT

PREPARATION OPPORTUNITIES OF SMART CITIES AGAINST DEADLY HEATWAVES

Due to the anthropogenic climate crisis, extreme heatwave events in Türkiye are expected to increase significantly. This study employs the Holiday Climate Index (HCI) in conjunction with HUMIDEX to assess Türkiye's future climatic comfort. For this purpose, the outputs of the MPI-ESM-MR global climate model (GCM) were downscaled to 50 km using the RegCM4.4 regional climate model. Subsequently, HCI and HUMIDEX values for the summer and spring seasons were computed for two future periods, 2021–2050 and 2070–2099, with respect to the reference period of 1971–2000 under two scenarios, RCP4.5 and RCP8.5. The findings revealed alarming increases in extreme heat events accompanied by dangerous HUMIDEX risks. To investigate further, this study further analyzed future extreme heatwaves using temperature-related extreme indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI). Outputs from two GCMs, MPI-ESM-MR and HadGEM2-ES, were downscaled to 50 km with RegCM4.4, and the indices were computed for 2071–2100 relative to 1971–2000 under RCP4.5 and RCP8.5. The results indicate that future heatwaves will be so severe and prolonged that they could lead to significant fatalities without smart precautions. This study finds the most promising solution in air-conditioned facilities, such as libraries, shopping malls, gyms which can function as cooling centers and accommodate solar panel installations on their rooftops to provide a safeguard in the event of a power outage.

ÖZET

ÖLÜMCÜL SICAK HAVA DALGALARINA KARŞI AKILLI ŞEHİRLERİN HAZIRLANMA OLANAKLARI

İnsan kaynaklı iklim krizi nedeniyle, Türkiye'de aşırı sıcak hava dalgası olaylarının önemli ölçüde artması beklenmektedir. Bu çalışma, Türkiye'nin gelecekteki iklimsel konforunu değerlendirmek için Holiday Climate Index (HCI) ile HUMIDEX'i birlikte kullanmaktadır. Bu amaçla, MPI-ESM-MR küresel iklim modeli (GCM) çıktıları, RegCM4.4 bölgesel iklim modeli kullanılarak 50 km ölçeğine indirgenmiştir. Ardından, 2021–2050 ve 2070–2099 dönemleri için yaz ve ilkbahar mevsimlerine ait HCI ve HUMIDEX değerleri, 1971–2000 referans dönemi ile karşılaştırmalı olarak, iki senaryo (RCP4.5 ve RCP8.5) kapsamında hesaplanmıştır. Bulgular, aşırı sıcak hava olaylarında tehlikeli HUMIDEX riskleriyle birlikte endişe verici bir artışa işaret etmektedir. Daha ayrıntılı bir inceleme yapmak amacıyla, çalışma ayrıca İklim Değişikliği Tespiti ve İndisleri Uzman Ekibi (ETCCDI) tarafından geliştirilen sıcaklıkla ilgili aşırı indisleri kullanarak gelecekteki aşırı sıcak hava dalgalarını analiz etmiştir. İki GCM'nin (MPI-ESM-MR ve HadGEM2-ES) çıktıları, RegCM4.4 ile 50 km ölçeğine indirgenmiş ve indisler 2071–2100 dönemi için, 1971–2000 referans dönemi ile karşılaştırmalı olarak, RCP4.5 ve RCP8.5 senaryoları kapsamında hesaplanmıştır. Sonuçlar, gelecekteki sıcak hava dalgalarının o kadar şiddetli ve uzun süreli olacağını göstermektedir ki, akıllı önlemler alınmazsa önemli can kayıplarına yol açabilir. Bu çalışma, en umut verici çözümü, kütüphaneler, alışveriş merkezleri ve spor salonları gibi soğutma merkezi olarak işlev görebilecek klimalı tesislerde bulmaktadır. Bu binaların çatılarında güneş panellerinin kurulumu önerilerek, elektrik kesintileri durumunda bir güvence sağlanması hedeflenmektedir.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	**Explanation**
CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous Oxide
O_3	Ozone
H_2O	Water

Abbreviation	**Explanation**
ANTEM	Antalya Metropolitan Municipality Education Center
AR4	IPCC Fourth Assessment Report, 2007
AR5	IPCC Fifth Assessment Report, 2014
AR6	IPCC Sixth Assessment Report, 2022
BCI	Beach Climate Index
CDO	Climate Data Operators
CID	Daily Comfort Index
CID	Daytime Comfort Index
CIT	Climate Index for Tourism
CFCs	Chlorofluorocarbons
DEM	Digital Elevation Model
ED	Emergency Department
ETCCDI	Expert Team on Climate Change Detection and Indices
GCM	General Circulation Model
GHG	Greenhouse Gas
GIS	Geographic Information System
GrADS	Grid Analysis and Display System
HadGEM2-ES	Hadley Centre Global Environment Model version 2 Earth System
HAPs	Heat Action Plans
HCI	Holiday Climate Index
Humidex	Humidity Index
ICT	Information and Communication Technologies
ICTP	The Abdus-Salam International Centre for Theoretical Physics
iklimBU	Boğaziçi University Climate Change Research Laboratory

IPCC	The Intergovernmental Panel on Climate Change
MAPE	Mean Absolute Percentage Error
MCIT	Modified Climate Index for Tourism
MGM	Meteoroloji Genel Müdürlüğü
MPI	Max Planck Institute
MPI-ESM-MR	Max Planck Institute Earth System Model Mixed Ratio
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NetCDF	Network Common Data Form
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
P	Precipitation
ppm	parts per million
PSA	Public Service Announcement
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RegCM4	Regional Climate Model 4
S	Sunshine
SRES	Special Report on Emissions Scenarios
SRTM	Shuttle Radar Topography Mission
SU25	Summer Days
TCI	Tourism Climate Index
TNn	Annual minimum of daily minimum temperature
TNx	Annual maximum of daily minimum temperature
TN10p	Cool Nights
TN90p	Warm Nights
TRNC	Turkish Republic of Northern Cyprus
TRT	Turkish Radio and Television Corporation
TR20	Tropical Nights
TUİK	Turkish Statistical Institute
TXn	Annual minimum of daily maximum temperature
TXx	Annual maximum of daily maximum temperature
TX10p	Cool Cays
TX90p	Warm Days
UHI	Urban Heat Island

UN	United Nations
UNEP	United Nations Environment Programme
W	Wind
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WSDI	Warm Spell Duration Index

1. INTRODUCTION

Anthropogenic climate change is one of the most significant problems that the Earth and human beings have ever encountered. Burning of fossil fuels, deforestation and other industrial processes lead to extensive greenhouse gas (GHG) emissions into the atmosphere which in return enhance the natural greenhouse gas effect and therefore cause global warming. Climate change affects the Earth and all livings in countless different ways. Some of these include melting of glaciers and rising sea levels, ocean acidification, change in precipitation patterns leading to droughts and floods therefore posing a threat for agriculture, impacts on biodiversity, social and economical impacts on several sectors such as tourism, health, energy, and most relevant to the subject of this study, rising temperatures and increased frequency of extreme heatwave events.

1.1. A Brief Overview to Anthropogenic Climate Change

Before focusing on the specific focus of this research, it is important to discuss the significance of climate change due to its complicated nature. After the beginning of the industrial revolution in 1750s, GHG emissions into the atmosphere have increased tremendously and many scientists from different disciplines have been interested in this research area. The warming effect of GHGs (the major ones are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and ozone (O_3)) in the atmosphere, was first discovered in 1827 by the French scientist Jean-Baptiste Fourier, who is mostly known for his contributions to mathematics. He was also the one who proposed the term 'greenhouse effect' by pointing out the similarities of radiative properties between the Earth's atmosphere and of the glass in a greenhouse. Figure 1.1 shows the schematic representation of natural greenhouse effect, which is actually essential for sustaining the life on Earth. While the gases nitrogen (N_2) and oxygen (O_2), which constitute most of the atmosphere with percentages of approximately 78% and 21% respectively, do not absorb or emit thermal radiation, the GHGs which have much smaller fractions in the atmosphere absorb some of the thermal radiation that is emitted from the surface of the Earth and re-emit some back in all directions. Thus GHGs act as a blanket therefore causing 20-30 °C difference between the actual average surface temperature on Earth and the surface temperature Earth would have if there were no greenhouses gases in the atmosphere (Houghton, 2009). The name 'natural' comes from the fact that all these GHGs except CFCs were in the atmosphere long before the history of human beings on Earth. The enhanced greenhouse effect on the other hand, is the additional effect of the intensively emitted GHGs into the atmosphere due to human activities since the industrial revolution, mostly by

burning of fossil fuels and deforestation (Houghton, 2009).

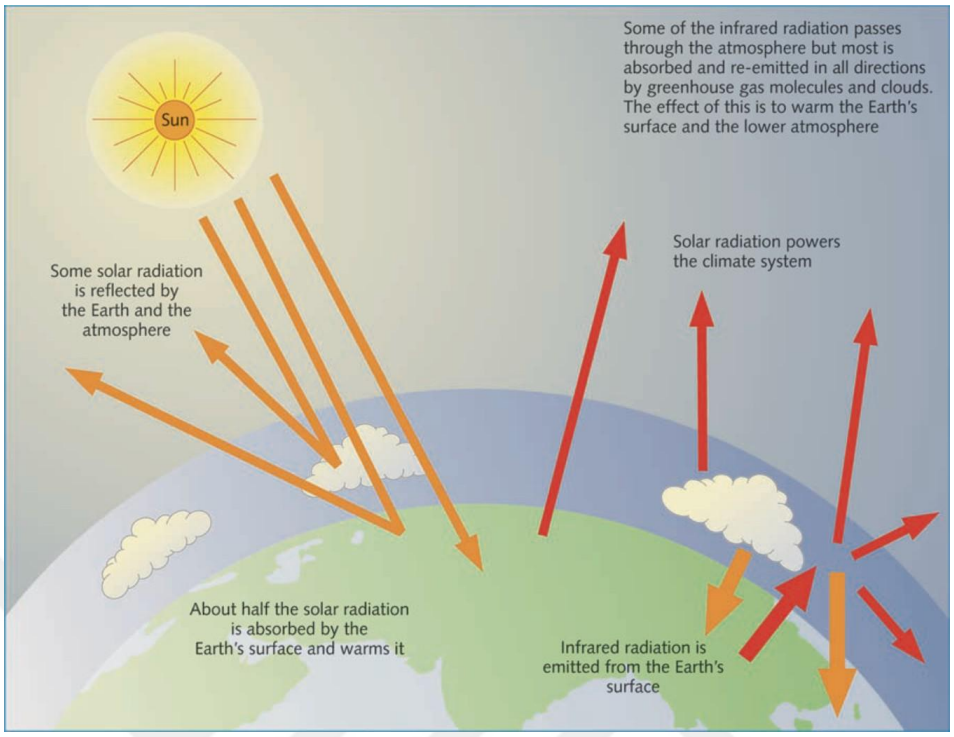

Figure 1.1 A schematic representation of natural greenhouse effect (Adopted from Houghton, 2009).

Even after accounting for natural fluctuations, the current atmospheric CO_2 concentrations, which is 420 parts per million (ppm) as of January 2024, has reached its highest levels of at least 800,000 years with an unprecedented speed (United States Environmental Protection Agency, 2023). While the CO_2 emissions account for about three fourths of total GHG emissions, the extensive accumulation of GHGs in the atmosphere leads to climate forcing, which refers to a disruption of Earth's energy balance. In our case, a positive climate forcing, meaning more energy is entering Earth compared to the energy leaving Earth, resulting in global warming. Although Earth has warmed and cooled before, went through ice ages and warm episodes (inter-glaciers), however, the problem we are facing today is that this has never happened with this speed before. Therefore, neither species, environment nor cities, countries have much time to adapt to this rapid human-induced climate change. Even the species that have the ability of tracking their preferred climate by migrating will keep facing different abiotic and biotic conditions under this fast transition (Anderson et al., 2012). Figure 1.2 shows the atmospheric CO_2 over 800,000 years and throughout this history the highest previous was only 300 ppm. Over the last 60 years, the increase is found to be 100 times faster than the previous natural increases and this increase from the end of the last ice age may be regarded as instantaneous on the geological time scale.

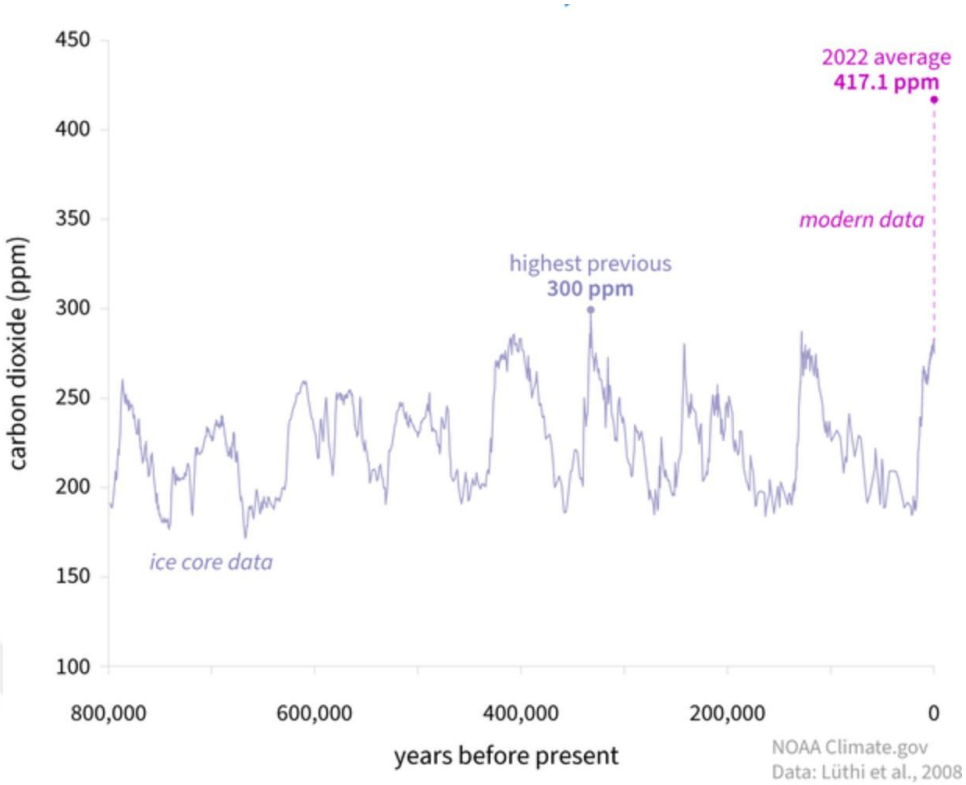

Figure 1.2. Atmospheric CO_2 in ppm for the past 800,000 years according to ice-core data, represented with light purple, compared with the unprecedented increase during the last century and 2022 average, represented with bright purple dot. Adopted from NOAA climate.gov based on data from Lüthi et al., 2008.

Intergovernmental Panel on Climate Change (IPCC), established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988, is the main body for assessing the science related to climate change. By collaborating with many scientists, IPCC prepares comprehensive Assessment Reports that explain the state of scientific knowledge on climate change, the future impacts and risks that could be expected according to the level of increase in temperature at the end of the century as well as offering options to slow the rate of climate change for policy makers. Their most up to date report, Sixth Assessment Report (AR6), has been finalized in March, 2023 and it is stated with *high confidence* (about 8 out of 10 chance) in this report that principally through emissions of GHGs, human activities have unequivocally caused global warming, with global surface temperature in 2011-2020 rising 1.1°C more than the value it had in 1850-1900 as shown in Figure 1.3 (IPCC, 2023). Unsustainable energy use, land use and land use change, lifestyles and consumption patterns of individuals, production patterns across regions and countries have caused global GHG emissions to increase tremendously as depicted in Figure 1.4 and almost all of this increase is attributable to human activities (IPCC, 2023).

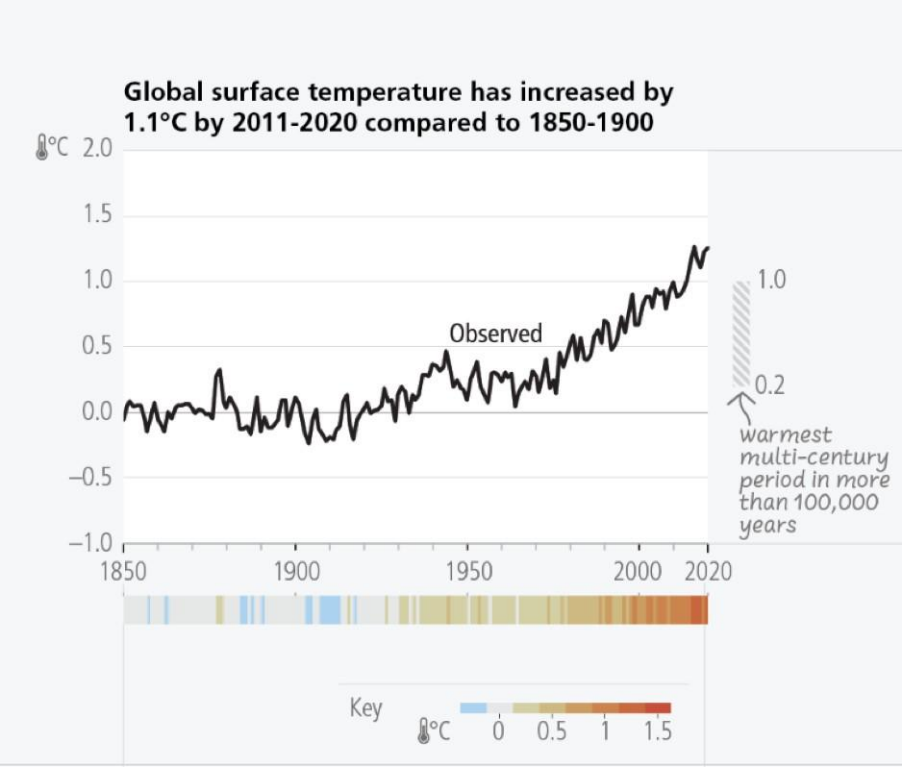

Figure 1.3. The increase in global surface temperature in 2011-2020 with respect to 1850-1900. Adopted from IPCC, 2023.

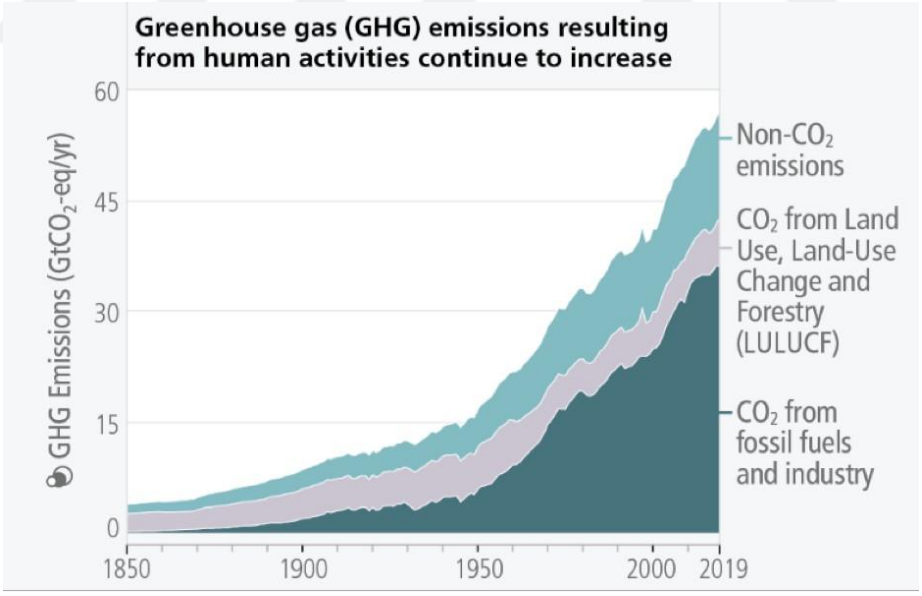

Figure 1.4. The increase in GHG emissions due to human activities since 1850. Adopted from IPCC, 2023.

The energy budget of Earth represents the balance between the radiant energy incoming to Earth from the Sun and the thermal energy outgoing from Earth back to space. When the incoming energy is higher than the outgoing energy, the Earth has no other option but to warm up. Figure 1.5 shows the schematic representation of the Earth's energy budget considering the climate conditions of early

21st century. According Wild and colleagues, (2015), the incoming radiation from the Sun to Earth's atmosphere is found to be 340 W/m^2. About 100 W/m^2 of this solar short-wave radiation (with an uncertainty range 97 to 100 W/m^2) is reflected from the atmosphere, about 80 W/m^2 (with an uncertainty range 75 to 89 W/m^2) is absorbed by the atmosphere and the remaining half of this solar radiation is absorbed by the Earth's surface. With evapotranspiration and longwave radiation, the absorbed energy by Earth's surface is transferred to the atmosphere by heating the air in contact with the surface. The atmosphere radiates longwave energy back to Earth because of the GHGs as well as back out to the space. Figure 1.5 shows the energy imbalance to be 0.7 W/m^2 (with an uncertainty range 0.5 to 0.9 W/m^2). Although this value is only a small fraction of the incoming solar radiation, the presence of this energy imbalance of Earth occurs every second of every day throughout the year.

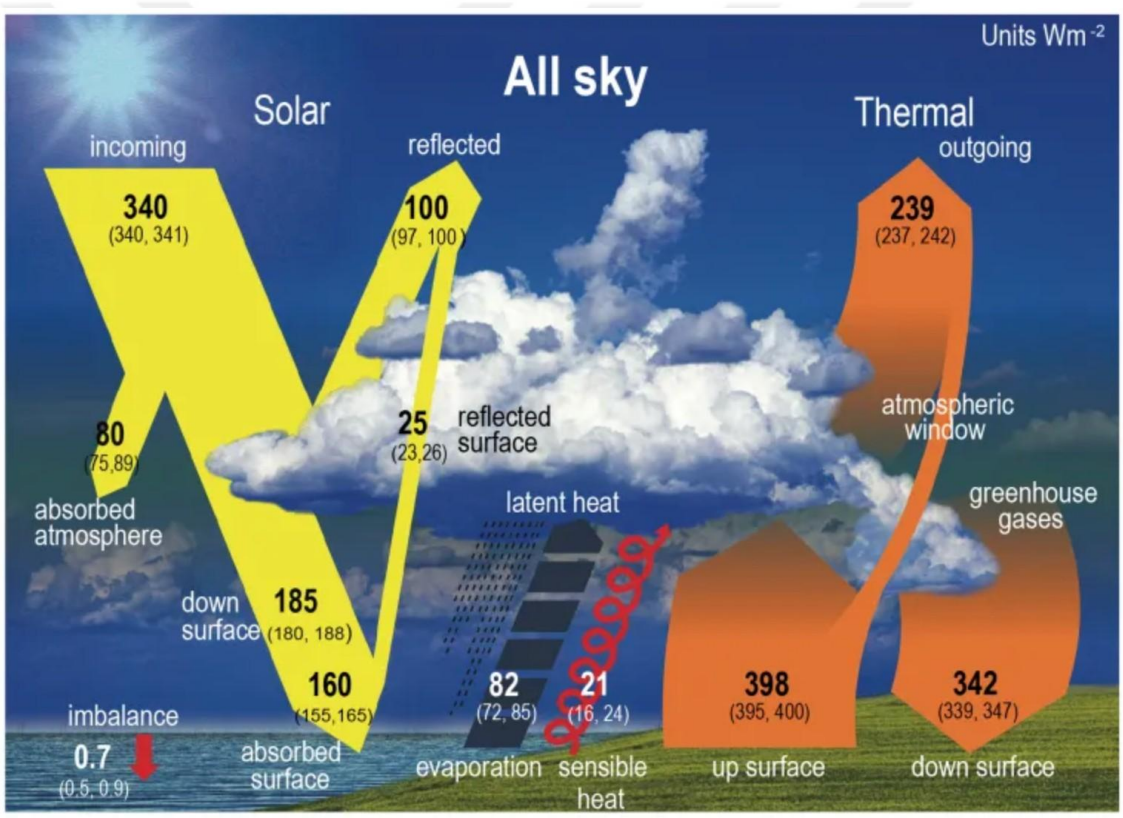

Figure 1.5. Schematic representation of the global incoming and outgoing radiation averages of the Earth for the early 21st century. Numbers show the best estimates of global mean energy balance components in W/m^2 and their uncertainty ranges are given in parentheses (5–95% confidence range). Adopted from Wild et al., 2015.

There are several key terms in the literature to better understand the climate change and its impacts. IPCC defines one such term, risk, to be the potential for adverse consequences for human or ecological systems, which could be on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure and services, ecosystems and species, that can arise

from potential impacts or human responses to climate change. Another term, vulnerability, is defined to be the propensity or predisposition to be adversely affected from climate change and its impacts while exposure refers to the presence of people, livelihoods, ecosystems and species, services, resources, infrastructure, economic, social and cultural assets that could be adversely affected from climate change and its impacts (IPCC, 2022). Another term frequently mentioned in the literature is resilience and its definition is given as in case of a disaster or a hazardous event the capacity of social, economic and ecological systems to cope with and maintain their fundamental function while leaving room for adaptation and/or transformation (Arctic Council, 2016).

Adaptation, which has crucial importance for the purposes of this study and also for any country which is under risks of extreme impacts of climate change, is defined to be the process of adjustment to expected climate change and its impacts in pursuance of moderating the harm and/or exploiting beneficial opportunities (IPCC, 2022). Some structural, institutional, ecological or behavioral strategies and measures to address adaptation may include public health measures, disaster risk management, technological improvements such as smart grid technology or better communication technologies, early warning systems, energy efficiency measures, renewable energy integration, demand response programs, resilient infrastructure planning and improvements to the existing infrastructure, improvements in agricultural area for food security, community engagement and education, and better climate policies in accordance with future climate forecasts through the use of high resolution climate models (Austin, 2019; Turek-Hankins, 2021). Mitigation, on the other hand, refers to all actions and global efforts to reduce or prevent GHG emissions and to enhance carbon sinks in order to minimize the adverse impacts of human activities on the climate as well as ecosystems. Some strategies that address adaptation can also account for mitigation such as renewable energy integration, smart grid implementation to enhance energy efficiency, sustainable agriculture practices, educational initiatives for community, and infrastructural design and planning. Other measures for mitigation in the context of climate change and environmental issues may include afforestation and reforestation to enhance natural carbon sinks, carbon capture and storage practices to prevent its release into atmosphere, waste management practices to minimize methane emissions, and expansion and improvement of public transportation while promoting active transportation (Fawzy, 2020).

Adaptation and mitigation are the most crucial components of global efforts to tackle the anthropogenic climate change and to achieve a more sustainable and resilient future. Through sustainable practices and by adopting environmentally friendly technologies, individuals, communities, businesses, governments and countries can contribute to adaptation and mitigation.

Figure 1.6 represents an integrated framework of anthropogenic climate change with a complete cycle of cause and effect relations (Houghton, 2009). Starting from the box of human systems, which shows small and large scale economic activities of both developed and developing countries, it can be seen that all kinds of activities for socio-economic development cause emissions: The next box in the clockwise direction lead to the increases in GHG concentrations and aerosols, which can cause radiative forcing directly through scattering and absorbing radiation and indirectly by acting as cloud condensation nuclei or ice nucleating particles that affect the properties of clouds (IPCC, 2022). Increased GHG concentrations then alter the energy input and output of Earth and therefore cause changes in the climate system. The following box in the framework indicates that changing climate has impacts on humans in terms of resource availability, food security, health and also human livelihood by affecting the settlements society and natural ecosystems. Returning to the first box again, all these changes affect human development in every aspect. Possible improvements in global emissions and development pathways which could reduce the risks of future climate change impacts are represented by the anticlockwise arrows (Houghton, 2009). Here in the same figure, the adaptation and mitigation efforts that can change all these causes and effects are also shown.

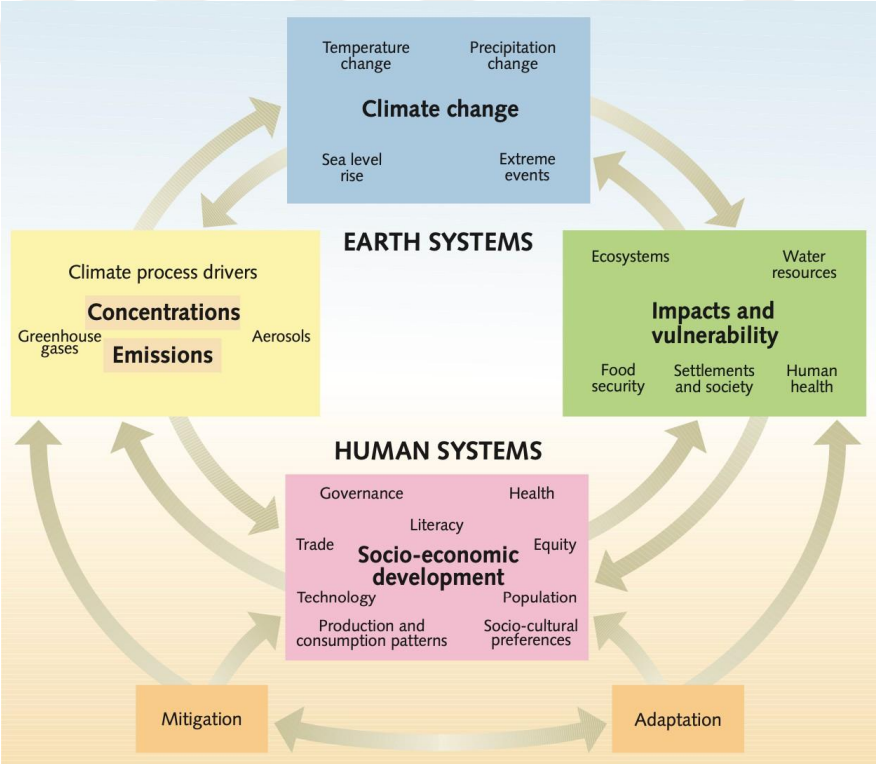

Figure 1.6. An integrated framework of climate change. Adopted from Houghton, 2009.

1.2. Climate Modeling

Understanding and predicting climate change have gained importance and developed an increased sense of urgency as a result of the climate-related difficulties people are facing. Since the beginning of increased need in this research area, computer simulations of global circulation models (GCMs) have been primary and principal tools of climate science (Edwards, 2010). GCMs are numerical models that describe the processes in the atmosphere, the ocean, the cryosphere and on the land surface based on several inputs, such as air temperature, pressure, density, water vapor content and wind magnitude. Their calculations employ fundamental mathematics and physics equations that are given as follows (Houghton, 2009):

- The horizontal momentum equations by Newton's Second Law, which account for the horizontal acceleration of a volume of air due to Coriolis acceleration, that is balanced by the horizontal pressure gradient and the friction.
- The hydrostatic equation which accounts for the pressure of a point due the mass of the atmosphere above that point.
- The continuity equation for conservation of mass.
- The equation of state which gives the relations between pressure, volume and temperature of the atmosphere.
- The thermodynamic equation accounts for the conservation of energy.
- Parameterization of moist processes (including evaporation, condensation, formation and dispersal of clouds).
- Parameterization of absorption, emission, reflection of solar and thermal radiations.
- Parameterization of convective processes, exchange of momentum, heat and water vapor on the surface.

Most of these equations in GCMs are differential equations, which means that they can give information about how quantities, such as ground surface temperature, surface pressure, air temperature, specific humidity in air, etc. change with respect to time and location if the rate of change at a given time is known. Because of the nonlinearity and coupling of these processes, iterative methods, in other words by constant repetition of this process, are used to estimate future values of required quantities, demonstrating the models' predictive powers (Houghton, 2009).

By using a three-dimensional grid over Earth, GCMs project the climate with a horizontal resolution of about 250 to 600 km, 10 to 20 vertical layers in the atmosphere and up to 30 layers in the oceans (IPCC, 2002). GCMs are constantly being updated by several modelling groups which

incorporate higher spatial resolution together with new physical processes, biogeochemical cycles and feedback loops (Carbon Brief, 2019). These modelling groups coordinate their updates according to the schedule of IPCC assessment reports. These collaborative endeavors are part of the Coupled Model Intercomparison Projects (CMIP). CMIP is a global initiative which involves a collection of GCMs developed by several research institutions worldwide with the purpose of advancing climate research and understanding by simulating the climate system and providing projections of future climate under different GHG emission scenarios. The 2013 IPCC fifth assessment report (AR5) featured climate models from CMIP Phase 5 (CMIP5) which employed IPCC's Representative Concentration Pathways (RCPs) as their emission scenarios while AR6, published in 2021, featured most up to date CMIP Phase 6 (CMIP6) models which employed new emission scenarios called Shared Socioeconomic Pathways (SSPs). These scenarios are necessary for future projections of climate models to provide a prediction of how humankind will respond to climate change through technological advancements, changes in lifestyles and policies. Since the projections run for this dissertation was completed before the publication of AR6, RCPs were used as emission scenarios in this study.

The RCPs are a set of four pathways named after their radiative forcing target values by the year 2100 as represented in Table 1.1. These scenarios are the product of a strong collaboration between modelers of climate, terrestrial ecosystem, integrated assessment and experts of emission inventory (Van Vuuren et al., 2011).

Table 1.1. An overview of Representative Concentration Pathways. Adopted from Van Vuuren et al., 2011.

Scenario	**Description**
RCP2.6	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_2 eq) before 2100 and then decline to 2.6 W/m^2 by 2100
RCP4.5	Stabilization without overshoot scenario to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100
RCP6	Stabilization without overshoot scenario to 6 W/m^2 (~850 ppm CO_2 eq) at stabilization after 2100
RCP8.5	Rising radiative forcing scenario leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100

The coarser grid resolution of GCMs restrains their applicability to climate assessments at the regional and local scales. The coarser grid size of GCMs does not account for some regional features such as topography, cloud, land use, etc., which have significant effect on the regional climate (Coulibaly et al., 2005; Koukidis and Berg, 2009). To be able to deal with this scale mismatch, scientists developed Regional Climate Models (RCMs). With the nestling of a higher resolution RCM within a GCM, higher resolution climate projections are obtained by dynamical downscaling. In other words, RCMs add further details to global climate simulations as represented in Figure 1.7, allowing more detailed climate process analysis and vulnerability, impact, adaptation assessments. Although GCMs simulate the climate with increasingly higher resolutions, the development of RCMs for more than 30 years has allowed higher resolution both in time and space as well as increased model simulation lengths up to centennial scales. The strategy behind the dynamical downscaling technique that RCMs employ is that while the GCMs outline the response of the global circulation to large scale GHGs or solar radiation forcings, RCMs spatially and temporally refine this information provided by the GCMs by accounting for sub-GCM grid scale forcings such as topography, coastlines, inland water bodies or dynamical processes at mesoscale (Giorgi, 2019).

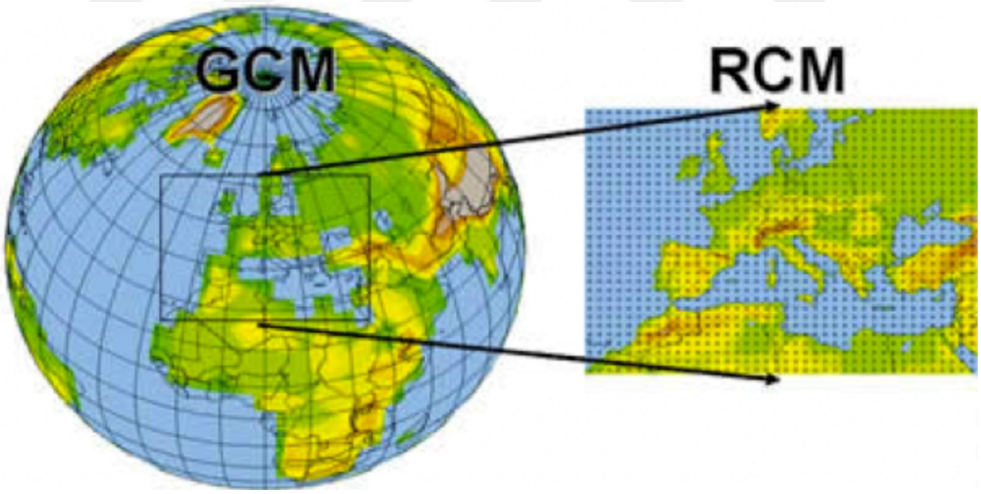

Figure 1.7. Schematic representation of regional climate modelling. Adopted from Giorgi, 2019.

The Coordinated Regional Downscaling Experiment (CORDEX) is an international project supported by the World Climate Research Programme (WCRP) with the aim of organizing and coordinating a framework to produce coordinated sets of regional downscaled projections for every continental area across the globe. The main goals of CORDEX project are to better understand regional climate phenomena as well as their variability through downscaling, to provide a framework for evaluating and improving regional climate downscaling models and techniques, to faster communication and knowledge by providing an interface for users of climate simulations on impact, mitigation or adaptation to climate change studies (Giorgi, 2006).

1.3. Purpose of This Study

Since climate change is such an intricate and multifaceted field of study, many disciplines are deeply interconnected. This interconnectedness often means that while focusing on one specific area, insights or findings relevant to another field may naturally emerge. This dissertation is a product of such case, where the exploration of one topic provided valuable perspectives on another, enriching the overall research scope.

During the last 30 to 50 years, many countries and cities around the world have faced an alarming increase in the frequency and intensity of extreme heatwave events. These events have tragically resulted in thousands of fatalities, severely affecting public health and economic stability. However, the advent of smart city technologies and adaptive urban planning has allowed some regions to mitigate the worst impacts of such crises. By implementing protective measures, these forward thinking cities have significantly reduced mortality rates during subsequent heatwave events. Their experience underscores the critical importance of preparation and innovation in addressing the escalating challenges posed by climate change.

Türkiye, a country uniquely located at the crossroads of Europe and Asia, experiences four distinct seasons, characterized by hot summers and cold winters. The nation is renowned for its diverse climatic conditions and abundant natural beauty, which attract millions of tourists each year. Among its many attractions, the “sea, sand, and sun” tourism of the Mediterranean and Aegean regions stands out as a vital contributor to the country’s economy. However, climate change poses an existential threat to this sector. Numerous studies have consistently projected that Türkiye will experience hotter and drier conditions in the coming decades (Turkes et al., 2000; Kuglitsch et al., 2010; Erlat et al., 2021). Such changes not only threaten the ecological balance but also carry profound implications for tourism—a key pillar of the national economy.

This dissertation begins by examining the future climate conditions in Türkiye and their potential impact on recreational and touristic activities. Utilizing advanced climate models and data-driven analyses, the findings reveal alarming trends. High temperatures combined with increased humidity levels paint a grim picture for the future, raising serious concerns for both human comfort and safety. These findings suggest that without timely intervention, future extreme heat events could result in the loss of thousands of lives, alongside economic and social disruptions.

To substantiate these conclusions, the study continues deeper into the projected changes in extreme temperature events across Türkiye. This secondary investigation not only corroborates the initial findings but also highlights the severity and widespread nature of future heat extremes. By understanding these patterns, the research establishes a robust foundation for proposing effective mitigation and adaptation strategies.

Recognizing the urgent need for solutions, this dissertation delineates its focus to exploring global examples of smart cities and their innovative approaches to climate challenges. Smart cities worldwide have demonstrated remarkable resilience by integrating technology, urban planning, and community participation to tackle extreme weather events, including deadly heatwaves. By studying their strategies, this research identifies key principles and practices that can be adapted to the unique socioeconomic and climatic context of Türkiye.

Finally, the dissertation outlines specific smart solutions tailored to address the future threat of extreme heatwaves in Türkiye. These recommendations include urban heat island mitigation strategies, enhanced green infrastructure, advanced warning systems, and community based interventions. The proposed measures aim not only to save lives but also to build long term resilience against the escalating impacts of climate change. In doing so, this study contributes to a broader understanding of how nations like Türkiye can safeguard their people and economies while adapting to an increasingly hostile climate.

2. LITERATURE REVIEW

2.1. Extreme Heatwaves Due To Human Induced Climate Change

Extreme weather events such as heatwaves, droughts, heavy precipitation, hurricanes, coastal floods, etc., have always posed risks for human civilization. However, along with increasing human induced GHG emissions, the patterns of extreme weather events have changed. Several studies with a substantial body of evidence showed that human-induced climate change caused discernible and quantifiable changes in the intensity and/or frequency of extreme events (Seneviratne et al., 2012; Donat et al., 2013a), especially the temperature and precipitation extremes (Fischer et al., 2013). Several studies addressed the issue with climate simulations (Orlowsky and Seneviratne, 2012; Kharin et al., 2013; Sillmann et al., 2013b) and future precipitation extremes are found to be more ambiguous compared to the temperature extremes, although there are some robust findings such as increasing dryness in Mediterranean region or increasing heavy precipitation in Northern high latitudes. Since the Earth is warming, the duration and frequency of extreme heatwaves are expected to increase for several countries in the future, even with the commonly discussed global 2 °C warming target (Orlowsky and Seneviratne, 2012). Although there are several definitions of a heatwave in the literature, the most common definition is consecutive exceptionally hot days with air temperatures higher than a given relative or absolute threshold (Perkins and Alexander, 2013). Extreme heatwaves attract more attention than other extremes since they are the most obtrusive reason of weather related human mortality, morbidity and hospitalizations (Muthers et al., 2017). Other than causing wildfires, they also have negative impacts on agriculture, power generation and infrastructure performance (Erlat et al., 2021), water supply, transportation (Smoyer-Tomic et al., 2003), retail industry, ecosystem services and tourism (Ciais et al., 2005). This year in 2024, Scientific American reported that extreme heat is the deadliest weather related disaster, having claimed the lives of 489,000 individuals since 2000. Additionally, it is responsible for approximately 18,970 deaths each year among workers who are exposed to high temperatures Scientific American, 2024).

One of the most catastrophic extreme heatwave events occurred in Europe in 2003. It mostly affected Western Europe, including France, Italy, Spain, Portugal, Germany, and the United Kingdom. The probability of occurrence of a heatwave in Europe with a similar severity to that of summer of 2003, which caused USD 10 billion economic loss and 70,000 heat related deaths, most of which were elderly (García-Herrera et al., 2010), is estimated to have doubled due to the increase in anthropogenic GHGs (Schar et al., 2004). Other than the elderly, it was estimated that the 2003

heatwave has caused an increase of a few tens of thousands premature deaths (Mitchell et al., 2006). Other extreme heatwave events have also occurred in Europe in the past. For example, 1976 heatwave affected mostly Western Europe, especially the United Kingdom, France, Italy and Spain causing thousands of excess deaths which refer to the number of fatalities during a heatwave that exceed the usual number of deaths under normal conditions. Excess deaths include the deaths that are directly attributable to the heatwave and those indirectly related to the heatwave, such as exacerbation of pre-existing medical conditions, overcrowding in hospitals. In the case of the 1976 heatwave in Western Europe, excess deaths were again principally among the elderly and vulnerable populations. The UK experienced 15 consecutive days with temperatures exceeding 32.2 °C and then 5 more days with temperatures reaching 35 °C (Russo et al., 2015). This event was particularly memorable since it also caused exceptionally persistent and severe drought over most of the British Isles. Another extreme heatwave event in 2006 affected Southeastern Europe, primarily the Balkans and Greece, with hundreds of mortalities especially among the elderly and those with pre-existing health conditions (Russo et al., 2015). In summer 2019, two record breaking extreme heat events hit Western Europe, with temperatures exceeding the historical records by more than a degree in many locations, causing the deaths of several thousand people (Vautard et al., 2020). It is important to specify that heatwaves have indirect effects on health besides deaths, such as aggravating existing medical conditions of people, therefore it is difficult to precisely quantify the total effect.

While the 2003 heatwave in Europe is considered to be the second strongest of the observational period (Barriopedro, 2011; Christidis et al., 2015), the 2010 Russian heatwave is regarded as by far the worst extreme heatwave event in Europe since at least 1950 in terms of both the duration and severity (Russo et al., 2015). The event resulted in 55,000 heat related fatalities and more than 600 wildfires, whose smoke also had negative implications on human health (Rahmstorf and Coumou, 2011). Moscow suffered from temperatures exceeding 30 °C for 33 consecutive days (L. Alexander, 2010). While this major event caused an estimated 55,000 deaths in Russia alone (Coates et al., 2022), 15,000 deaths were reported to be directly attributable to the heatwave by the Russian government (Russo et al., 2015). 500 year long seasonal temperature records have been broken by these ’mega-heatwaves’ in 2003 and 2010 for approximately half of Europe. Within the next 40 years, the probability of Europe experiencing such mega-heatwaves has been calculated with regional multi-model experiments to increase by a factor of 5-10 (Barriopedro, 2011). In spite of this increase, the severity of 2010 heatwave event was so extreme that the probability of occurrence of such event remains relatively low until the second half of the century (Barriopedro, 2011). Previously, it was difficult to compare heatwaves across regions since certain temperatures are regarded as normal for regions with hot climates while they are considered to be a heatwave for cooler regions (Lass et al.,

2011). Therefore, in order to overcome this problem some indices were developed, such as the heatwave magnitude index daily (HWMId) (Russo et al., 2015), which is defined as the maximum magnitude of the heatwaves in a year, where a heatwave is described as 3 or more consecutive days with maximum temperature (Tmax) above the daily threshold for the reference period of the study 1981-2010. The 90th percentile of daily maxima temperature calculated over a 31-day period is defined to be the threshold. This way, Russo, and coworkers (2015) were able to rank the top ten heatwaves in Europe between 1950 to 2014. Figure 2.1 shows the historical newspaper headings of the 10 strongest heatwaves in Europe since 1950 together with their spatial distribution and corresponding HWMId observed values (Russo et al., 2015).

Although there were previous efforts in a few cities to implement strategies such as early warning systems to mitigate the catastrophic impacts of similar heatwaves, the excess mortality numbers of the summer 2003 heatwave have highlighted the widespread unpreparedness of civil and health authorities to cope with such extreme events even for the developed countries of Europe (García-Herrera et al., 2010). Moreover, future simulations of IPCC suggest that Europe would experience similar summers with extreme heatwaves about every two years around 2050 (Nakicenovic, 2000) and these summers would be regarded as a cool summer by the end of the century (Stott et al., 2004). Therefore, to reduce or to diminish the dramatic impact of future similar events, it is crucial to prepare cities, governments, authorities and communities with versatile strategies and solutions.

Other parts of Earth have also been experiencing extreme heatwave events which are increasing in frequency and intensity as well. For example, India has been suffering from major heatwaves with a rising trend in recent decades which is again attributable to global warming (Ratnam et al., 2016). General climatic conditions of India make uncomfortably high temperatures expected just before the monsoon season, which is around May. Over the North India, May is the hottest month of the year and average temperature exceeds 35 °C (Ghatak and Zaitchik, 2017). In some years maximum temperature exceeds 45 °C (Pattanaik et al., 2017) for many days in most parts of north-western, eastern coastal states of India. Still, some years are distinguished from others with their extreme heat, such as in 1998 (Jenamani, 2012), 2003 (Bhadram et al., 2005), 2005 (Pattanaik and Hatwar, 2006), 2015 and 2016 (Ghatak and Zaitchik, 2017). The 2015 heatwave was more pronounced in world media due to its dramatic impacts on large populations, causing more than 2500 deaths (Pattanaik et al., 2017).

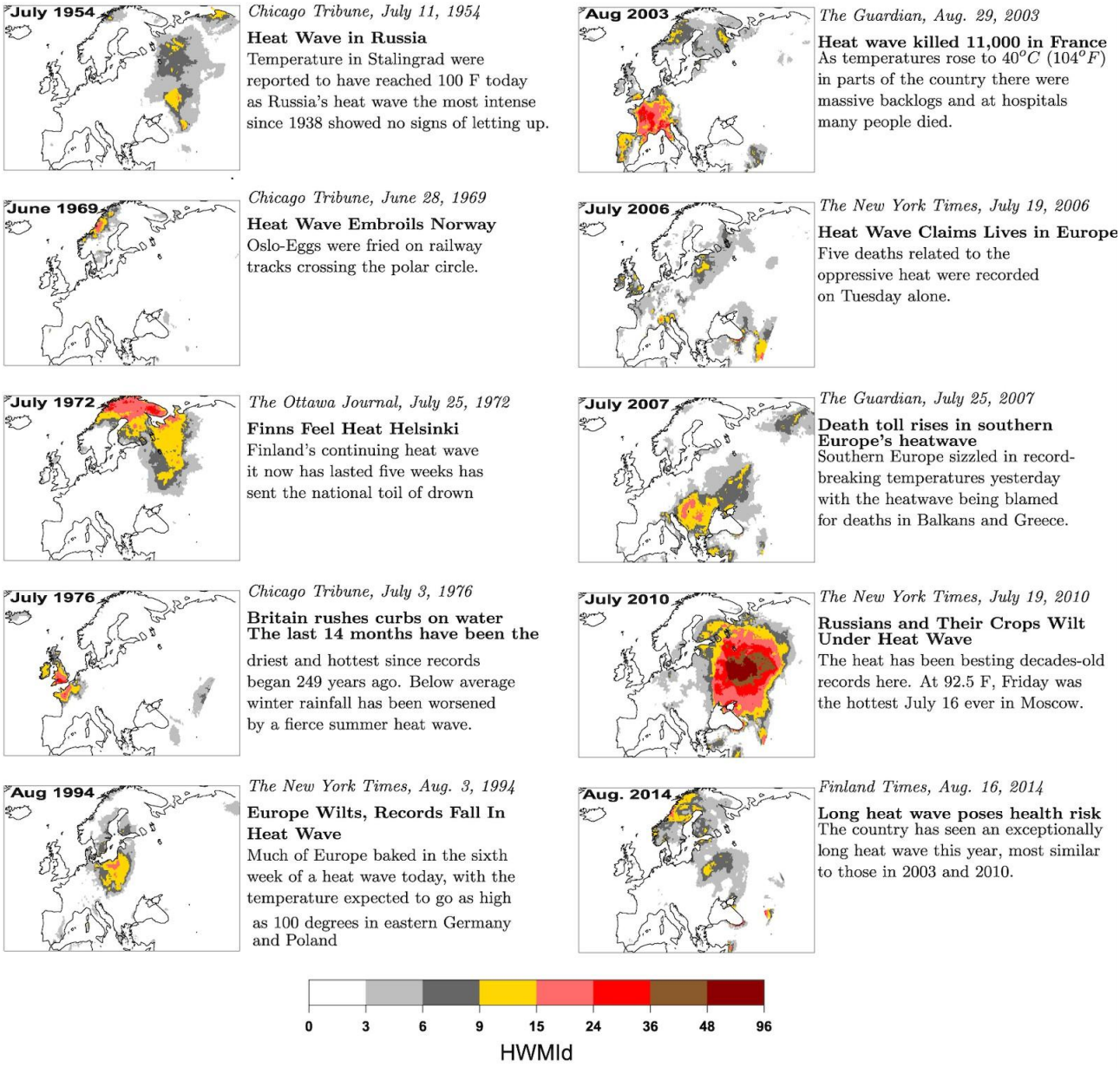

Figure 2.1. Newspaper headings and Geographical distribution of the HWMId observed values of the top 10 heatwaves in Europe since 1950. Adopted from Russo et al., 2015.

Middle Eastern countries Iran and Iraq also experienced severe heatwaves in 2015 that resulted in hundreds of deaths in both countries. Iran has warmed approximately 1.3 °C between 1951-2013 and the minimum temperatures increased at a rate two times higher than the maximum temperatures. Therefore, the country has been experiencing more frequent heat extremes and less frequent cold extremes during the last decades (Alizadeh-Choobari and Najafi, 2018). Similar trend has been observed for Iraq as well and during the 2015 heatwave the authorities declared a 4-day mandatory holiday in Iraq to protect people from extreme heat since high humidity caused perceived temperature to reach 66.2 °C (Abc News, 2015).

Australia has experienced the hottest summer in 2013 since the records began in 1910. January 2013 was the hottest month on record with average temperature reaching 36.9 °C and for more than three consecutive weeks much of inland Australia suffered from extreme temperatures and heatwaves (Perkins et al., 2014). During the recent decades, the frequency and severity of the heatwaves in Australia have increased together with a concomitant increase in heat related mortalities. Climate projection studies for Australia show 10-50 additional heatwave days for most of the climate scenarios by the end of 21st century (Perkins-Kirkpatrick et al., 2016; Ebi et al., 2020). Studies reported that apart from epidemics and pandemics, the most significant environmental threat in Australia in terms of mortality rates are extreme heatwaves (Coates, 2014; Coates et al., 2014; Coates et al., 2022). Coates and colleagues (2022) also stated that, as the population grows in Australia, urbanization and housing density also increases and people living in cities rely on mostly air conditioning instead of passive cooling strategies. In the case of an extreme heatwave event, the load on electricity grid also increases due to the excess usage of air conditioners and the operation of the grids cannot be guaranteed (Coates et al., 2022). With these words, this study offers a glimpse into the focus of this dissertation.

The 2018 extreme heatwave in Japan is another catastrophic event that warrants meticulous attention. Between July 14 and July 24 2018 Japanese hospitals were reported to have admitted unprecedentedly massive heat related disorders, primarily heat stroke, which is often fatal even when treated adequately. The wet bulb temperature is a meteorological term measured by wrapping a wet cloth around the bulb of a thermometer and with the evaporation of water it accounts for the humidity. By combining air temperature and relative humidity, the wet bulb temperature provides a more accurate measure of the discomfort on the body compared to air temperature alone. Therefore, it is used to better understand human thermal comfort as well as to calculate heat indices. The mean wet bulb temperature in 2018 reached 30.9-31.5 °C in six fixed-point observation cities in Japan, namely Tokyo, Osaka, Nagoya, Hiroshima, Niigata, Fukuoka. The highest temperature on record in Japan was measured 41.1 °C in Kumagaya city, approximately 64 km northwest of Tokyo on 23rd of July 2018 (Hayashida et al., 2019). Figure 2.2 shows the total number of patients with heat related illnesses that were brought to the emergency by an ambulance throughout Japan in July 2017 and in July 2018 and by comparison the effect of heatwave can clearly be seen. During the 11 consecutive days of this extreme heatwave event, there were 34,147 heat related ambulance transfers out of which 15,994 (46.8%) were for individuals aged 65 or above (Hayashida et al., 2019). After this calamitous event, the Japanese Association for Acute Medicine has called for taking measures against heat strokes which are considered as the most severe heat related syndrome.

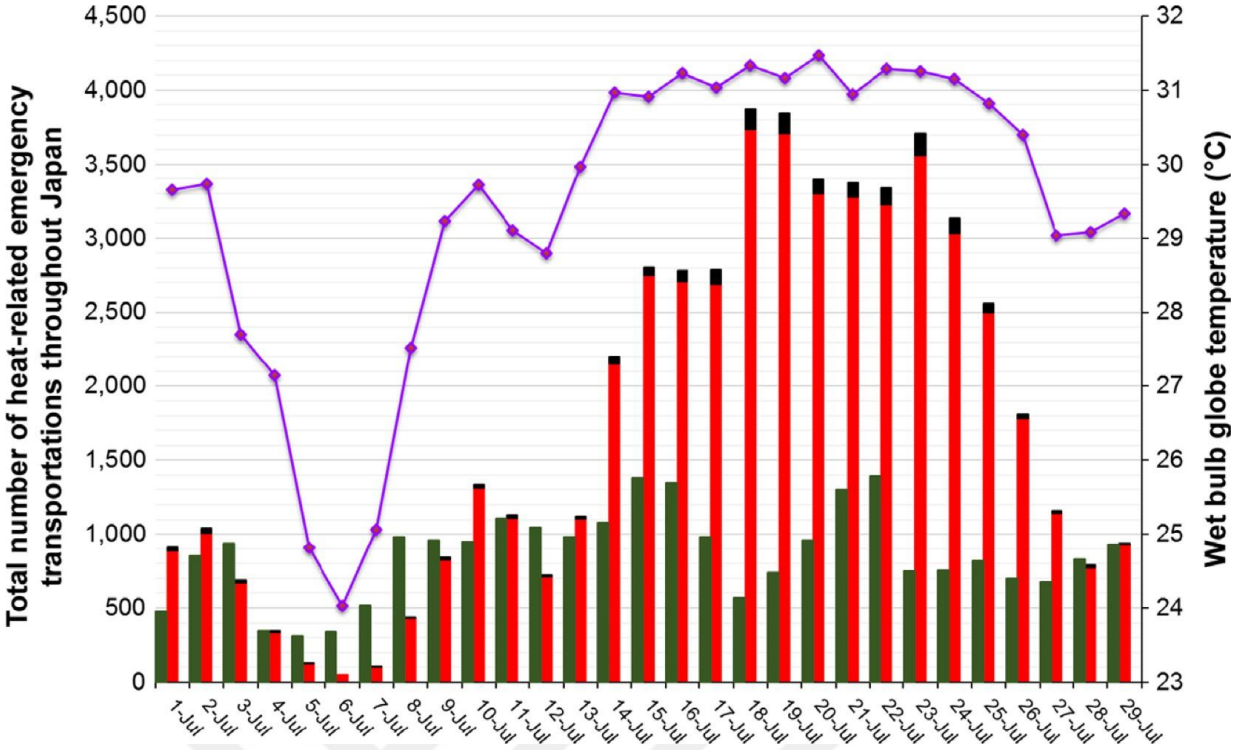

Figure 2.2. The total number of heat related emergency transportations throughout Japan in July 2017 (green bars) and in July 2018 (red bars). The black bars indicate the number of patients with severe heat related disorders including cardiac arrest upon arrival to the emergency. The mean wet bulb temperatures of the six fixed-point observation cities (Tokyo, Osaka, Nagoya, Hiroshima, Niigata, Fukuoka) are represented by the purple line. Adopted from Hayashida et al., 2019.

The United States of America also experienced extreme heatwaves in the recent decades. For example, the July 2009 heatwave in Western Oregon and Washington broke daily maximum temperature records in the area with temperatures reaching to 39.4 °C at Seattle–Tacoma International Airport (Bumbaco et al., 2013). One major event that caused hundreds of mortalities was in Midwest and Eastern United States, in July 1995. Chicago, Illinois was affected the most with 514 heat related deaths and 696 excess deaths and the event is reported to be amongst the highest in the history of the United States (Whitman et al., 1997).

Looking at more recent history, in July 2023 an extreme heatwave hit the Southwest of the United States together with Mexico, China and Southern Europe. On the 16th of July, 2023, temperatures were reported to exceed 50 °C in Death Valley, USA and in Northwest China (CNN Laura Paddison, 2023). On the same day, the heat record for all China was broken in Sanbao. In Europe, on the same day, Catalunya had the hottest day in its history and in other parts of Spain highest daily minimum temperature records were broken. Furthermore, in the US, highest ever temperatures have been reached in Colorado, New Mexico and parts of Nevada while in Phoenix highest of all time nighttime

temperatures were measured, setting a record in Arizona for the longest duration of temperatures without falling below 32.2 °C. Zachariah and coworkers (2023) employs three distinct definitions to be able to specifically explain the event in three regions, USA/Mexico, Southern Europe and China, as shown on the left side of Figure 2.3. For USA/Mexico, annual maxima of 18-day average of daily maximum temperatures; for Southern Europe, annual maxima of 7-day average of daily maximum temperatures; for China, annual maxima of 14-day average of daily maximum temperatures were used and by carrying out spatial and temporal averaging maximum July temperatures averaged over the length of the heat events for each specific definition. Figure 2.3 also shows the anomalies of these findings compared to the period of 1950-2023 on the right side (Zachariah et al., 2023).

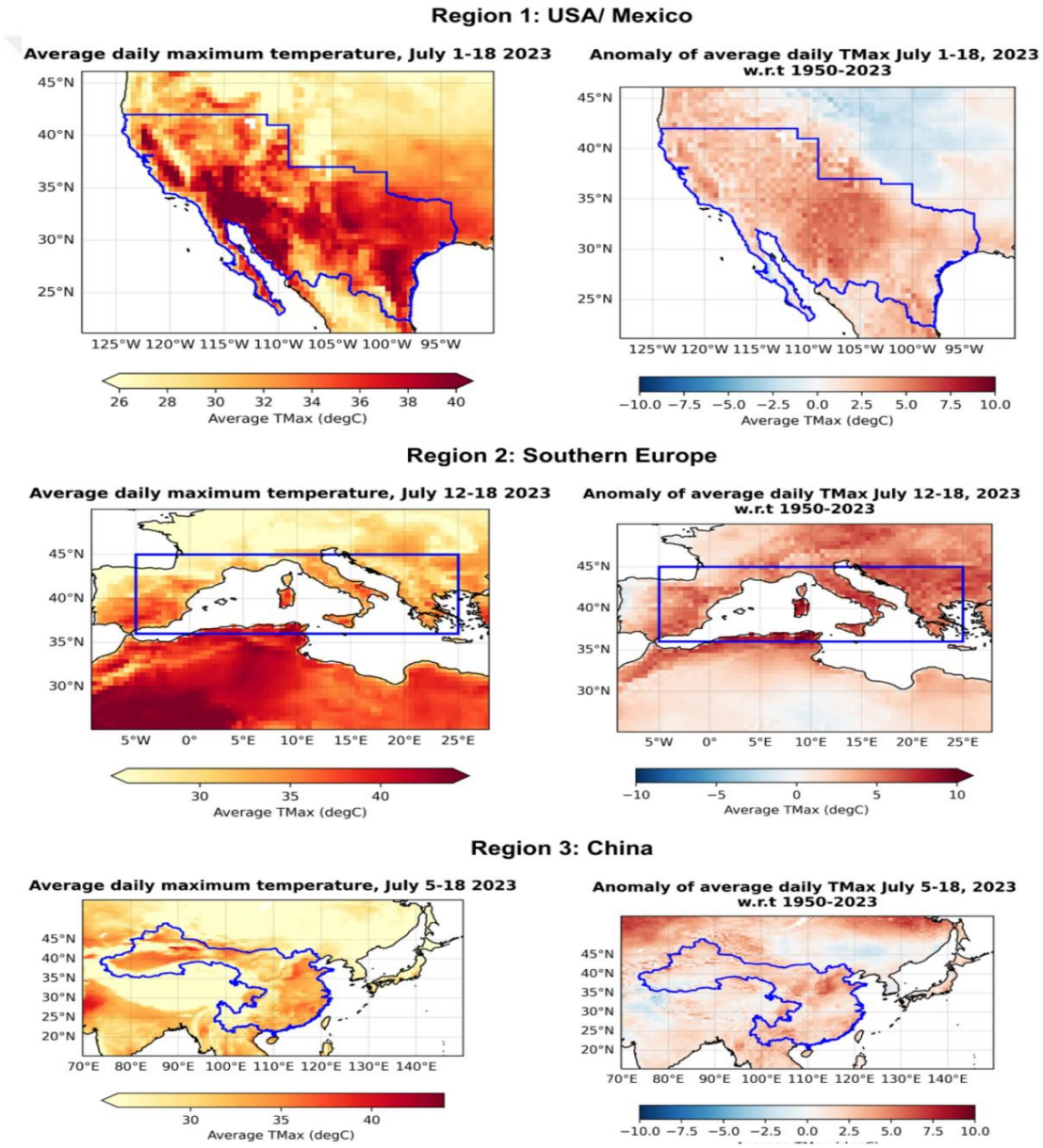

Figure 2.3. Maximum temperatures of July 2023 averaged over the length of each specific heat event (left-hand side) for USA/Mexico, Southern Europe and China, and their anomalies with respect to 1950-2023 (right-hand side). Adopted from Zachariah et al., 2023.

Several fatalities due to this extreme heatwave event have been confirmed in the US, Spain, Italy, Greece, Cyprus, Algeria, China as well as excess hospital admissions and the mortality numbers exceeded 200 people in Mexico alone. In Italy, at least 4 people reported to have lost their lives all while doing construction work (Independent, 2023). Demand for power spiked and broke power production records across China (CNN, 2023) and due to the decreased efficiency of power stations during heat wave events power blackouts in US and Europe (Los Angeles Times, 2023) caused large scale crop damage for corn, soybeans in US; reduction in olive harvest in Spain, Italy, Portugal; reduced productivity for cotton and grain harvest in China; and crop damage for coffee, maize, beans, oats, sugarcane along with more than 200 cattle losses in Mexico (Zachariah et al., 2023). These power outages leave people without consistent access to effective cooling technologies such as air conditioning or fans and exacerbate mortality numbers in these catastrophic extreme heatwave events.

Looking at more recent history, in June 2024 more than 900 hajj pilgrims were reported to have died due to the scorching heat in Saudi Arabia. Moreover, it is reported that there were many dead Egyptians unregistered (Le Monde, 2024), which may be due to the fact that many Egyptians go to hajj illegally because of the costly official permits. During the annual pilgrimage, around 1.8 million people in total were in Mecca while the temperature reached 51.8 °C (Le Monde, 2024). Despite Saudi Arabia's reluctance to disclose the number of fatalities, it was reported that on Sunday, June 16th alone, there were over 2,700 cases of 'heat exhaustion.' Last year, the number of fatalities during the hajj period exceeded 200, indicating that this issue in Mecca is likely to persist and worsen in the future.

Again in June 2024, Greece experienced an unusually hot period when five tourists were reported dead the following week in the Greek Islands such as Samos, Symi and Mathraki (Reuters, 2024b). It was reported that the temperatures exceeded 40 °C, which could be dangerous for humid regions like islands. The police stated that all the tourists went for a hike. Moreover, two French women, who also went for a hike, were missing on the island of Sikinos and rescue teams were on the search (Reuters, 2024a). These news reveal the relation between the tourism and extreme heat events and they highlight the critical need for informing and educating tourists about the risks of extreme heat, as well as implementing precautionary measures to safeguard them, even if such measures are not initially desired by the tourists. When their life is on the line, authorities may have to take such measures against their will.

When we consider Türkiye, it is important to underline the general climatic conditions for the country. The empirical study of The Köppen climate classification (Peel et al., 2007) defines climate

in a region according to the long term (usually 30 years for temperature and 40 years for precipitation) average observational data calculated annually or monthly. Letters are used to define large clusters of climates with their seasonal characteristics of temperature and precipitation. There are five main climatic clusters in the Köppen system, namely A representing humid tropical (hot) climates, B representing arid climates, C representing humid mid latitude (temperate) climates, D representing humid cold mid latitude (severe winter) climates, and E representing polar climates (Peel et al., 2007). This classification scheme, which was firstly introduced by Wladimir Köppen, is the most widely applied climate classification for more than a century now (Peel et al., 2007). Türkiye has mostly C (temperate) zones, that is Mediterranean climate, in the Aegean, Mediterranean and Southeastern Anatolia regions. B (arid) and D (cold) classes of climatic effects are observed mostly in Central Anatolia and Eastern Anatolia regions. The cities of Türkiye that are subject to this study with their high potential of experiencing extreme heatwaves in the future, such as İstanbul, İzmir, Manisa, Muğla, Antalya, Mersin, Adana, etc are all in the Csa classification in the Köppen climate scheme, that is temperate dry and hot summer. Eastern Anatolia is in the Ds classification, meaning continental climate with hot and warm summers. These regions are already prone to extreme heat events especially during summer due to their natural climate.

Heatwaves are a common and familiar feature of the Mediterranean region and being in the Mediterranean, Türkiye has also been suffering from extreme heatwave events in the recent decades, some of which caused huge forest fires that received lots of coverage in the world press. Erlat and coworkers (2021) investigated the observed trends and changes in the characteristics of heatwaves in Türkiye since 1950. They researched on the long term trends and spatiotemporal changes of heatwave characteristics such as heatwave number, duration, frequency, magnitude and amplitude by employing indices and using 88 meteorological stations in Türkiye. The calculations of the 90th percentile of the daily minimum air temperature and the 90th percentile of the daily maximum air temperature, which are calculated and used in this dissertation as well, showed that Türkiye has been experiencing hotter, longer and more frequent heatwaves since 1950 (Erlat et al., 2021). The most significant and abrupt changes are found to occur in the Black Sea and the Mediterranean coasts after the 1990s. Although the findings of some other studies for Türkiye showed similar results and although climate simulation studies show that Türkiye is amongst the most vulnerable countries to extreme heatwaves in Europe in terms of increased intensity and quantity (Ozturk et al., 2015), there exists only a few epidemiological articles that investigated the impacts on public health with mortality rates or hospitalizations due to extreme heatwave events. One such study reviewed the excess fatalities due to the extreme heatwave events in Istanbul between 2013 and 2017. In their research, they defined an extreme heatwave event as a period of at least three consecutive days with a daily

average of the mean temperature above the 95th percentile, and with this definition they identified four distinct extreme heatwave events in Istanbul; one in 2015 that resulted in 118 excess deaths, one in 2016 with 96 deaths, and two in 2017 with 205 deaths, summing up to 419 heat related deaths in Istanbul only within this 5 years period (Can et al., 2019). This study also reported that since there exists no research on the number of fatalities due to past extreme heatwave events in Istanbul such as the ones in 2000, 2003, 2007, and 2010, it was not possible to compare the mortality numbers and come to a conclusion on whether there were any improvements, adaptations or behavioral changes. The study also emphasized the necessity of public health intervention plans at the local and national scale (Can et al., 2019). Another study conducted in İzmir examined the emergency department (ED) admissions and in-hospital mortalities (in only 1 hospital) during the heatwave event between 17th and 25th of June, 2016 and compared this data with the same period in 2015 (Oray et al., 2018). The study revealed that admissions in the ED and the mortality numbers were significantly higher in the study period compared to the reference period. The admissions in ED increased by 19.2% (448 extra ED visits) and the mortality numbers increased by 181.3% (29 extra deaths) compared to the reference period in 2015 (Oray et al., 2018). In Figure 2.4, the effect of the increase in maximum daily temperatures on the number of daily fatalities during the heatwave event in June, 2016 can be seen. Even though the causality of deaths were beyond the scope of the research, since this was a study examining only the in-hospital deaths, the study reported that the most common pre-existing diseases of the patients that lost their lives were hypertension, malignancy, dementia, coronary artery disease, diabetes and history of cerebrovascular accident (Oray et al., 2018). This research, as in many others, did not include the effect of humidity and employed only the mean and maximum daily temperatures as they are the most commonly used indicators in the literature. However, Oray and coworkers (2018) underline the significant effect of humidity on the ambient temperature and therefore on human health, and state that indices like Heat Index or Humidity Index (Humidex) better incorporate the effects of temperature, humidity and sometimes wind speed on human discomfort. Hence, the apparent temperature together with heat index or Humidex calculations enunciated to be better exposure metrics for human mortality and morbidity during extreme heatwave events (Oray et al., 2018). This is the reason why in this dissertation Humidex is utilized.

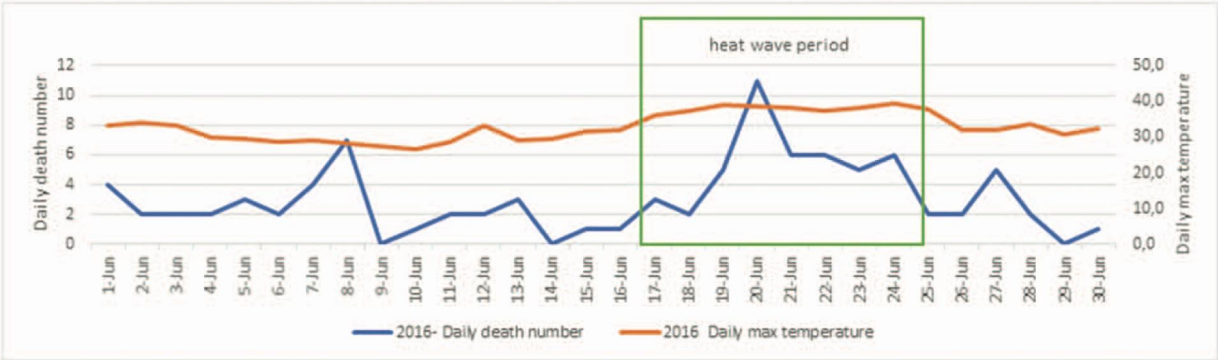

Figure 2.4. Mortality numbers per day and maximum daily temperatures in June, 2016. Adopted from Oray et al., 2018.

Unal et al., (2013) focused on the western part of Türkiye since simulation studies indicate the highest temperature change in summer occur over this region and due to the high population density of the region that would be affected from extreme heatwave events. By defining a heatwave event as at least three consecutive days of a threshold value, which is the 90th percentile value of daily maximum temperature for each region, the study found that the number of heatwaves as well as the number of hot days and the duration of heatwaves increased in western Türkiye between the years 1965-2006 and their rate of change is greater for the period of 1996-2006. Extreme heatwave events have been reported to occur more frequently especially after 1998 and a significant correlation has been found between the number of heatwaves and fire occurrences (Unal et al., 2013). By employing the same definition of heatwave, one recent study focused on the mortality numbers and hospitalizations due to the heatwaves that occurred in Fethiye, Türkiye between 1st of May to 30th of September in 2019 (Ozturk et al., 2023b). Since southern regions of Türkiye are considered hot spots and since they host millions of tourists every year in summer in addition to their already existing dense population, these regions are expected to get most affected by extreme heatwaves. To be exact, the population of Fethiye is announced by Turkish Statistical Institute (TUİK) to be 177,569 on 31st of December, 2023 (TÜİK, 2023), and approximately 1 million people visit the province each year for touristic purposes (Ozturk et al., 2023b). Despite their overpopulation during the summer, their proximity in latitude to desert areas and also their frequent experience of heatwaves, observed health effects of extreme heatwave events in southern areas of Türkiye do not get investigated often. Therefore, Ozturk and colleagues (2023b) reviewed Fethiye from this large territory and found that there were three distinct heatwave events during the research period of five months that lasted 6, 7 and 5 days in 2019. The effect of a heatwave on human health is found to be highest on the first day of exposure, then to decline rapidly and come to an end on the third day after the event ends (Huang et al., 2012). Therefore, 3-lag days were added to each heatwave to better analyze the effect. The study revealed 9%, 11% and 13% increase in hospitalizations, respectively, for each heatwave event,

2,524 extra admissions in total (Ozturk et al., 2023b). Figure 2.5 displays the relation between the three heatwave events and the hospitalizations together with the temperature increase and hospital admissions in the reference period of May 1 to September 30 in the years 2014 to 2018. Moreover, 22 excess fatalities occurred due to the three heatwaves of 2019, out of which 18 were aged 65 and over, that is 82% of the extra deaths (Ozturk et al., 2023b).

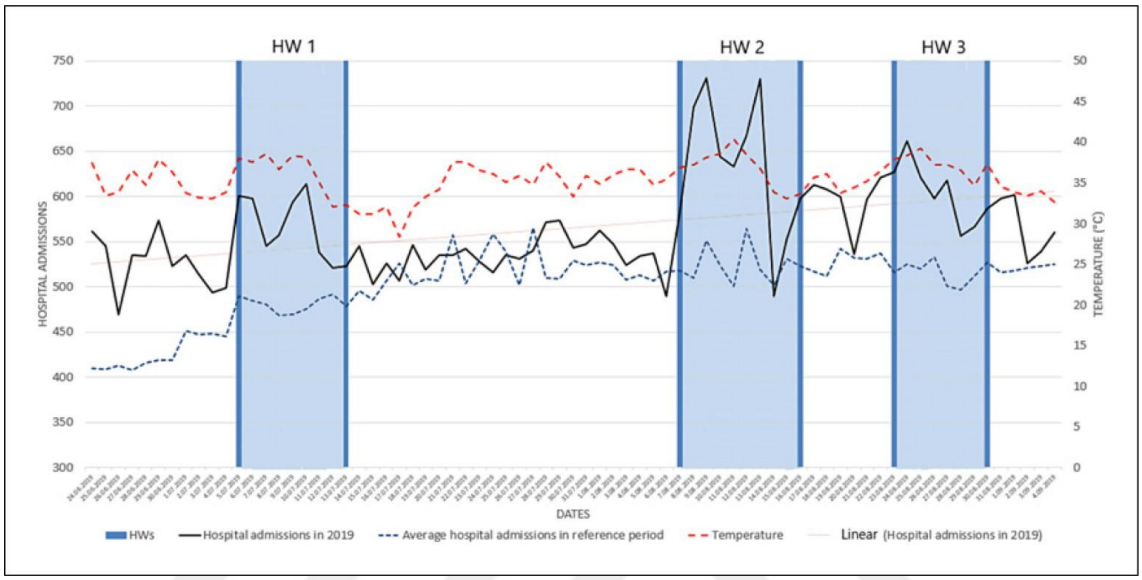

Figure 2.5. Three heatwave events and hospital admissions depicted together with average temperature and average hospital admission in reference period. Adopted from Ozturk et al., 2023b.

Another recent study, published in 2023, investigated the effect of heatwaves in 2018 on hospital admissions in all hospitals in Edirne, Türkiye (Ozturk et al., 2023a). Again, by using the definition of a heatwave as a period lasting for 3 or more consecutive days with temperatures above the 90th percentile of the threshold of daily maximum temperatures, Ozturk and coworkers, detected a 6-day long heatwave in Edirne in the study period of 1st of May to 30th of September, 2018. By adding the aforementioned 3-day lag period, they obtained the number of daily polyclinic admissions data for 9 days from all hospitals in Edirne with the permission of Edirne Provincial Health Directorate. As a reference, the study employed the hospital admissions data from August 6 to 29, which is right before the heatwave, and from September 10-October 3, which is right after the heatwave. The research revealed the heatwave event caused 19% increase in polyclinic admissions, that is 2557 excess admissions in total, compared to the reference period. The Cardiology polyclinic was found to have the highest number of admissions, with 36% increase with respect to the reference period (Ozturk et al., 2023a). Additionally, in contrast to previous studies, this research asserted that the children aged 14 or less were the most affected group with an increase of 33%, whereas the admissions for elderly increased by 22% (Ozturk et al., 2023a). The reason behind this difference could be explained by social isolation of the elderly or their limited mobility or lack of transportation to the hospital, etc..

As can be understood from this literature review of recent extreme heatwave events, climate change has become an increasingly important public health issue manifested in morbidity and mortality rates. Even though no segment of the population can be considered exempt, impacts of extreme heatwaves are felt disproportionately within society and global epidemiological studies showed that the most important risk factors are being elderly (aged ≥ 65), or being young children having pre-existing medical conditions, chronic mental disorders, low economic status (low education, low income, homelessness, social isolation) (Coates et al., 2022). A healthy adult body has a momentous skill to keep the core temperature stable between 36.6 and 37.7 °C regardless of the ambient temperature. To maintain the stability of the body temperature, complex physiological feedback loops are employed and there is a sensitive balance between the produced, conserved, dissipated heat and the environmental conditions. One of the most important feedback loops is of course sweating. When the weather is extremely hot, the body sweats to keep its temperature stable. While the sweat is evaporating from the skin, it takes away some heat and that is basically how the body cools. However, when humidity levels reach 90% or higher, the evaporation of sweat from the skin becomes impossible, as the atmosphere is already saturated with moisture. Consequently, the body is unable to cool itself, prompting the heart to pump faster in an effort to produce more sweat and achieve cooling. This positive feedback loop can lead to a heart attack and ultimately cardiac arrest, particularly among the elderly and other aforementioned vulnerable groups. If the excess heat cannot be dissipated sufficiently by sweating or other complex mechanisms, the risk of a heat stroke or an uncontrollable rise in body temperature increases tremendously. A core body temperature above 40.5 °C can cause complications in the central nervous system or failure in cardiovascular and respiratory system resulting in morbidity and mortality (Liss and Naumova, 2019). Elderly people (aged ≥ 65) are reported to get affected 12 to 23 times higher from heat strokes due to the weakening of their thermoregulatory mechanisms, side effects of their medications, their limited mobility, increased blood viscosity, increased cholesterol level, and so on (Gamble et al., 2012). Moreover, in the literature, the wet bulb temperature of 35 °C is commonly considered to be the human heat stress limit for survival since the dissipation of metabolic heat becomes increasingly impossible and results in hyperthermia for humans and other mammals (Sherwood and Huber, 2010). The McKinsey report on extreme heat and humidity states that a healthy human being doing no work but resting in the shade can survive for about five hours at 35°C wet bulb temperature (McKinsey Sustainability, 2020). Considering the extent of the lethality of the situation, it is crucial to develop key approaches to address the risk of mortality of especially the vulnerable populations, in our case, mostly elderly people by acknowledging their limitations and barriers.

There is not enough research for extreme heatwave events, their impact on human health and death tolls in Türkiye. Accordingly, there is no heatwave emergency action plan for any city in Türkiye. Scientific research, public health interventions, preparedness of cities with established and publicized action plans, without a doubt, would reduce the mortality numbers during extreme heatwave events. Extreme heat affects people's physical conditions very slowly therefore it is commonly too late for recovery when people actually realize the dangers. Therefore, along with preparing cities, educating people to increase their preparedness has also vital importance to combat high death tolls.

2.2. Smart Cities

2.2.1. Definition of Smart City

The concept of "smart cities" has recently been introduced in academic articles as a strategy to mitigate various problems created by unprecedentedly growing urban population, rapid urbanization and also the popular concerns of sustainability. However, the phenomenon is still elusive and is still being researched on. There are frameworks proposed in the literature to better understand and address the term 'smart' and this section aims to clarify the meaning through a broad review on the relative studies. Critical concerns on what actually is a smart city, what are its aspects and components, how it is compared to traditional cities are addressed.

During the last two decades, the concept of smart cities and making a city "smart" has become a more and more popular topic that is discussed in the academic literature as well as in the political agenda of the many megacities and cities. The use of the term is rapidly increasing even though the term is not clear, not well understood and has no agreed upon definitions. However, it is agreed and well recognized that cities have the biggest role in social and economic aspects of the world and also have a tremendous impact on the environment. According to the United Nations (UN), the world's population reached 8 billion in November 2022 with 55% residing in cities and this number is projected to rise to 70% by 2050 (UN, 2023). Correspondingly, they consume most of the food and resources, and they create most of the waste. In the 2024 report of UN, it is stated that cities consume between 60-80% of the energy worldwide and they are responsible for 75% of the energy related GHG emissions (UN, 2024). World population is increasing with an unprecedented speed and most of this population prefers to live in cities which amplifies the problems that cities have and cause. Due to their vast and growing populations, cities rely on and consume large amounts of external resources. With the extreme resource use, problems such as waste management, air pollution, human

health concerns, scarcity of resources arise. To make the cities sustainable, promotion of natural capital stocks is vital which includes electricity, foods, health services, natural gas, oil and all other people's needs. Therefore, cities worldwide are in research of solutions which enable transportation linkages, technologies including Information and Communication Technologies (ICT), mixed land uses, higher quality of infrastructure and urban services with the hope of sustainable development as well as social justice, environmental justice and green growth. Academia and practitioners are trying to find all the answers in the term smart city and therefore the term is still being defined and there is an ongoing process of conceptualizing.

A number of studies in the literature imply that the only requirement for a smart city is technology. For example, Batty and colleagues (2012) describes a smart city as a city which has integrated ICTs with their traditional infrastructures such as electricity, water, transportation. To give another example, Ahvenniemi and coworkers (2017) define smart cities as cities using technology to enable sustainable development

Albino and coworkers. (2015) has published an article that presents and discusses many different definitions and dimensions of smart cities. The first appearance of the term in the literature was in the 1990s, and back then it was mostly evoking ideas equipping cities with ICTs; however, the definition of the term expanded to include today several different meanings and conceptions. It stopped being limited only to the utilization of technologies in cities, instead it started to pay attention to the needs of individuals. The review paper of Albino and colleagues. (2015) presents more than 23 different definitions of smart cities from the literature, and it is stated that the reason for the term having many understandings might be due to the fact that it is actually applied to two domains, consisting of purely technological or including more holistic views emphasizing sustainability. In other words, one is the hard domains where ICTs have a significant role such as buildings, water and electricity infrastructure, waste management, and logistics; and the other one comprises the soft domains where ICT applications have a less prominent role such as education, culture, health, social inclusion, social justice, and governance. Other than this distinction, it is actually difficult to categorize all these definitions since they are very similar in many ways and yet still have many different focuses. It is also stated in the study that the term is fuzzy and there is neither a single template, nor a one-size-fits all kind of definition for it (Albino et al., 2015).

Bakıcı and coworkers (2012) defined the term as an advanced city equipped with high-tech intensive applications and a city that leverages new technologies to integrate information with urban elements, such as health services, to build a sustainable, resilient city and enhance quality of life.

Eger (2009) had ideas about smart community as well by arguing that smart community, that makes a deliberate decision to adopt technology as a powerful tool in order to address any social, economical, and environmental challenges, will undoubtedly focus on building its high-speed, broadband, smart infrastructures. A smart community would be aware that the real opportunity is in rebuilding and renewing a sense of place that would make them feel civic pride. Smart community does not mean just implementing technological exercises, the meaning also refers to promotion of economic development, job growth, improved quality of life and well being. In other words, deployment of technology of smart communities is not a final target in itself, but only a means to recreating cities for an improved economy, environment and society.

Giffinger and coworkers (2007) draw attention to the citizen's needs by saying that the objective of smart cities is to perform well in a forward-thinking way for economy, people, governance, mobility, environment, and living, which are built on the smart combination of self-decisive, independent and aware citizens, endowments and their activities. The term is stated to include the pursuit and identification of intelligent solutions to the common specific challenges enabling these modern cities to enhance the quality of the services offered to citizens.

Guan (2012) defines a smart city as being prepared against the challenging economical, global, environmental and social conditions to ensure a healthy and happy population.

Nam and Pardo (2011) characterize smart city as a city which infuses information into its physical infrastructures for several purposes such as conserving energy, deploying resources effectively improving the quality of air and water, identifying problems and fixing them quickly, recovering rapidly from disasters, improving conveniences, facilitating mobility and efficiencies and also sharing data to enable collaboration between entities and domains.

Although it is possible to increase the definitions of smart city from the literature, in order to provide a more-in-depth perspective, I will present the components of a smart city and the success factors of smart city initiatives.

2.2.2. Components of a Smart City

As stated before, it is very difficult to classify or categorize the definitions of the term smart city because all of them include an integration of a city's specific systems none of which operates in isolation. Kanter and Litow (2006) strongly suggest that creating a smart city requires treating all the

city's subsystems— such as transportation, energy, physical infrastructure, healthcare, education, buildings, public safety, food, and water—as an interconnected and integrated network. However, if not classified one way or other, all these definitions become frustrating for both academicians and practitioners and the term will lack a clear meaning. Therefore, scientists attempted to at least develop some subtitles or features which can provide some generalization. Other scientists developed other names or frames all for the sake of simplification of the fuzzy concept. Kominos (2002, 2011) for example created four dimensions. The first one being the application of various electronic and digital technologies with the purpose of creating a cyber, digital, knowledge-based city. The second one is the application of information technologies in life and work, the third one is the application of ICT in the city infrastructure and the last one is to bring ICT and people together. To give another example, Giffinger and coworkers (2007) mentions four components of a smart city, that are industry, education, participation and technical infrastructure. Then, the Centre of Regional Science of the Vienna University of Technology expanded these four components to six (Giffinger and Gudrun, 2010) that are smart economy, smart mobility, smart environment, smart people, smart living, and smart governance. Even though some scientists add another component of increasing life quality, some other scientists argue that it is not a valid component or a feature since it comes by itself if the other components are applied (Shapiro, 2006). Lombardi and colleagues (2012) linked the six components offered by Giffinger and Gudrun (2010) with related aspects of city life as given in Table 2.1 . Here smart economy is related with the industries that adopt ICT, smart mobility is associated again with the use of ICT in transportation sector with the purpose of reducing and improving urban traffic, smart environment is related with the efficient use of all resources and includes the sustainability targets of the cities. Smart governance is related with diversified stakeholders being engaged in decision making and public services, and ICT adopted governance, also called e-governance being fundamental to bring new initiatives and to employ transparent processes during decision making. Albino and colleagues (2015) emphasize the importance of citizen-centric and citizen-driven spirit of e-governance. In their review paper, Albino and coworkers (2015) claimed that identification of a smart city goes beyond the dense presence of ICT, and called all these features and components as dimensions of a smart city. They agree that a smart city must have ICT and internet based government services, however, they state, smart cities must also integrate technologies, systems, services, and capabilities into an organic network which is open-access and is sufficient for future developments (Albino et al., 2015). Shapiro (2006) agrees by claiming that smart cities start from the perspective of human capital instead of just expecting that ICT can automatically create smart cities. The term has to refer to the capacity of clever people to find clever solutions to urban problems.

Table 2.1. Components of a smart city and related aspects as proposed by Lombardi et al., 2012.

Components of a Smart City	**Related aspect of Urban Life**
Smart Economy	Industry
Smart People	Education
Smart Governance	E-democracy
Smart Mobility	Logistics and Infrastructure
Smart Environment	Efficiency and Sustainability
Smart Living	Secure and Quality

2.2.3. Success Factors of Smart City Initiatives

After the exhaustive investigation of the rich but different definitions of the smart city term, Chourabi and colleagues (2012) proposed a framework including a comprehensive set of factors to better understand the initiatives and projects of smart cities. Their target is not to rate smart cities but instead, they want to address the internal and external factors related to design, implementation and the usage in addition to sustainability and livability features of smart city initiatives. Chourabi and coworkers (2012) state that this proposed framework can be used to characterize how to envision and design initiatives that advance this vision by implementing services and maneuvering the challenges created by these initiatives. This framework divides success factors of smart city initiatives into eight clusters.

a. Management and Organization: Although only a few studies have included issues related to management and organization, they bear great importance for smart city initiatives. The list proposed by Gil Garcia and Pardo (2005) describing managerial and organizational challenges include the size of the project, attitudes and behavior of managers, users or organizational diversity, lack of alignment of organizational objectives and project goals, multiple or conflicting aims, and resistance to change. The strategies offered to cope with these challenges are enhanced skills and expertise within the project team, competent and well-respected IT leader (in terms of both technical and social skills), well defined and achievable goals, recognition of relevant stakeholders, active participation from end users, comprehensive planning, defined milestones and measurable outcomes, effective communication strategies, improvement in previous business processes, adequate and effective training programs, innovative funding solutions and evaluation of best or current practices (Gil-García and Pardo, 2005).

b. Technology: ICTs are undeniably the key drivers of the initiatives for smart cities (Hollands, 2008). Application of ICT offers many potential opportunities, and it can boost the functioning of a city (Odendaal, 2003). Even though there are concerns whether ICT is a business opportunity for technology companies, and even though their impact is still not clear, their benefit is repeatedly emphasized in the literature (Odendaal, 2003; Hollands, 2008; Vasseur, 2010). There could be some unavoidable organizational challenges while adapting technological applications, which include lack of cross-sectoral cooperation, lack of inter-departmental coordination, unclear vision of IT management, politics and culture issues (Ebrahim and Irani, 2005). Nevertheless, these challenges must be overcome since technology is an integral part of smart cities.

c. Governance: The increase in the initiatives to make cities smarter brought an increasing need of better governance to manage all these projects (Griffith, 2001). Public governance is described as "systems of laws, administrative regulations, judicial decisions, and practices that regulate, guide, and enable government actions, which encompass the provision and delivery of goods and services supported by the public" (Lynn et al., 2000). After an intensive research on challenges of e-government projects Scholl and colleagues (2009) concluded that the relations of stakeholders, which are the ability to cooperate, support of relationship, structure of alliances and the work under different jurisdictions, is one of the most important success factors of the smart city initiatives. Table 2.2 outlines the existing literature on governance as a success factor.

d. Policy Context: To transform a traditional city to a smart city, policy context has crucial importance for the use of ICTs and information systems appropriately. A government must insist on being innovative and give significance to change in policies, because without a normative drive addressed in policy, the government cannot bring innovations (Eger and Maggipinto, 2010). Making any kind of differences or decisions for IT projects, managers and practitioners have to follow a broad range of laws and regulations. Removing legal and regulatory barriers is essential for the implementations of initiatives for smart cities (Dawes and Pardo, 2002; Mahler and Regan, 2002). Other challenges are related to general institutional structures and politics that follow specific norms, actions, behaviors apart from the laws and regulations (Brown and Brudney, 2003).

Table 2.2. Success factors of governance on smart city initiatives. Adopted from the study of Chourabi et al., 2012.

Factors	**In the Literature**
Collaboration	Lam, 2005; Luna-Reyes et al., 2007
Leadership and champion	Lam, 2005; Mooij, 2003; Scholl et al., 2009
Participation and partnership	Giffinger et al., 2007; Odendaal, 2003
Communication	Odendaal, 2003
Data-exchange	Luna-Reyes et al. 2007; Nfuka and Rusu, 2010
Service and application integration	Nfuka and Rusu, 2010; Odendaal, 2003
Accountability	Johnston and Hansen, 2011; Mooij, 2003
Transparency	Johnston and Hansen, 2011; Nfuka and Rusu, 2010

e. People and Communities: When the smart city term first emerged in the literature, addressing people and communities and their participation were neglected for some time because the focus was on the technologies and the policies that the smart city concept required. Smart city initiatives have an impact on the quality of life of the citizens, therefore they may have a word or opportunity to engage in with the process. Moreover, smart city initiatives encourage the participation of the members of the city in governance and management. In the literature, the factors of people and communities on the success or failure of smart city initiatives are reported to be digital divide, information and community gatekeepers, participation and partnership, communication, education, quality of life and accessibility (Chourabi et al., 2012).

f. Economy: The major driver of a smart city is economy and if a city has a high degree of economic competitiveness, it is believed to have one of the aforementioned six components of a smart city as proposed by Giffinger and Gudrun (2010). Having an environment where the industry can develop is crucial for a smart city because the initiatives are designed to improve information technology capacities and establish a plan for a change by industry actions and business development (Cairney and Speak, 2000). Economic outputs of the initiatives are commonly business and job creation, the development of workforce and productivity improvement.

g. Built infrastructure: Smart networks of electricity, internet or transportation and the availability as well as the quality of ICT infrastructure, as pointed out before, are essential to transform the traditional cities into smart cities. Since the smooth implementation of these technologies depend on the regulatory barriers as in the case of management and organizations,

Ebrahim and Irani proposed a set of success factors and challenges given in Table 2.3 (Ebrahim and Irani, 2005).

h. Natural environment: At the very core of the concept of smart city, the ideas of sustainability, sustainable development and sustainable use of natural resources lie with the use of ICT and advanced technologies. Therefore, when investigating smart cities, the factors of green growth and environmental justice have to be emphasized.

Table 2.3. Success factors of built infrastructure on smart city initiatives. Adopted from Ebrahim and Irani, 2005.

Factors	**Challenges**
IT Infrastructure	Lack of integration across government systems
	Existing internal systems have restrictions regarding their integrating capabilities
	Lack of knowledge regarding interoperability
	Availability and compatibility of software, systems and applications
Security and Privacy	Threats from hackers and intruders
	Threats from viruses, worms and trojans
	Privacy of personal data
	High cost of security applications and solutions
	Accessibility
Operational cost	High cost of IT professionals and consultancies
	High cost of IT
	Cost of installation, operation and maintenance of information systems
	Cost of training

Green growth is a complex concept like smart city. It has many definitions and very striking promises if it can be applied. These promises include conserving nature, overcoming poverty, providing equity, creating jobs and businesses without any additional investment specifically for nature protection. As in the case of smart cities, green growth requires a structural change, technological improvements and policy changes. With the ecological design it offers solutions to the challenges of sustainability related applications. Environmental economics is the disciplinary basis

of green growth. Environmental economics recognizes three production factors; capital, labor and natural capital. From this perspective, economic processes which result in environmental degradation or social damages are not perceived as successful business strategies, rather recognized as market failures. However, unsustainable development which can be regarded as Business-As-Usual (BAU) is not a market failure but rather a market system failure which means that in the long term it is impossible for this strategy to give favorable results in terms of environmental consciousness and social responsibility. Green growth is a political strategy as well as an economical strategy to essentially revitalize the conditions of business. Considering the planetary boundaries and global resource limits, it offers to turn challenges of sustainable development into a business opportunity. The fundamental macro-level goal of green growth initiative is to decouple growth and environmental limitations. The secondary aim of green growth is to avoid distribution debates. Justice cannot be accomplished by distributing surplus, and it can only be accomplished by taking from those who have more than needed amounts and giving to those who do not have the minimum required amounts.

Environmental justice is yet another term with a broad meaning which arose from that some communities or some parts of the world are disproportionately exposed to higher levels of environmental risk than others. As in the case of climate change for example, the poor always suffers more and the African continent is under higher risk of sea level increase and droughts in the future regardless of the fact that it is a continent that is barely causing the crisis of climate change. Another example is that the health and livelihoods of the working class, people of color and indigenous people get more affected by resource extraction, waste disposal and pollution in their neighborhoods and hazards in their workplace. The increasing concerns on the unequal environmental burdens as well as the racial and economic injustices of the world has caused the emergence of environmental justice movements in the 1980s and immediately after the emergence of the term in the literature. Theory and practice of environmental justice requires distributive conceptions of justice and at the same time it embraces notions of justice based in recognition, participation and capabilities (Schlosberg, 2007). The environmental justice perspective questions ‘who gets what, why, and in what amounts’ with the purpose of new public health strategies to ensure the equal protection of all citizens regardless of their social and economical status, age and color.

2.2.4. Integrative Framework of Smart Cities

After drawing attention to the conceptual literature and the success factors of smart cities, Chourabi and colleagues (2012) proposed an integrative framework, presented in Figure 2.6, to better explain the relationships between these factors and initiatives. This framework helps to

analyze the success of smart city initiatives and to disentangle the actual impact on organizational, technical and contextual variables.

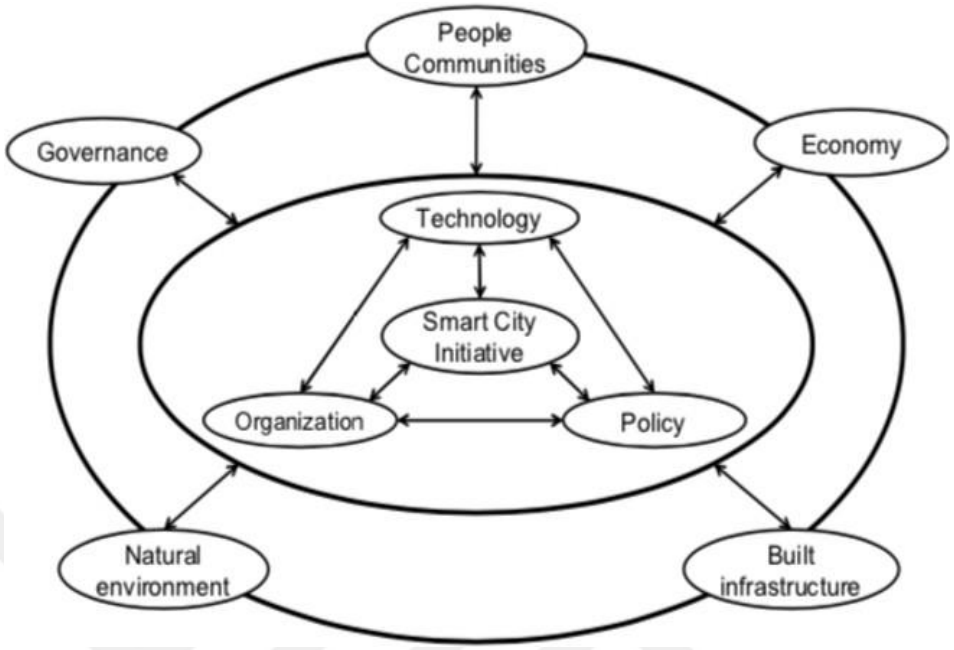

Figure 2.6. Integrative framework of the smart city initiatives. Adopted from Chourabi et al., 2012.

Here in this framework, it is seen that all the factors have a two-way impact on the success of smart city initiatives. Each factor is influenced by and influences other factors, however, some more than others. In order to show the different levels of impact, the factors are given in two different levels of influence. Outer factors of people and communities, economy, built infrastructure, natural environment, governance are themselves influenced more than the influential inner factors of technology, policy, organization before affecting the success of smart city initiatives. This applies for both direct and indirect effects of the outer factors. Technology is considered to be a meta-factor since it can have a great influence on all the other factors both inner and outer. Chourabi and coworkers (2012) conclude that technology by itself can influence a great deal the success of the smart city initiatives.

2.2.5. Synthesis: Climate Change, Public Health and Smart Cities

Since the term smart city is relatively recently introduced in literature, the relationship between smart cities and climate change is a nascent area of research. If we consider cities as socio-technical-environmental systems, it is evident that climate change will affect various urban services directly or indirectly. The framework-based smart city literature seldom discussed the role of climate change on infrastructure systems of the cities. Therefore, during recent years, the need for studies investigating

the connection between smart cities and anthropogenic climate change began to attract attention. The focus has been shifting towards sustainable smart cities that can address climate change mitigation and adaptation to its impacts.

The literature surrounding smart cities and climate change reveals a significant emphasis on infrastructure resilience compared to other areas (Obringer and Nateghi, 2021). Recent studies showed that together with growing population in cities, climate change is likely to exacerbate the amount of stress on infrastructure systems by increasing the demand on water and electricity (Kumar et al., 2020; Maia-Silva et al., 2020; Mukherjee and Nateghi, 2019; Obringer et al., 2020). As aforementioned, the increasing intensity and frequency of natural hazards, extreme events due to climate change such as hurricanes, floods, heatwaves will have powerful implications on critical infrastructure systems and grid resilience (Alemazkoor et al., 2020; Alipour et al., 2019; Mukherjee et al., 2018; Raymond et al., 2019; Staid et al., 2014). To avoid water shortages or electricity blackouts during natural hazards and to prevent catastrophic outcomes, the climate change impacts on infrastructure systems have to be taken into account. Smart cities have the potential to offer some solutions to climate change mitigation and adaptation efforts in different infrastructure sectors, for example, by building up ICTs to improve the management of infrastructure systems, by establishing real-time monitoring sensors and integrated cyber-physical systems that could provide self-monitoring as well as self-healing infrastructures (Kaluarachchi, 2020; Kumar et al., 2019; Liu et al., 2017). Furthermore, a smart grid technology implementation brings a mix of decentralized and centralized power systems (Obringer and Nateghi, 2021), which enhances the resilience and flexibility against disruptions, improves overall grid reliability and increases efficiency. Decentralization of electricity generation systems provide electricity on a localized scale during natural hazards such as storms or heatwaves when the centralized generators are negatively impacted (Hayat, 2019). The mixed nature of decentralized and centralized electricity generation reduces the load on the centralized power plants therefore alleviates the stress on the power infrastructure during a heatwave, which could be interpreted as an adaptation to climate change since an essential component of adaptation would be decreasing the stress on generators for a future with more frequent extreme heatwave events. There are other benefits of smart cities to climate change mitigation efforts, for example, Hunter and coworkers (2018) argue that ICT-based smart grid systems can provide more specific consumption information which would result in reduced energy use and together with the increased efficiency, decreases the carbon footprints. The implementation of ICTs solely in energy infrastructures is not enough to make them smart, decarbonization and sustainability understandings are the key requirements for smart grid systems (Drysdale et al., 2019). Therefore, smart energy systems aid mitigation efforts by boosting the integration of renewable energy sources (Parks, 2019),

by improving the resilience of cities against climate related disasters which have negative impacts on grids such as hurricanes and heatwaves (Hayat, 2019), by increasing the efficiency and reducing the carbon footprints (Hunter et al., 2018), by modulating the load on generators with decentralized systems (Obringer and Nateghi, 2021).

An ongoing process with smart cities is the inclusion of the actual needs and participation of community. Earlier research scientists neglected the participation process of the individuals and societies. However, it is recognized by scientists that as the cumulative literature increases on the issue, more and more focus is given to this component of the term. Many of the scientists have already recognized the fact that the technologies have to be developed with a bottom-up structure which means that the technologies should firstly keep pace with the citizens' needs and then be improved but always in accordance with the needs of individuals and communities rather than having a top-down design which means developing and trying to implement technologies to which the society might not be able to keep up with may be because of their education and knowledge level. With the inclusion of this dimension, smart city initiatives will have to put more emphasis on public health and well being, both of which are expected to get affected by climate change impacts. As mentioned before, increased frequency and intensity of heatwaves will lead to many related health issues especially in cities due to the urban heat island effect (Krayenhoff et al., 2021). Exposure to heat may result in morbidity and mortality due to heat stress, heat exhaustion, heat stroke, heart attack or failure, kidney failure because of dehydration. Elderly, outdoor workers, children, socially isolated groups and other predisposed vulnerable groups such as the ones with already existing health problems including cardiovascular or respiratory disorders are identified as most at risk (Analitis et al., 2014). Furthermore, climate change may pose other issues for public health such as food insecurity due to the increased wildfires or emerging diseases. However, many smart city initiatives still lack the inclusion of public health and wellbeing as a component to their implementation. One example comes from India. Although the government's current policy is to establish smart cities around the country, they simply do not account for public health and well being and solely focus on implementing more ICT (Butsch et al., 2017; Kumar Das, 2017). Neglecting public health and well being dimension while creating smart cities will worsen the already existing inequities within society and also reduce the resilience of the city to climate change impacts (Obringer and Nateghi, 2021). There are also examples which account for the human dimension in their smart city implementations. The smart city initiative in Barcelona, Spain is also called 'public city' due to their emphasis of public health and well being component (Ricci and Mariano, 2018). China, which suffers from long-standing air pollution issues, has started employing smart technologies to monitor and announce air pollution levels for their citizens, which enables citizens to take precautions (Tambo et al., 2016). Another

study conducted in Seoul stated that determining favorable and unfavorable areas in terms of thermal comfort is a preliminary step towards creating a smart city and by the use of data from sensors they determined the areas in the city that would benefit the most from thermal comfort improvement efforts (Kwon et al., 2019).

Integrating smart cities and public health is a relatively new research area and it is criticized that the focus of applications stayed mostly in theoretical possibilities instead of physical implementations (Rocha et al., 2019). However, the challenges remain for offering concrete solutions to different threats in cities such as air pollution, emerging diseases or extreme weather events. In order to step up this research area from theory to practice and to be able to mitigate the climate related impacts on public health, creating human-centric smart cities is of crucial importance.

2.3. Holiday Climate Index

Climate has long been known to influence the attractiveness of holiday destinations (Gearing et al., 1974; Lohmann and Kaim, 1999). To be able to assess climatic factors for recreation and tourism in the era of anthropogenic climate crisis, several indices were developed during the recent decades. These indices investigate the relation between climate change and tourism by combining and scoring climatic components such as temperature, humidity, precipitation, wind speed, cloud cover. Since human comfort is a special focus of these indices, and since these indices can also account for the effects of relative humidity, which is especially dangerous for human health during periods of elevated temperatures, it is found appropriate to include one such study in this dissertation.

One of the most promising socio-economic development opportunities for Türkiye lies within the tourism industry due to the country's sunny beaches, clear sands, seas and historical attractiveness with its cultural heritages. Since mid-1980s, the tourism indicators such as hotel occupancies, arrivals, number of travelers, tourism revenue of the country have been increasing with the exception of e few interruptions, that are political crisis, terror attacks and COVID-19 pandemic (Cinar et al., 2024). Out of 100 most visited tourist destinations in the world, Türkiye owns 3, Istanbul, Antalya and Muğla which hosted 14.7, 13.3 and 2.92 million tourists in 2019, respectively (World Data, 2023). In 2021, Türkiye hosted 29.93 million visitors, generating approximately 27.9 billion US dollars, which corresponds to 3.1% of the country's gross domestic product (World Data, 2023). Even though the tourism sector and the revenues continue to grow, there is substantial, undeniable evidence that the climatic conditions will change in the country in the future. IPCC classified the Mediterranean Region as "highly vulnerable" to anthropogenic climate change (Yohe et al., 2007). The literature on climate

change impacts has consensus on that the major threat for Mediterranean tourism in the future will be the increase in temperature (A. Perry, 2005; A. Perry, 2006). Moreover, it is critical to mention that while the climatic conditions in Türkiye are expected to worsen, climatic improvements are expected in some other major touristic destinations especially in northern Europe (European Commission [EU], n.d.), which would cause further challenges for Türkiye's tourism sector. Therefore, apart from investigating future human discomfort level due to extreme heat, climate assessment for tourism and creating smart solutions for both touristic and public health purposes have crucial importance for the country.

During the 1960s and 1970s, the international tourism sector has experienced an unprecedented growth. Since then, the relationship between tourism demand and climatic conditions of the destination became an active area of research and several studies have been published by various researchers (A.H. Perry, 1972; Crowe, 1976; Singh, 1977; Freitas, 1990; Smith, 1990). Among these researchers, Mieczkowski was the first to recognize the necessity of an index capable of evaluating the favorable and unfavorable climate conditions of a tourism destination. He developed Tourism Climate Index (TCI) to assess both the present and future climatic attractiveness of such destinations (Mieczkowski, 1985). After its development, the index has been found to be useful as a research tool; therefore, it has been used intensively for several regions in the world, including Europe (Nicholls and Amelung, 2008; Perch-Nielsen et al., 2010), the Mediterranean (Amelung and Viner, 2006), Australia (Amelung and Nicholls, 2014), China (Fang and Yin, 2015), Türkiye (Abbasnia et al., 2019) and so on. TCI calculates five sub-indices by making use of seven climatic variables. Daytime Comfort Index (CID), calculated from maximum daily temperature and minimum daily relative humidity, Daily Comfort Index (CIA), calculated from average daily temperature and mean daily relative humidity, Precipitation (P), Sunshine (S) and Wind (W). The two thermal comfort sub-indices CID and CIA are given a weight of 50% in TCI calculation by Mieczkowski (1985), who argued that temperature and relative humidity are more important for tourists compared to the other components. Precipitation sub-index P, having a weight of 20%, is calculated from the monthly precipitation data. The fourth sub-index S is the hours of bright sunshine during the day. The fifth and final sub-index W is calculated from temperature and wind speed data (Mieczkowski, 1985).

Although TCI has been employed in several different studies for various regions and countries in the world, being the first index in the area, it is frequently criticized due to its deficiencies. The mostly criticized feature of the index in the literature is the fact that its development based solely on the expert opinion of Mieczkowski (1985) and therefore the rating scales and weights of sub-indices became inevitably ultimately subjective (Scott et al., 2016; Rutty et al., 2020). Given Mieczkowski

is from North America, his opinions on the issue are arguably also based on the North American climatic and cultural context and therefore they do not empirically reflect what the actual tourists would want from their preferred destinations. To give an example, from the survey studies in the literature it is now known that most of the tourists are willing to tolerate high temperatures during their visit of the seaside especially but also urban destinations, however rain is regarded as an impediment for both urban and beach destinations. Therefore, the 50% weight of thermal comfort in TCI calculations becomes unreasonable since absence of rain is more important than comfortable temperatures for tourists (Maddison, 2001; Gössling et al., 2006; Moreno, 2010; Jacobsen et al., 2011; Dubois et al., 2016). The second feature mostly criticized by scientists is that TCI does not account for overriding effects of some components, for example intensive precipitation or strong wind may cancel out all favorable weather conditions (Scott et al., 2016; Rutty et al., 2020). The third feature is the fact that TCI has low temporal resolution because it employs mean monthly data for the calculation of its sub- indices since daily or diurnal data was not readily accessible during the times of the development of the index. Finally, TCI is developed only for general sightseeing activities and it does not account for the specific requirements of beach, urban or winter sports tourism (Scott et al., 2016; Rutty et al., 2020).

In the literature for applied climatology and human biometeorology there are more than 200 climate indices developed while seeking to overcome the deficiencies of TCI (A. Amiranashvili et al., 2015). Several in-situ and ex-situ surveys have been carried out with the purpose of including actual tourist preferences and their threshold perceptions. A survey study conducted by Rutty and Scott (2010) among 850 university students from Northern Europe in order to find out the perceptions of ”too hot” or ”too cold” revealed that for most of the respondents temperatures above 37 ◦C are considered to be unacceptably hot, below 22 ◦C unacceptably cold and between 27–32 ◦C ideal for beach tourism whereas temperatures above 30 ◦C are regarded as unacceptably hot, below 17 ◦C unacceptably cold, between 20–26 ◦C ideal for urban tourism (Rutty and Scott, 2010). In the future, these perceptions of European tourists may change since they would acclimatize over time to warmer average temperatures in their hometown.

One effort to overcome the deficiencies of TCI was by Morgan and coworkers (2000) who developed the Beach Climate Index (BCI) for 3S tourism (sun, sea and sand) destinations. They conducted in situ surveys in Wales, Malta and Türkiye to account for the actual tourist preferences in the index to replace Mieczkowski’s expert opinion. Respondents included tourists from Northern Europe (N = 1354) and Mediterranean, however, the study found differences in terms of climate preferences between the tourists with different origin. Since the main tourism market for the

Mediterranean is Northern Europe (Rutty and Scott, 2010), the index was developed according to the preferences of North European beach tourists. BCI employs mean daily maximum temperatures with monthly mean relative humidity instead of TCI's mean daily temperature component since 24-h comfort index contributes minimally to beach tourism. As early morning sunshine at 5-6 a.m. is not a significant concern for beach tourism, BCI replaces total sunshine hours component of TCI with the proportion of sunshine hours for the day. Without making any other change for precipitation in TCI ratings, the weight of the component is changed according to the tourist preferences. BCI does not associate the wind component with temperature as TCI does, because wind is reported to have an overriding effect and wind speeds higher than 6 m/s are found to be uncomfortable in any weather condition (Danilova, 1974; Freitas, 1985). As a result, the equation of BCI is devised with the weights of 18% thermal sensation, 26% wind speed, 27% sunshine and 29% absence of rain. Although BCI was a solid improvement to TCI, it still has weaknesses. Firstly, the index is developed to account particularly for the preferences of North European beach users. Since it is known that the climate preferences of tourists from other locations are different from North European tourists (Freitas, 1985), the index is not applicable to other beach users. Secondly, the index is created to evaluate climatic conditions for sedentary beach use only and it is again not applicable for other daytime activities of beach tourists or other recreational tourist activities in general (Morgan et al., 2000). One study employing BCI to investigate the future climate change impact on Europe's beach tourism in summer found that even under one of the former worst case scenarios of IPCC, the impacts may be less severe than anticipated on the Mediterranean coasts (Moreno and Amelung, 2009).

Another 3S index, Climate Index for Tourism (CIT), was developed in 2008 by De Freitas and colleagues (2008) who utilized a survey between university students (N=331) to determine the ratings of three facets of the index, that are thermal, aesthetic (sky conditions) and physical (precipitation and wind). The strength of CIT is that it brought a new perspective to index calculation in this research area by leaving the simple addition of sub-indices and by setting threshold values for precipitation and wind speed in order to take their overriding effect into account. The wind speed threshold of 6 m/s and the precipitation threshold of 3 mm or 1 hour duration were determined based on the survey results, and if one or both thresholds exceeded, then the physical facet outweighs any benefits of favorable thermal or aesthetic facets. Moreover, according to the responses of the students, the study revealed that scattered cloud is more favorable compared to clear sky and gentle breeze is crucial. The primary drawbacks of CIT are it does not have multicultural information since the survey was conducted in only one country, the sample group had a limited age spectrum (university students), and its area of usage is limited to 3S tourism like BCI (Demiroglu et al., 2020). In 2009, Modified Climate Index for Tourism (MCIT) was introduced with certain improvements on CIT (Yu et al.,

2009a). Two new sub-indices were added to the equation, visibility and significant weather (hail, snow, lightning, etc.) which could hinder several touristic activities. Sunshine and cloud cover sub-indices were removed since they do not have a significant effect on the execution of the activity. As a result, MCIT employs 4 sub-indices that are perceived temperature (accounts for the wind), wind speed, visibility and significant weather to classify the climatic conditions for tourism as unsuitable, marginal or ideal. Furthermore, MCIT replaces the daily average or daily maximum data with hourly data, giving the index higher temporal resolution compared to CIT. Another critical point of employing hourly data is that by this method the index can show the difference of equal volume of rain falling in one hour or spreading out over 10 hours of drizzle, which poses a great deal of difference for tourists. Another improvement of MCIT is that it can be applied to various tourism areas such as sightseeing and winter sports (Yu et al., 2009b). The weaknesses of MCIT are that it did not utilize the available literature on actual tourist preferences while determining the weights of the sub-indices and hourly data is not readily available for many destinations which causes a substantial obstacle for the utilization of this index (Demiroglu et al., 2020).

Although there were a few more efforts to improve the deficiencies of previous indices, such as Relative Climate Index (Li et al., 2017) and Beach Utility Index (Georgopoulou et al., 2018), they still had several weaknesses. These include small sample size and stratification, not accounting for the overriding effects of physical facets and most significantly the oversight of the effect of relative humidity on perceived temperature, which has crucial importance for the purposes of this dissertation.

One of the tools employed in this dissertation, the Holiday Climate Index (HCI) (Scott et al., 2016), was introduced in 2016 with the purpose of overcoming the various weaknesses of previous tourism climate indices. HCI can be distinguished from other indices through its several improvements and capabilities. Firstly, instead of employing a survey only in one country or only in one destination or only with a small sample group, HCI utilizes the existing literature on climatic preferences of tourists over a range of surveys conducted over the previous decade. The rating scales and weighing schemes of the facets and sub-indices are determined accordingly, therefore HCI is not based on subjective opinions of the creators of the index or of a small group of people. The weight of precipitation in TCI is increased to 30% in alignment with the specified tourist preferences and CIA component of TCI is removed because daily comfort index becomes irrelevant due to the intensive use of air conditioners at several destinations. Secondly, in order for the index to be applied to different tourism segments with different climatic demands, HCI is divided into HCI:Beach and HCI:Urban which have different weighing schemes for thermal sub-indices and cloud cover, in alignment with the specified tourist preferences. Thirdly, HCI utilizes daily data instead of monthly

data in order to address the low temporal resolution shortcoming of TCI. Finally, in order to account for the overriding effects of precipitation, wind and other physical facets HCI assigns a score of zero or even negative ratings when the predetermined thresholds are exceeded, again in accordance with the stated tourist preferences. The design of HCI meets all the fundamental requirements of a comprehensive and universal index (De Freitas et al., 2008). Moreover, HCI stands out among the rest of the indices with one more significant strength, it was empirically tested by two independent studies. The first study validated average monthly HCI:Urban scores with hotel occupancy in Paris (Scott et al., 2016) and the other study validated average monthly HCI:Urban scores with Canadian tourist arrivals to three different Caribbean destinations, that are Antigua and Barbuda, Barbados, Saint Lucia (Rutty et al., 2020). Last but not least, to maximize the explanatory power of the index, an optimization algorithm was utilized on visitation data of two provincial beach parks in Ontario, Canada (Matthews et al., 2019). By employing different weighing schemes and ratings for different parks, authors devised a methodological approach to tailor the index for the specified tourist preferences of specific destinations.

In 2021, a study was conducted to investigate the relation between HCI and public health by comparing the scores of HCI with health metrics of ambulance calls, hospitalizations, mean monthly values of mortality due to cardiovascular diseases and total mortality in Tbilisi and the Kakheti region (namely six locations of Dedoplistskaro, Gurjaani, Kvareli, Lagodekhi, Sagarejo, Telavi) of Georgia (Amiranashvili et al., 2021). The findings of the study reveal that the bioclimatic index HCI showed a second degree polynomial relationship with mortality due to cardiovascular diseases in Tbilisi. The index showed second-degree polynomial relationship with total mortality, ambulance calls and hospitalizations in Kakheti. For both regions, higher HCI scores correlated with lower mortality, and generally associated with decreases in other health metrics. Extremely high HCI scores resulted in slight increase in mortality and other metrics for both of the regions. Therefore, the findings of the study show that HCI is a significant measure of bioclimatic comfort and can be connected to public health indicators and increased bioclimatic comfort aligns with better public health up to a point. After this point, very high HCI scores result in increases in adverse health outcomes (Amiranashvili et al., 2021).

Here in this dissertation the HCI scores for Türkiye were investigated for the reference period of 1971-2000 and future periods of 2021-2050 and 2070-2099 with the use of two emission scenarios RCP4.5 and 8.5. By employing lapse rate corrections (Steiger, 2010) which extrapolates the climate model topography against a resampled digital elevation model, the outputs were adjusted to 500 m resolution. Moreover, the Humidity Index (Humidex), which gives a measure of how the weather is

perceived to the average person by accounting both for temperature and humidity, were utilized in the study in order to provide guidance on heat related human health concerns.

2.4. Extreme Temperature Indices

The scientific interest in climate extremes has progressed significantly due to the aforementioned catastrophic extreme heatwave and other extreme events over the last few decades (Donat et al., 2013a; Zwiers and et al., 2013). Due to the rare nature of extreme events, there is not abundance of data to make assessments on either their frequency or severity (IPCC, 2012). Moreover, since extreme events are multifaceted like many climate phenomena and since they are difficult to monitor, international coordinated efforts were needed in order to ease the research, as well as to encourage the comparison of observed and projected data (Ozturk et al., 2021). These coordinated efforts to collect, quality check, analyze and publish more extreme aspects of climate change provided the development of the literature in the area. One momentous effort and contribution has been conducted by the Expert Team on Climate Change Detection and Indices (ETCCDI), who enabled the calculation of climate extreme event indices by using daily precipitation and temperature data. Out of the total of 27 extreme indices, which can be viewed in the work of Sillmann and colleagues (2013a), 16 are based on temperature and 11 are based on precipitation data. Since precipitation extremes are beyond the scope of this dissertation, only the temperature extreme indices will be considered hereafter. Future changes of precipitation extremes can be viewed in our published study (Ozturk et al., 2021). Here in this dissertation, a subset of the temperature extreme indices was selected and used, which presents a broad and comprehensive overview of the future changes in temperature extremes under a changing climate.

The indices have found a broad application area in climate research and also other related areas since they are easy to interpret and give robust results (Sillmann et al., 2013b). Scientists have used these indices in order to investigate and monitor the changes in extreme events with the use of observational data (Frich et al., 2002; Alexander et al., 2006; Donat et al., 2013a; Ntoumos et al., 2020), projected future data provided by climate models (Kharin et al., 2007; Sillmann and Roeckner, 2008; Orlowsky and Seneviratne, 2012; Sillmann et al., 2013b; H. Chen and J.Q. Sun, 2014) and also in order to evaluate climate model performances (Kharin et al., 2013; Sillmann et al., 2013b). Since the indices are able to perform extreme event analysis on a regional basis, they have been used to evaluate climate model performances regionally (C. Chen and Knutson, 2008) and many studies have been conducted in different regions of the world in the last decades, for example in Australia (Alexander and Arblaster, 2007), North America (Peterson et al., 2008; Thibeault and Seth, 2014),

the United States (Scherer and Diffenbaugh, 2013), the Mediterranean Basin (Gao and Giorgi, 2008), countries of Western Indian Ocean (Vincent et al., 2011), the Arab Region (Donat et al., 2013b), China (Chen and Sun, 2015; You et al., 2008; Fan et al., 2012), Iran (Soltani et al., 2015), Egypt (Roushdi et al., 2016), Central and South Asia (Tank et al., 2006), East Asia (Lee et al., 2020), Ethiopia (Berhane et al., 2020; Shawul and Chakma, 2020; Degefu et al., 2021), Saudi Arabia (Islam et al., 2015). Moreover, the indices were employed for various detection and attribution studies (Morak et al., 2013; Fischer and Knutti, 2014). Collaborative studies with the use of extreme indices has shown that for many parts of the world, changes in temperature extreme events are usually in accordance with the changes in average temperatures. However, due to the sea ice and snow melting as a result of global warming, cold extremes are shown to be warming faster than warm extremes (Kharin and Zwiers, 2000; Kharin and Zwiers, 2005). Warm extremes are expected to have larger relative increases compared to the average summer temperatures since summertime temperature variability is found to be increasing over land (Kharin and Zwiers, 2005; Kharin et al., 2007; Lee et al., 2014)

Here in this part of the dissertation, the projected changes in temperature related climate extreme indices defined by ETCCDI over Türkiye for the end of 21st century are investigated. As mentioned before, Türkiye, being in the CORDEX Region 13, that is Middle East and North Africa Region, has well-recognized high vulnerability to negative effects of climate change (Waha et al., 2017). Due to its high potential of having extreme events in the future, scientists have been conducting studies by employing climate extreme indices throughout whole MENA region.

One study (Zhang et al., 2005) conducted at 52 stations covering 15 countries in MENA for the period of 1950–2003 with extreme indices indicated that annual maximums of daily maximum and minimum temperatures, the annual minimums of daily maximum and minimum temperatures, the number of summer days where the daily maximum temperatures were above 25 °C, and the quantity of days where daily temperature was higher than its 90th percentile, all showed increasing trends. Another study (Lelieveld et al., 2016) employing the extreme indices conducted with CMIP Phase 5 climate model simulations with the use of RCP4.5 and RCP8.5 scenarios found that MENA differs from rest of the world by showing strongest climate warming in summer, while for the rest of the world it is typically in winter. Moreover, while the hot desert climate is found to be intensifying and becoming more extreme, summertime warming is extending the thermal low or heat low, which is a low-pressure area resulting from high temperatures, at the surface from South Asia across MENA. Another study investigating climate extreme events in MENA for the future by employing a regional climate model called ALADIN-Climate showed that extreme heatwave events will increase in

duration, frequency and intensity in MENA. Depending on the scenario, the projected increase in temperature is found to be between 0.2 to 0.5°C/decade over land. Moreover, the study states that considering both the precipitation and temperature indices, the increase in drought will be at a higher rate and the findings of ALADIN-Climate Model corroborates the previous studies employing different regional climate models (Driouech et al., 2020). Zittis et al., 2021). On the other hand, the study employed Heat Wave Magnitude index but with the use of a comprehensive ensemble of regional climate simulations to investigate future periods of extreme heat in MENA under the RCP8.5 scenario found that MENA will experience super- and ultra- extreme heat waves, which are potentially life threatening with extended duration (several weeks) of temperatures exceeding 56°C in the second half of the 21st century (Zittis et al., 2021). The study indicates that by the end of the 21st century, the urban population in MENA will be experiencing annually occurring super- and ultra-extreme heatwaves, which will have many negative impacts on many sectors such as agriculture, water and energy, labor productivity, biodiversity, livestock, etc. Therefore, it is of crucial importance to assess regional precautions, underline the mitigation and adaptation measures based on the robust information provided by the climate projection studies (Zittis et al., 2021).

It is unfortunate that there are not many studies in the literature that investigate the changes in temperature extremes and therefore extreme heatwave events over Türkiye, neither at regional nor local scales (Vilibić et al., 2019). One study conducted in 2013 employed the indices with observational data from 109 stations in Türkiye over the period of 1960-2010 (Sensoy et al., 2013). Although the study calculated both temperature and precipitation extreme indices, here in this dissertation only the temperature related results will be discussed. Table 2.4 shows the selected heat and temperature related extreme climate indices of ETCCDI with their definitions and units, still the definitions will be shortly mentioned in the text to ease the reading since there are many indices. The findings of the study showed that numbers of summer days (SU25), which is the count of the days with daily maximum temperature (TX) higher than 25°C, have been showing an increasing trend over all Türkiye, especially in the northern regions, with an estimated mean increase of 39 days in 100 years. Tropical nights index (TR20), which is defined as the number of days in a year with minimum daily temperatures above 20°C, followed an increasing trend with an estimated mean increase of 37 days in 100 years only with the exception of Tigris-Euphrates Basin, and Elazığ which experienced a decreasing trend after the construction of Keban Dam. The presence of a dam in a region is shown to cause significant variations in climate of the region, such as increases in monthly minimum temperature, decreases in monthly maximum temperatures and monthly average temperatures (Arslan, 2017). Warm days index (TX90p), defined as the number of days when daily maximum temperature is above the 90th percentile, has been found to increase in all 109 stations of Türkiye

with an estimated average increase of 14 days in 100 years. Warm nights index, the number of days when the daily minimum temperatures are above the 90th percentile, also showed an increasing trend over all Türkiye, again with the exception of Tigris-Euphrates Basin, and the average increase has been found to be 15 days in 100 years. Cool days (TX10p) and cool nights (TN10p) indices, that are the number of days with maximum daily temperature is below 10th percentile and with minimum temperature below 10th percentile respectively, were found to show a decreasing trend for 99 and 89 stations with an estimated mean decrease of 6 and 15 days in 100 years, respectively. Warm spell duration indicator (WSDI), which is defined as the number of days with at least 6 consecutive days when daily maximum temperature is above the 90th percentile, has been found to be increasing all over Türkiye with the exceptions of Marmaris, Bayburt, Yüksekova, Kilis, Kırklareli, Kayseri, Ceylanpınar and Tunceli. The estimated average increase in WSDI was calculated to be 23 days in 100 years. For all the results, most of the trends were stated to be statistically significant at the 95% level (Sensoy et al., 2013).

Table 2.4. List of the selected heat related extreme climate indices of ETCCDI (Sillmann et al., 2013b).

Index	**Indicator name**	**Definition**	**Unit**
SU25	Summer days	Annual count when TX (daily maximum) > 25 °C	Days
TR20	Tropical Nights	Annual count when TN (daily minimum) > 20 °C	Days
TXx	Max T_{max}	Annual maximum of daily maximum temperature	°C
TNx	Max T_{min}	Annual maximum of daily minimum temperature	°C
TXn	Min T_{max}	Annual minimum of daily maximum temperature	°C
TNn	Min T_{min}	Annual minimum of daily minimum temperature	°C
TN10p	Cool nights	Exceedance rate of days when TN < 10th percentile	%
TX10p	Cool days	Exceedance rate of days when TX < 10th percentile	%
TN90p	Warm nights	Exceedance rate of days when TN > 90th percentile	%
TX90p	Warm days	Exceedance rate of days when TX > 90th percentile	%
WSDI	Warm spell duration	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days

Another study used observational data obtained from seven meteorological stations across the Mediterranean region of Marmara, which is stated to have the highest climate variability of all geographical regions of Türkiye, to calculate the ETCCDI extreme event indices in Türkiye for the period of 1961-2016 (Vilibić et al., 2019). The results of the study showed that while the intensity

and frequency of the warm temperature extremes increased, the intensity and frequency of cold temperature extremes decreased continuously in Marmara during the study period. The summer days index (SU25) has been found to strongly increase over the study area while the metropolitan areas such as Sarıyer, Yalova showed significantly higher trends. SU25 increased 4 days per decade in average throughout the region. The warm days (TX90p) significantly increased and the highest increase of 2 days per decade detected in Sarıyer, Tekirdağ and Edirne, which meant extremely warm days were affecting mostly the metropolitan and inland areas of the region (Vilibić et al., 2019). Tropical nights (TR20) showed a statistically significant positive trend in all stations of the study. While the mean increase in tropical nights was found 7 nights per decade, coastal station of Çanakkale showed the highest rate with 10.2 days per decade. Warm spell duration index (WSDI) showed a remarkable increase especially for Edirne and Sarıyer with 2 days per decade. WSDI can be regarded as a good indicator that the region is experiencing persistent warm conditions (Vilibić et al., 2019). On the other hand, the study found that the cool days index (TX10p) has shown a decreasing trend throughout the study area, with an average rate of 1 day per decade. Highest decreases were in urbanized regions such as Yalova, Sarıyer, Tekirdağ. Similarly, cool nights index (TN10p) followed a significant decreasing trend with the highest decrease of 2 nights per decade in Çanakkale and Bursa (Vilibić et al., 2019). The findings of this study were consistent with the findings of 2013 study by Şensoy and colleagues (2013).

One recent study employing the ETCCDI extreme and relative value indices over Türkiye assessed the long term changes in temperature extremes over the period of 1960-2019 by the use of observational data of daily maximum, minimum, and mean temperatures from 61 stations (Ciftci and Sahin, 2023). The findings of the study revealed a general upward trend in temperature indices with the monthly minimum value of the daily maximum temperature (TXn) increasing 2°C per decade. The findings of the study revealed a significant increase in temperatures during the summer months compared to the other months and this anomaly was detected to be more pronounced in metropolitan areas such as İstanbul, Ankara, İzmir and Antalya due to the urban heat island effect. Moreover, the study states that energy consumption mostly because of the increase in air conditioning due to urban warming should be expected to increase especially in summer and for these 4 cities in Türkiye. The study also reports that there are some studies in the literature demonstrating strong correlation between temperature increase and electricity consumption by the use of principal component analysis and linear multiple regression (Ciftci and Sahin, 2023; Dogan et al., 2016a; Dogan et al., 2016b). Moreover, the study revealed significant increasing trends in TX90p and TN90p and significant decreasing trends in TX10p and TN10p for all regions in all seasons, which are consistent with the findings of other studies.

There are other studies in the literature employing extreme climate indices globally, therefore providing results for Türkiye to some extent, however, all these studies are not sufficient to assess the variations in extreme temperatures on a regional level (Ciftci and Sahin, 2023) especially for the future, therefore cannot provide the basis for efforts of mitigation, adaptation or for taking precautions against extreme heatwave events. Here, the objective of this part of the dissertation is to detect extreme temperature events and subsequently investigate the occurrence of such events by calculating the projected changes in extreme temperature indices of ETCCDI over Türkiye for the future, which was never done before. Therefore, a set of selected extreme indices were analyzed over Türkiye for the period of 2071-2100 with respect to the reference period of 1971-2000 under the emission scenarios of RCP4.5 and 8.5 with two different global climate models. By the use of regional downscaling model, comprehensive information, which is critical for decision making, is provided to be used as a reference or guide for the purposes of urban planning, mitigation and adaptation efforts, and essential health related precautions on both local and regional scales.

3. MATERIALS AND METHODS

3.1. Holiday Climate Index

The methodology employed in this dissertation for HCI can be categorized in 5 sections namely, collection of dynamically downscaled data from the regional climate model of RegCM version 4.3 of the Abdus Salam International Centre for Theoretical Physics (Giorgi et al., 2012), temperature adjustments according to the lapse rate corrections, computation and visualization of HCI scores, preparation of a basic climate service on the web page of iklimBU in order to share the complete results interactively with interested parties and finally, validation and calibration of HCI:Beach according to the hotel occupancy data of Antalya.

3.1.1. Climate Data

The steps followed in this study for the calculation of HCI scores together with Humidex values are shown in a flowchart in Figure (3.1). Here, the outputs of the MPI-ESM-MR (Max Planck Institute Earth System Model Mixed Resolution) global circulation model have been downscaled to 50 km resolution with the RegCM4.3. There are three main reasons of choosing MPI-ESM-MR as the driving global climate model for this study. Firstly, the performance of MPI-ESM-MR, as well as the HadGEM2-ES (Met Office Hadley Center Earth System Model), is found to be relatively better compared to the other GCMs over the CORDEX MENA domain (Endris et al., 2015). Secondly, RegCM was proven to give outputs in a better agreement with the observational data, when the projections were made by employing MPI-ESM-MR data compared to HadGEM2-ES data for MENA region (Ozturk et al., 2018). Thirdly, MPI-ESM-MR uses a “365-day” calendar and it takes the leap years into consideration, while HadGEM2-ES uses a “360-day” calendar where every year is considered to be 12 months, each of which has 30 days. Since HCI employs daily data, MPI-ESM-MR provides more realistic data for the objectives of this dissertation.

In order to get robust and realistic outcomes as much as possible, working with high spatial resolution as well as high temporal resolution has essential importance. For this reason, the initial plan was to employ horizontal resolution of 0.22° MENA-CORDEX data, which corresponds to approximately 25 km, however, the RCP4.5 scenario datasets were not readily accessible for MENA domain on the Earth System Grid Federation (ESGF) servers when the analysis was conducted. Therefore, the historical and future data under RCP4.5 and RCP8.5 were retrieved from the MPI-

ESM-MR global climate model dataset of Boğaziçi University Center for Climate Change and Policy Studies (iklimBU) and dynamically downscaled to a horizontal resolution of 0.44° data, which corresponds to approximately 50 km, by the use of RegCM4.3.

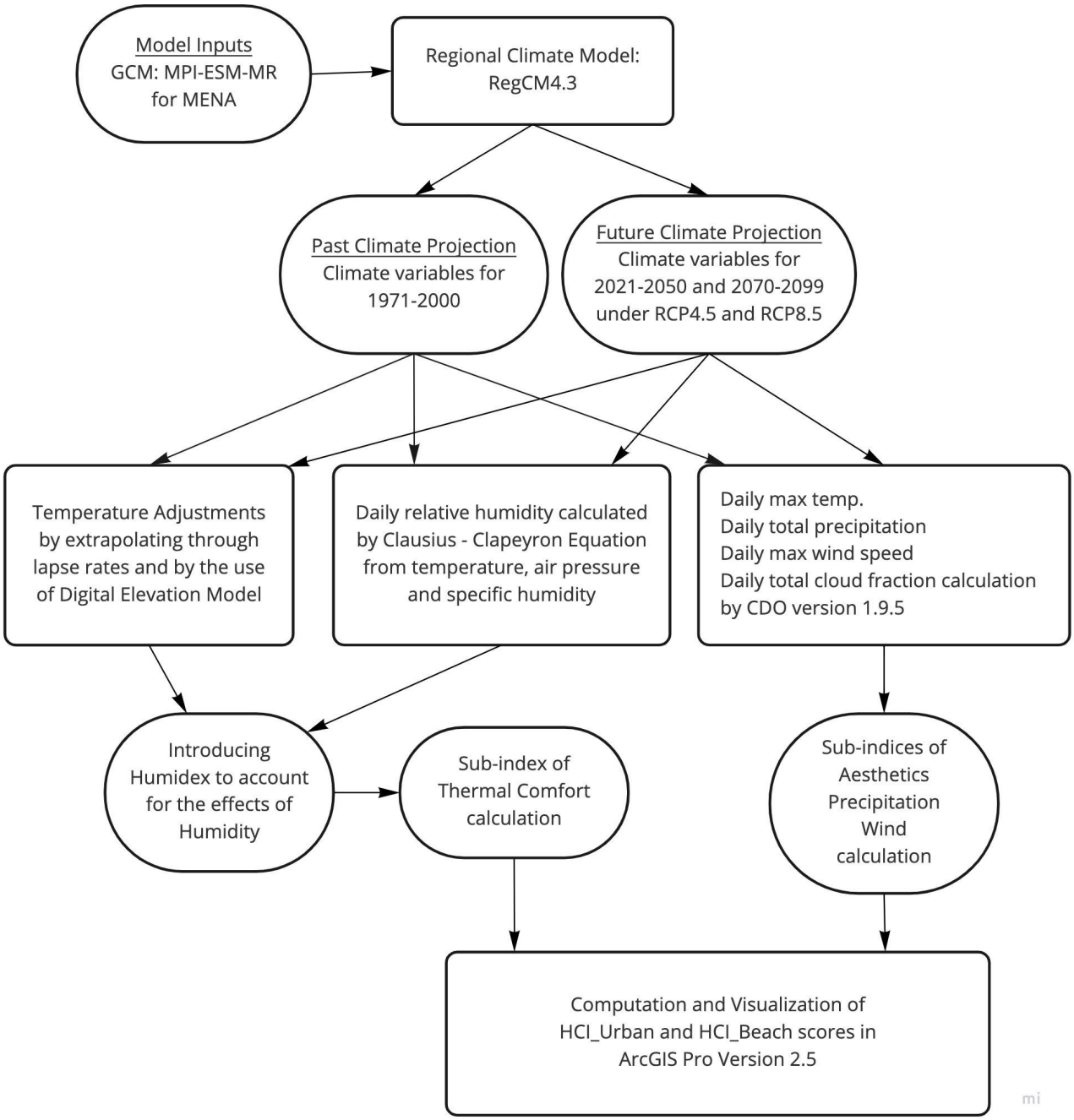

Figure 3.1. Steps of employing the simulated reference and future period climate data to compute HCI scores and Humidex values.

Finally, the climate variables required for HCI were computed for the reference period of 1971- 2000 and the future periods of 2021–2050 and 2070–2099 under the two emission scenarios. With the use of Climate Data Operators (CDO) version 1.9.5 (Schulzweida, 2018), three-hour RegCM outputs of daily maximum temperatures, daily total precipitation, daily maximum wind

speed and daily total cloud fraction were obtained. By the use of Clausius-Clapeyron Equation from specific humidity, temperature and air pressure, daily relative humidity was computed.

3.1.2. Temperature Adjustments

As the objective of this study is to provide meaningful outcomes for both tourism and extreme heat related health sectors, necessary adjustments were made in order to accurately capture details in topographically diverse grids particularly at urban and coastal areas, which may result in under or overestimation of climate outputs. One approach to address this issue is to extrapolate the temperature outputs with the use of lapse rate corrections (steiger2010impact) and vertical residuals obtained from the differences between the model topography and a high resolution Digital Elevation Model (DEM). Therefore, deviations in elevation between MENA region topography and Shuttle Radar Topography Mission (SRTM) version 4.1 DEM at 500 m resolution (Jarvis et al., 2020) were computed in order to adjust the simulated temperature outputs with an environmental lapse rate of 0.5 ◦C/100 m for the entire study region. In Figure 3.2, the advancements achieved through this method by using the case of Antalya, improvements on the spatial resolution of maximum summer temperatures and their resultant HCI scores for the reference period 1971-2000 are shown. After the refinement of temperature simulations, lower band of the range was extended by 12.7 °C to enhance the distinction of mountainous landscapes. This way, the remaining geoprocessing workflow (refer to Section 3.1.3 and Figure 3.3 for more details) can be conducted on 500 m cell size of the refined temperature raster. Therefore, all the throughput and output data for Humidex and HCI calculations can now be spatially adjusted. Figure 3.2 demonstrates the preadjusted and adjusted versions of HCI scores representing slightly larger climate model grids and DEM resolutions grids respectively for the case of Antalya.

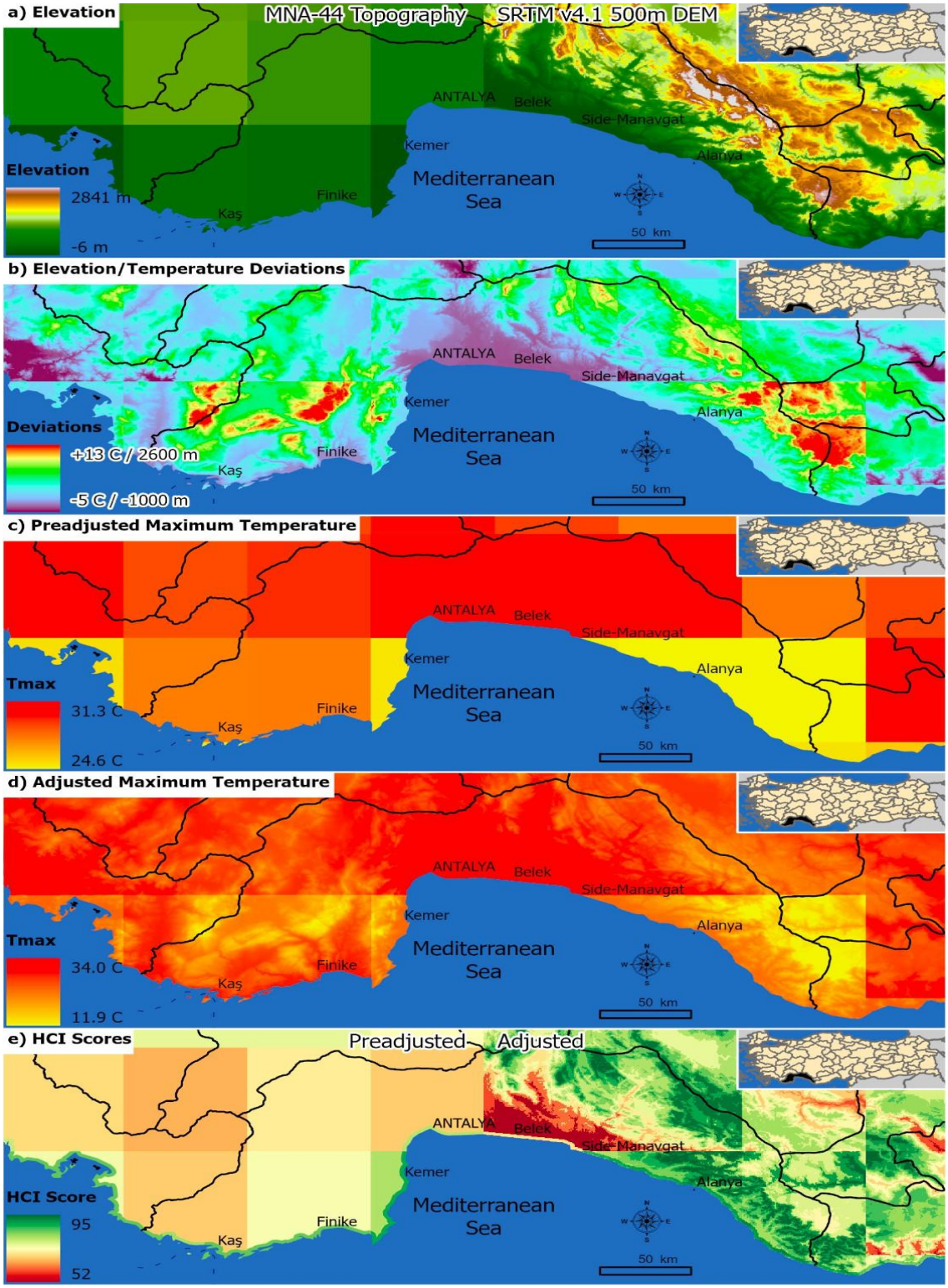

Figure 3.2. Digital Elevation Model based lapse rate refinements on the maximum summer temperature outputs in Antalya, Türkiye for the period of 1971-2000.

(a) MENA-44 Topography vs SRTM version 4.1 500 m Elevations

(b) Elevation/Temperature Deviations

(c) Maximum summer temperature before refinement

(d) Maximum summer temperature after refinement

(e) MENA-44 Topography vs SRTM version 4.1 500 m HCI scores.

3.1.3. GIS-Based HCI Computations and Visualizations

In order to calculate HCI scores, a geoprocessing model was employed in this study. Geoprocessing models are simply conceptual frameworks used for automating and streamlining spatial data analysis and geographic information system (GIS) tasks. Their primary feature is to transform input datasets into desired outputs through a series of processing steps by employing a sequence of interconnected operations or tools. They are frequently created and managed by a GIS software, such as ArcGIS. They automate repetitive tasks, such as iterations as used in this study, ensure and maintain consistency in analysis, and improve productivity by executing complex workflows with minimum manual input. Here in this study, ArcGIS Pro version 2.5 was utilized to create the Batch Geoprocessing Model. Figure 3.3 shows the stages of model workflow for the calculation of HCI scores with Humidex values. Firstly, to obtain the initial input datasets for the model, the daily CDO outputs of maximum temperature, relative humidity, cloud cover, precipitation, wind speed were compiled into seasonal means and recorded in spreadsheets for the reference 1971–2000 and study periods of 2021–2050, 2070–2099 under RCP4.5 and RCP8.5 pathways. All the variables were vectorized and rasterized for each grid point with an optimal resolution of 0.61° in order to maintain a continuous cellular coverage while minimizing loss of granularity. Then, by reclassifying these raster layers, the four sub-indices of HCI (Thermal Comfort, Aesthetics, Precipitation and Wind) were obtained in accordance with the ratings on Table 3.1 for HCI:Beach and Table 3.2 for HCI:Urban. For the Thermal Comfort sub-index, after the refinements explained in the previous section, an additional correction was made in order to account for humidity effects. For this purpose, the Humidex Equation 3.1 (Burke et al., 2006; Government of Canada, 2020), which underscores the additive effects of relative humidity on perceived temperature, was employed as in the study by Rutty et al. (Rutty et al., 2020). Then, by the use of Equation 3.2 for HCI:Beach and Equation 3.3 for HCI:Urban, and with the output cell size set to 500 m of the Thermal Comfort layer, final HCI scores were calculated. These scores were further reclassified in accordance with the HCI rating schemes on Tables 3.1 and 3.2. It is critical to mention that the original articles (Scott et al., 2016; Rutty et al., 2020) give a range of HCI score between 0 and 100, while extreme cases based on the equations can actually yield negative scores, which was the situation in this study. These extreme cases were also rated as “dangerous” for tourism in this study. While visualizing these HCI scores, “great discomfort” and “dangerous” ratings of Humidex were also visualized to enable the health related risk discussion from both HCI and perceived temperature perspectives. The four seasons were visualized separately with five periods (reference and future periods under RCP4.5 and RCP8.5) in our published article, however, in this dissertation only the spring and summer seasons were presented since extreme heat events are related to these seasons. Additionally, a specific focus on the case of

Antalya were displayed. While the HCI:Urban ratings portray the entire region, HCI:Beach ratings were clipped along a 2 km wide strip along the shorelines of seas including some minor islands and major lakes based on the digitization by Natural Earth (Natural Earth, 2020).

$$Humidex = T + \frac{5}{9} \times \left(\left(6.112 \times 10^{\left(\frac{7.5 \times T}{237.7+T}\right)} \times \frac{H}{100} \right) - 10 \right) \quad (3.1)$$

$$HCI: Beach = 2(TC) + 4(A) + 3(P) + (W). \quad (3.2)$$

$$HCI: Urban = 4(TC) + 2(A) + 3(P) + (W) \quad (3.3)$$

3.1.4. Climate Service

The study area of our original work of HCI calculations (Demiroglu et al., 2020) was the Greater Mediterranean, extending its hinterlands to the Red Sea and the Persian Gulf in the east, and the Canary Islands in the west. Therefore, the breadth of findings of this study from climate modelling and geoprocessing chain was extensive on a very large area. For this reason, a basic climate information service, Holiday Climatology of the Mediterranean (HCM), was launched on the webpage of iklimBU (https://climatechange.bogazici.edu.tr/en/holiday-climatology-of-the-mediterranean/). This way, a specific focus on any area of interest in this large research region, such as Türkiye as in this dissertation, was made possible. Similar platforms designed for tourism stakeholders are becoming increasingly popular. In spite of the challenges of their use in the beginning (Damm et al., 2019), various macro-regional services have already been created (Matthews et al., 2021; Morin et al., 2021; The Copernicus Programme, 2024). All 60 layers of the results (4 seasons, 5 periods, 3 indices) were shared via a web map with a visualization setup which utilizes rapid rendering by the use of pre-generated tiles, hosted by Umeå University's ArcGIS Online (AGOL) organization. For each period and scenario, the three index layers were integrated and further aligned in AGOL Map Viewer Beta, and finally embedded into iklimBU's web page, where any user can zoom in and see the findings of the study for their place of interest.

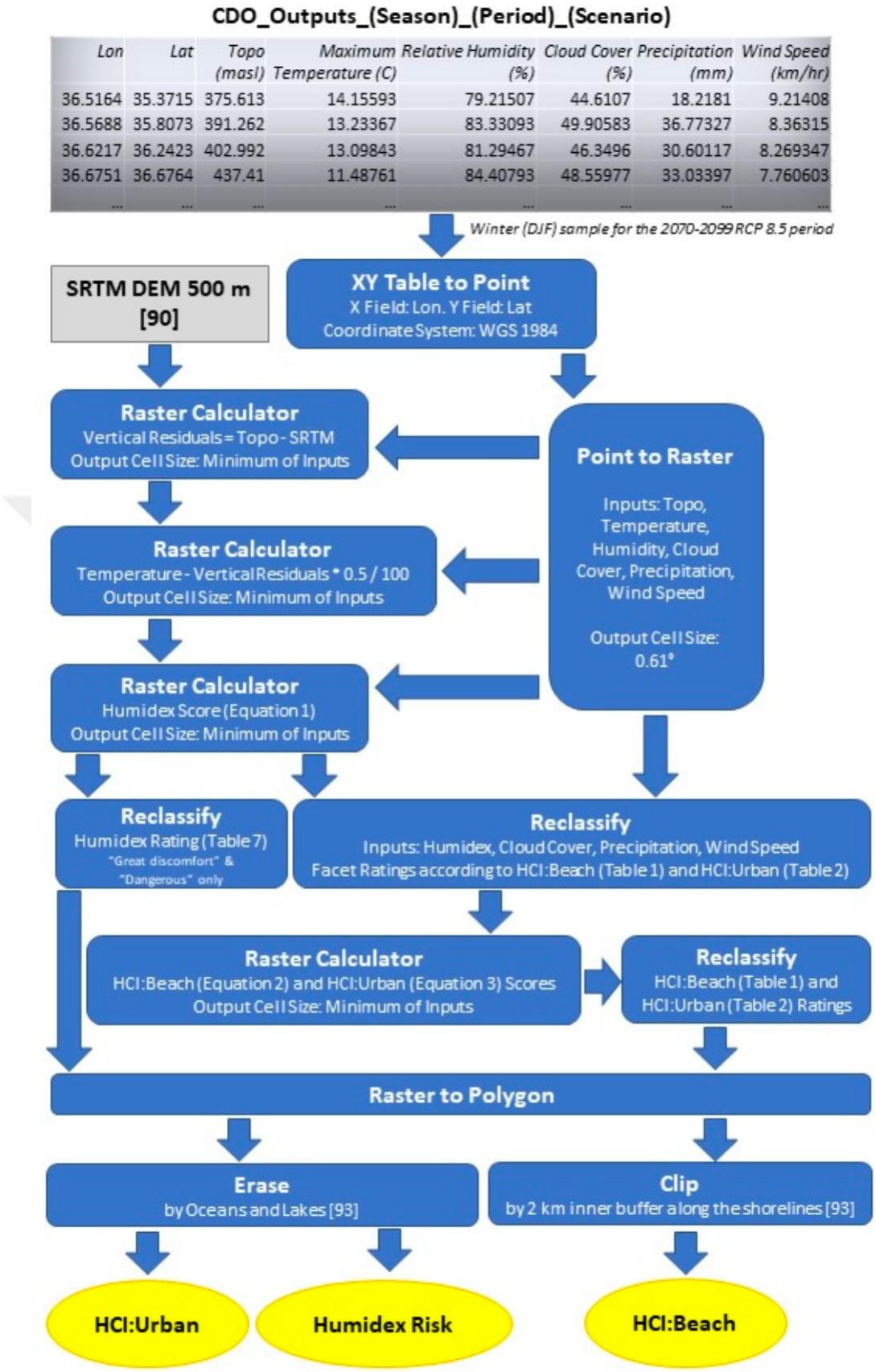

Figure 3.3. Steps of the Batch Geoprocessing Model Workflow on Climate Data Operator (CDO) Outputs for the HCI Variables. The model is iterated for each dataset of different seasonal averages, periods and scenarios.

Table 3.1. The ratings of thermal comfort (according to Humidex), aesthetic (according to cloud cover), precipitation, wind facets and HCI:Beach. Compiled from Scott et al., 2016 and Rutty et al., 2020.

THERMAL COMFORT (TC)			**AESTHETIC (A)**			**PRECIPITATION**			**WIND**			**HCI BEACH SCORE**		
Humidex			**Cloud cover**											
Min	*Max*	**Rate**	*Min(%)*	*Max(%)*	**Rate**	*Min(mm)*	*Max(mm)*	**Rate**	*Min(km/hr)*	*Max(km/hr)*	**Rate**	*Min*	*Max*	**Rate**
-9999	9.9	-10	0	0.99	8	0	0.01	10	0	0.59	8	-25	19.99	Dangerous
10	14.99	-5	1	14.99	9	0.01	2.99	9	0.6	9.99	10	20	39.99	Unacceptable
15	16.99	0	15	25.99	10	3	5.99	8	10	19.99	9	40	49.99	Marginal
17	17.99	1	26	35.99	9	6	8.99	6	20	29.99	8	50	59.99	Acceptable
18	18.99	2	36	45.99	8	9	11.99	4	30	39.99	6	60	69.99	Good
19	19.99	3	46	55.99	7	12	24.99	0	40	49.99	3	70	79.99	Very Good
20	20.99	4	56	65.99	6	25	9999	-1	50	69.99	0	80	89.99	Excellent
21	21.99	5	66	75.99	5				70	9999	-10	90	100	Ideal
22	22.99	6	76	85.99	4									
23	25.99	7	86	95.99	3									
26	27.99	9	96	9999	2									
28	30.99	10												
31	32.99	9												
33	33.99	8												
34	34.99	7												
35	35.99	6												
36	36.99	5												
37	37.99	4												
38	38.99	2												
39	9999	0												

Table 3.2. The ratings of thermal comfort (according to Humidex), aesthetic (according to cloud cover), precipitation, wind facets and HCI:Urban. Compiled from Scott et al., 2016 and Rutty et al., 2020.

THERMAL COMFORT (TC)			**AESTHETIC (A)**			**PRECIPITATION**			**WIND**			**HCI URBAN SCORE**		
Humidex			**Cloud cover**											
Min	*Max*	**Rate**	*Min(%)*	*Max(%)*	**Rate**	*Min(mm)*	*Max(mm)*	**Rate**	*Min(km/hr)*	*Max(km/hr)*	**Rate**	*Min*	*Max*	**Rate**
-9999	-6	1	0	0.99	8	0	0.01	10	0	0.01	8	-11	19.99	Dangerous
-5.99	-0.01	2	1	10.99	9	0.01	2.99	9	0.02	9.99	10	20	39.99	Unacceptable
0	6.99	3	11	20.99	10	3	5.99	8	10	19.99	9	40	49.99	Marginal
7	10.99	4	21	30.99	9	6	8.99	5	20	29.99	8	50	59.99	Acceptable
11	14.99	5	31	40.99	8	9	11.99	2	30	39.99	6	60	69.99	Good
15	17.99	6	41	50.99	7	12	24.99	0	40	49.99	3	70	79.99	Very Good
18	19.99	7	51	60.99	6	25	9999	-1	50	69.99	0	80	89.99	Excellent
20	22.99	9	61	70.99	5				70	9999	-10	90	100	Ideal
23	25.99	10	71	80.99	4									
26	26.99	9	81	90.99	3									
27	28.99	8	91	99.99	2									
29	30.99	7	100	101	1									
31	32.99	6												
33	34.99	5												
35	36.99	4												
37	38.99	2												
39	9999	0												

3.1.5. Validation and Calibration

Even though HCI:Urban was found to perform better than TCI for major urban destinations, such as Barcelona and Istanbul, HCI:Beach needs to be validated with greater urgency for various destinations and primary markets. As mentioned before, Matthews and colleagues (2019) were the first to attempt improving the R^2 determination coefficient by treating the HCI:Beach scores as explanatory variables to forecast observed visitation . They have adjusted the weights and rating schemes of sub-indices in accordance with the specific requirements of source markets and they were able to improve the R^2 values from 0.67 to 0.73 and from 0.43 to 0.66 for two different beach destinations in Ontario, Canada. Here, one of the aims of this study is the validation of HCI:Beach with the visitation data to the one of the Mediterranean's leading beach vacation destinations, Antalya (World Travel and Tourism Council, 2019). With this purpose, simple linear regression analyses were conducted between the visitation data and HCI:Beach scores. The correlation values, r, display the direction of relationship (positive or negative), and the magnitude of the relationship between the two variables as well as their constituent variables and sub-indices. As usual, r^2 values represent the model fit; in other words, they indicate how well the independent variables explain the variability of the dependent variable. The visitation data of Antalya for 2007-2015 contains monthly arrivals information from the top source markets and the total international arrivals, and it is provided from the Turkish Ministry of Culture and Tourism (Turkish Ministry of Culture and Tourism, 2020). The related climate data for the HCI:Beach scores was obtained from the ERA5 reanalysis dataset's closest grid point to the coordinates of the Turkish State Meteorological Service's (MGM) Antalya Bölge station (WMO ID: 17302), located at latitude 36.8851° and longitude 30.6828° (Copernicus Climate Change Service, 2017; Hersbach et al., 2020). Since in situ observational temperature data was available from a station with some gaps, this data was also employed to have an alternative for the maximum temperature variable and its derivatives (Turkish State Meteorological Service, 2020). This station is relatively more relevant to this study due to its close proximity to one of the most visited main public beach in Antalya, Konyaaltı, and also to one of the most visited touristic downtown, Kaleiçi. Finally, for the calibration of HCI:Beach index, a careful examination is conducted to search for improvement areas by breaking down the HCI:Beach scores and visitation relationships. As a result of this effort, HCI:Beach-Med index is proposed for the Mediterranean. The future performance of HCI:Beach-Med compared to HCI:Beach, HCI:Urban and Humidex results are presented for the case of Antalya in this dissertation, however, a comparison of the performance of one of the most visited beach destinations in Black Sea, Sochi against Antalya to evaluate their attractiveness for the Russian market in the future in a changing climate can be viewed in our published work (Demiroglu et al., 2020).

3.2. Extreme Temperature Indices

Following the HCI calculations, in this part of the study, the extreme temperature indices were aimed to be calculated. The determination of the future changes in the intensity and frequency of extreme temperature events provide the basis for an early warning system for the cities in Türkiye. Therefore, better preparation opportunities against severe impacts of such events would be possible for the municipalities. For this purpose, steps followed in this study for the calculation of extreme temperature indices are shown in a flowchart in Figure (3.4). Firstly the outputs of two different GCMs, that are MPI-ESM-MR of the Max Planck Institute for Meteorology and HadGEM2-ES of the MET Office Hadley Centre, which were stated in the literature to work better with RegCM for MENA (Almazroui, 2019; Ozturk et al., 2018; Demiroglu et al., 2020) as previously mentioned before, were downscaled to 50km resolution for MENA by RegCM4.4 (Giorgi et al., 2012). The use of two separate GCMs made the findings of this study more robust and comprehensive, while the comparison of the outputs of two GCMs became possible. Intermediate level emission scenario RCP4.5 and business- as-usual scenario RCP8.5 were employed for the 2071-2100 future projections with respect to the 1971–2000 reference period. The different radiative forcing amounts in two emission pathways lead to different average temperature responses at the end of the century therefore this difference will be evident in the findings of seasonal and annual temperature extremes in this study. Then, a subset of the 27 ETCCDI indices that are suitable for the purposes of this study were selected to assess the changes in frequency, intensity and duration of extreme temperature events for the future in a changing climate. It is worth to mention that in our published study (Ozturk et al., 2021), the precipitation extreme indices were also calculated; however, they are not included in this dissertation since precipitation extremes are beyond the scope of this thesis.

The indices used in this study with their definitions and units are presented in Table 3.3. These indices can be classified in four categories. The first category, absolute indices of temperature include the maximum of TX (TXx) and the minimum of TN (TNn) and they represent the hottest or coldest day in a year, season or month. Usually, the annual temperature extreme indices are employed in academic studies to investigate the changes in extreme temperature events in history (L.V. Alexander et al., 2006; Tebaldi et al., 2006) and in the simulated future (Kharin et al., 2007). The second category, threshold index for temperature, includes tropical nights (TR) and it describes the number of days when a previously defined temperature threshold (20 °C in this study) is exceeded. This index is commonly utilized in the literature to assess climate impacts on agriculture (Terando et al., 2012) or human health (Patz et al., 2005). The third category, percentile-based threshold indices include warm nights (TN90p) and it describes the exceedance rate (in %) above previously fixed threshold of

the 90th percentile derived from 1971–2000 base period for this study. In other words, this index represents the rate of days where TN is above the 90th percentile. Final category is the duration index for temperature, that is warm spell duration (WSDI), describing the length of the warm spells. This index basically counts the days in a year when TX is above the 90th percentile for six or more consecutive days by taking the percentile threshold of the base period 1971–2000 for this study. After the calculation of the selected indices with the use of CDO version 1.9.5, 95-percentile confidence ranges of temporally averaged changes were calculated. Finally, the findings were visualized by the use of NCAR Command Language NCL, which was designed specifically for scientific data analysis and visualization (National Center for Atmospheric Research, 2024).

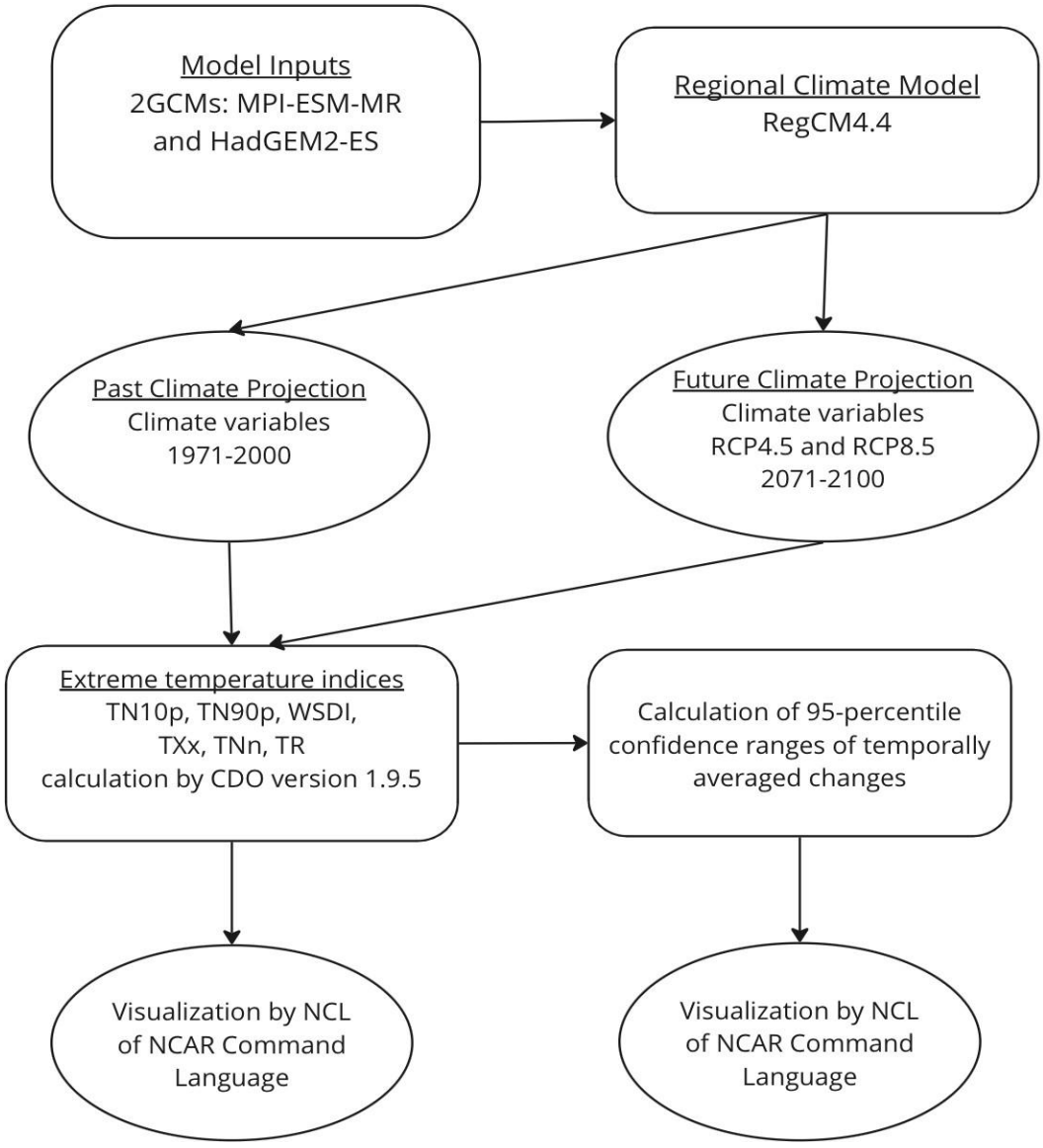

Figure 3.4. The steps of employing the simulated reference and future period climate data to compute extreme temperature indices.

Table 3.3. A subset of the climate extreme event indices recommended by the ETCCDI that are used in this study. (Adopted from the work of Sillmann et al., 2013a.)

Label	***Index Name***	***Index Definition***	***Unit***
TXx	*Max TX*	*TXx* is the daily maximum temperature in month *k*, period *j*. The maximum daily maximum temperature each month is then: $TXx_{kj} = max(TXx_{kj})$	°C
TNn	*Min TN*	*TNn* is the daily minimum temperature in month *k*, period *j*. The minimum daily minimum temperature each month is then: $TNn_{kj} = max(TNn_{kj})$	°C
TR	*Tropical Nights*	*TN* is the daily minimum temperature on day *i* in period *j*. TR counts the number of days where $TN_{ij} > 20°C$	days
TN90p	*Warm Nights*	TN_{ij} is the daily minimum temperature on a day *i* in period *j* and let $TN_{in}90be$ the calendar day 90^{th} percentile centered on a 5 day window. The percentage of days in a year is determined where $TN_{ij} > TN_{in}90$	%
WSDI	*Warm Spell Duration Index*	TX_{ij} is the daily maximum temperature on a day *i* in period *j* and let $TX_{in}90$ be the calendar day 90^{th} percentile centered on a 5 day window for the base period 1971-2000. Then the number of days per period is summed where, in intervals of at least 6 consecutive days: $TX_{ij} > TX_{in}90$	days

4. RESULTS

4.1. Holiday Climate Index

The results regarding both HCI:Urban and HCI:Beach together with Humidex risks for summer and spring months for the reference period 1971-2000 and the climate projections of 2021-2050 and 2070-2099 periods under the RCP4.5 and RCP8.5 scenarios for Türkiye are presented on Figures 4.1, 4.2, 4.3, 4.4. The results regarding the case of Antalya are presented on Figures 4.5 and 4.6. The graph displaying the comparison of number of arrivals from top source markets to Antalya and HCI:Beach and Humidex scores is presented in Figure 4.7, and the linear relationships between the climatic and touristic data are given in Table 4.1. Thermal Comfort Rating Scheme based on Humidex scores are presented on Table 4.2, the results of the regression analysis on the effects of Monthly HCI:Beach-Med Scores to Arrival data between 2007-2015 to Antalya are given in Table 4.3. Moreover, an application of the proposed index HCI:Beach-Med to Antalya can be viewed on Tables 4.4 and 4.5. All of these results will be discussed in the following sections.

4.1.1. HCI:Urban Performance in Türkiye

Figure 4.1 shows the average HCI scores and Humidex risks during the summer months for the reference period of 1971-2000 (a.) and the projected period of 2021-2050 under RCP4.5 (b.) and RCP8.5 (c.) throughout Türkiye. The legends are provided next to the maps. The reference period does not display any Humidex risk. HCI results show Ideal conditions in the Aegean coast, in the southern coastal areas including Antalya, Mersin and in eastern cities such as Kahramanmaraş, Malatya, Elazığ, Tunceli. Excellent to Very Good conditions can be observed in central and southeastern regions, such as Konya, Adana, Diyarbakır. Good and Acceptable conditions are present in northern regions including some parts of İstanbul, Bursa, Eskişehir and Ankara. Marginal and Unacceptable conditions can be seen in northeastern regions especially in Black Sea coast of Samsun and Trabzon. When we look at the HCI projections for near future under RCP4.5 scenario, we notice the appearance of Humidex risks with Great Discomfort rating in western, southern and southeastern regions with some parts in Manisa, İzmir, Muğla, Antalya, Mersin, Adana, Gaziantep, Diyarbakır, Batman. Dangerous and Great Discomfort Humidex results are seen together in Adana and Turkish Republic of Northern Cyprus (TRNC). HCI results show an increase in Unacceptable and Dangerous conditions in northern and northeastern regions compared to the reference period even under the RCP4.5 scenario, which foresees significant global efforts to mitigate GHG emissions with solid

policy interventions. Ideal and Excellent conditions decrease in southern coastal and central areas in Türkiye indicating worsening conditions. The last map on Figure 4.1 displays results for near future under worst case emission scenario RCP8.5 and there is a significant increase in Great Discomfort due to Humidex in Marmara Region, especially in Çanakkale, Balıkesir, Bursa and southern areas of İstanbul. There is also significant increase in Unacceptable to Dangerous HCI scores particularly in northern and northeastern regions of Türkiye. Similarly, Ideal to Excellent scores of HCI decrease in southern coastal areas and central regions indicating less favorable climatic conditions for the RCP8.5 scenario.

Figure 4.2 displays the average projected HCI scores for the far future period under RCP4.5 (d.) and RCP8.5 (e.). The reference period (a.) is also given for simpler comparison. When we look at the results for the more optimistic scenario, we can see extensive increase in Great Discomfort Humidex in southeastern, southern, and parts of western Türkiye, including major cities like Istanbul, Bursa, Izmir, Antalya, indicating great health risks. Adana and TRNC show Great Discomfort together with Dangerous conditions due to Humidex. Unacceptable and Dangerous HCI scores expand in northern and northeastern regions while Ideal and Excellent conditions show further reduction in the southern coastal areas compared to near future results. RCP8.5 results for the far future show tremendously widespread increase in Great Discomfort as well as Dangerous conditions due to Humidex, which would cause many health risks including fatal heat stroke. High Humidex values indicate symptoms such as altered mental state, confusion, rapid breathing, nausea and most lethally the inability to sweat despite the heat and high body temperature. These Humidex scores describe reduced sweat evaporation due to high humidity, which inevitably leads to rapid rise in core temperature and finally causing fatality. According to the findings of this study, all the Turkish cities in the Balkan Peninsula, most parts of the Marmara Region, the Aegean Region, Central Anatolia Region, many cities in the Mediterranean Region including Antalya, Karaman, Mersin, and Adana, many areas in the Southeastern Anatolia Region, many cities in the Black Sea Region and TRNC are at risk of extreme heat and high humidity related health implications during the last 30 years of the century under the business-as-usual scenario, which unfortunately has a high probability of realization.

Figure 4.3 displays the average HCI scores for the spring months for the reference period (f.), the projections of 2021-2050 under RCP4.5 (g.) and RCP8.5 (h.). The reference period 1971-2000 predominantly experienced Unacceptable HCI scores for the Eastern Türkiye, mostly Marginal with some Unacceptable scores for the Central Anatolia Region and Marginal to Acceptable conditions for the Western Türkiye. Coastal areas in the Mediterranean Region showed Acceptable to Good conditions. The near future projections under RCP4.5 show a transition from Unacceptable to

Dangerous comfort levels for the Eastern Türkiye, while the inland regions display an increase in Acceptable conditions with some Good scores around Aksaray. In the Aegean Region, there is an increase in Good to Acceptable comfort levels with Muğla showing some very good comfort levels. Adana, Gaziantep, Diyarbakır and Batman show better comfort levels for both RCP4.5 and RCP8.5 scenarios compared to the reference period for the spring months. RCP8.5 projections display a decrease in Good to Acceptable comfort levels for the Aegean and the Central Anatolia Regions compared to the RCP4.5 projections. When compared with the reference period, under the RCP8.5 scenario HCI scores show better comfort levels for the Aegean region and for the Central Anatolia Region with increases in Acceptable and Good conditions. Moreover, there is a decrease in Unacceptable to Marginal comfort levels for Kayseri, Kahramanmaraş, Malatya, Elazığ. Diyarbakır and Batman show increased Good conditions. It is good news that for the near future there is no Humidex risk for either of the scenarios, however, this result only by itself does not mean there will not be any deaths due to heat during the spring months in the near future. It should not be forgotten that these results are averaged for all the spring months between the years 2021-2050. There is a possibility some spring months during these years will have hotter days, possibly for prolonged durations. Therefore, it is of crucial importance to have the precautions for the spring months as well, especially for the Eastern regions of Türkiye for the near future.

Figure 4.4 displays the average HCI scores for the spring months for the reference period (f.), the projections of the far future, 2070-2099 under RCP4.5 (i.) and RCP8.5 (j.). At first glance, it seems that the country will become more comfortable for urban tourism in terms of climate in the far future when compared to the spring season reference period. The RCP4.5 results show an increase in regions with Acceptable HCI scores, while the RCP8.5 results indicate increased areas with Good and Very Good comfort levels compared to the reference period. Northeastern Türkiye experiences more discomfort under both scenarios, transitioning from Unacceptable to Dangerous conditions in some cities, such as Artvin, Ardahan, Kars, Ağrı, and Van. The results may indicate severe impacts for both scenarios in these cities. Coastal regions show less discomfort compared to the reference period, with mostly Acceptable HCI scores for the Aegean and mostly Good HCI scores for the Mediterranean under RCP4.5. RCP8.5 indicates even better conditions, with mostly Good and Very Good scores for both regions. The results show no Humidex risk for Türkiye under either of the scenarios. As pointed out before, these results do not indicate that there will not be any deadly heatwave events or basically no deaths due to extreme heat in either near future or far future since these scores are averaged over 30 years.

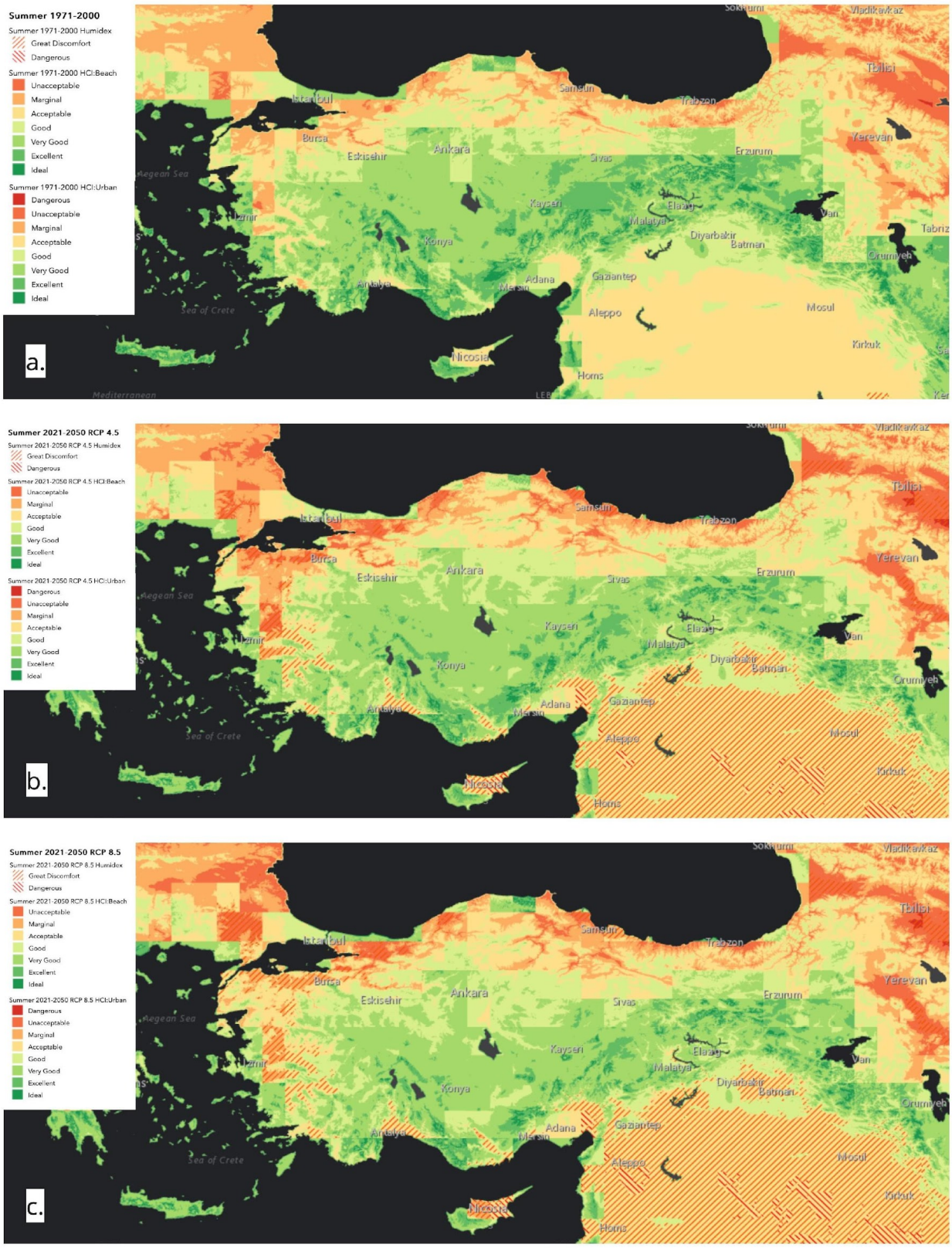

Figure 4.1. Summer season Holiday Climate Index (HCI) ratings and Humidex risks throughout Türkiye for the reference period of 1971-2000 (a.) and the projected period of 2021-2050 under RCP4.5 (b.) and RCP8.5 (c.)

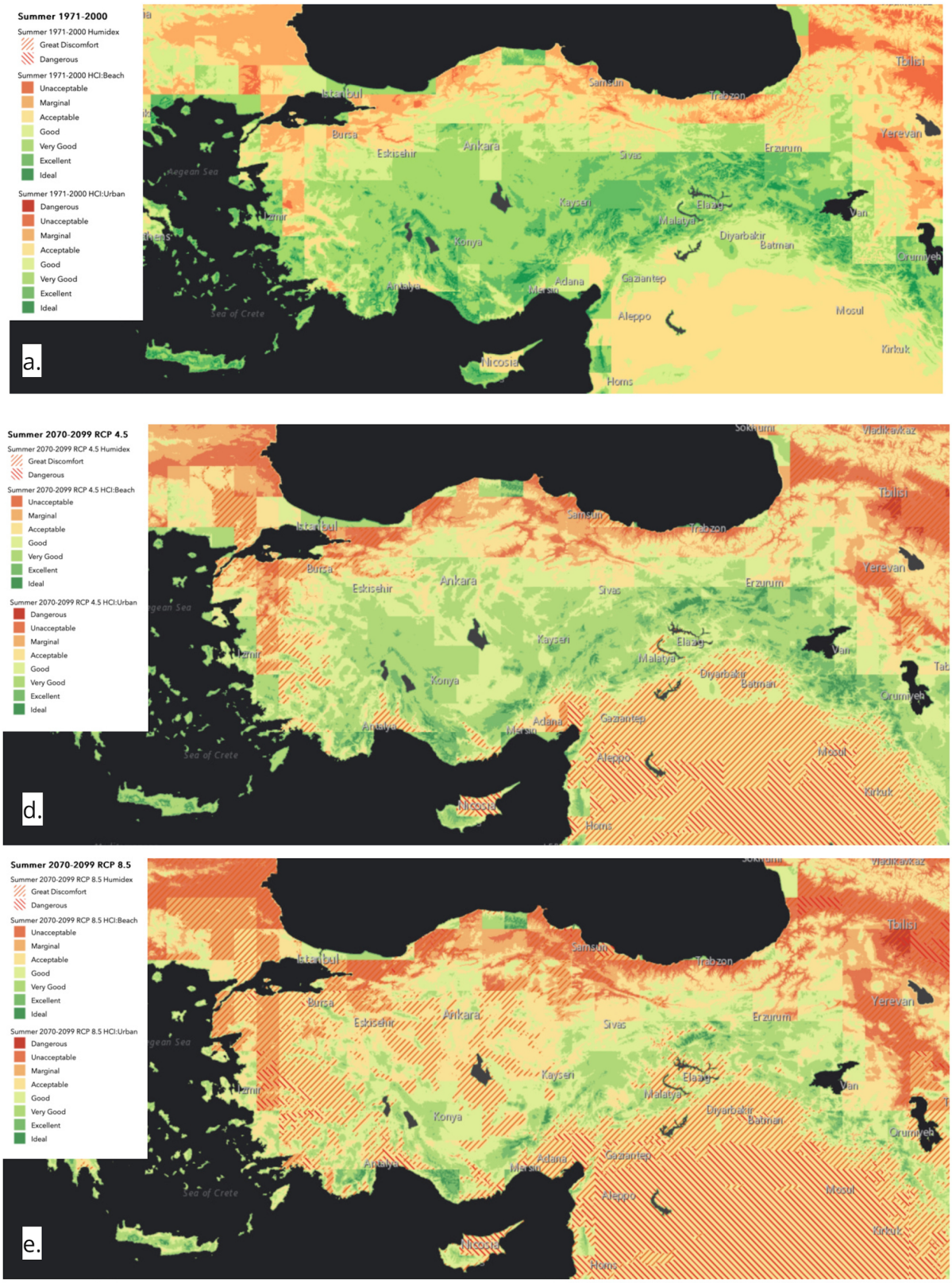

Figure 4.2. Summer season Holiday Climate Index (HCI) ratings and Humidex risks throughout Türkiye for the reference period of 1971-2000 (a.) and the projected period of 2070-2099 under RCP4.5 (d.) and RCP8.5 (e.)

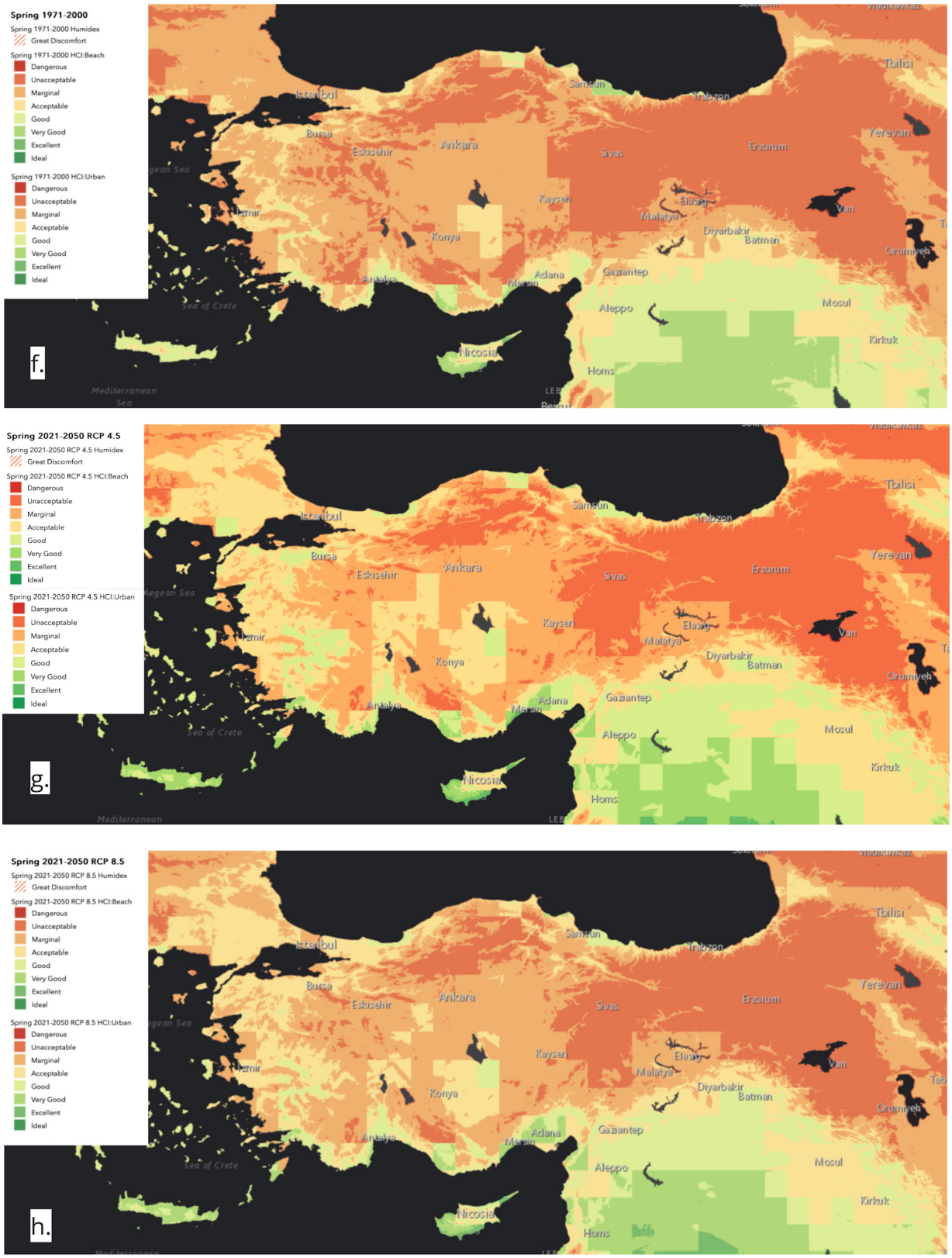

Figure 4.3. Spring season Holiday Climate Index (HCI) ratings and Humidex risks throughout Türkiye for the reference period of 1971-2000 (f.) and the projected period of 2021-2050 under RCP4.5 (g.) and RCP8.5 (h.)

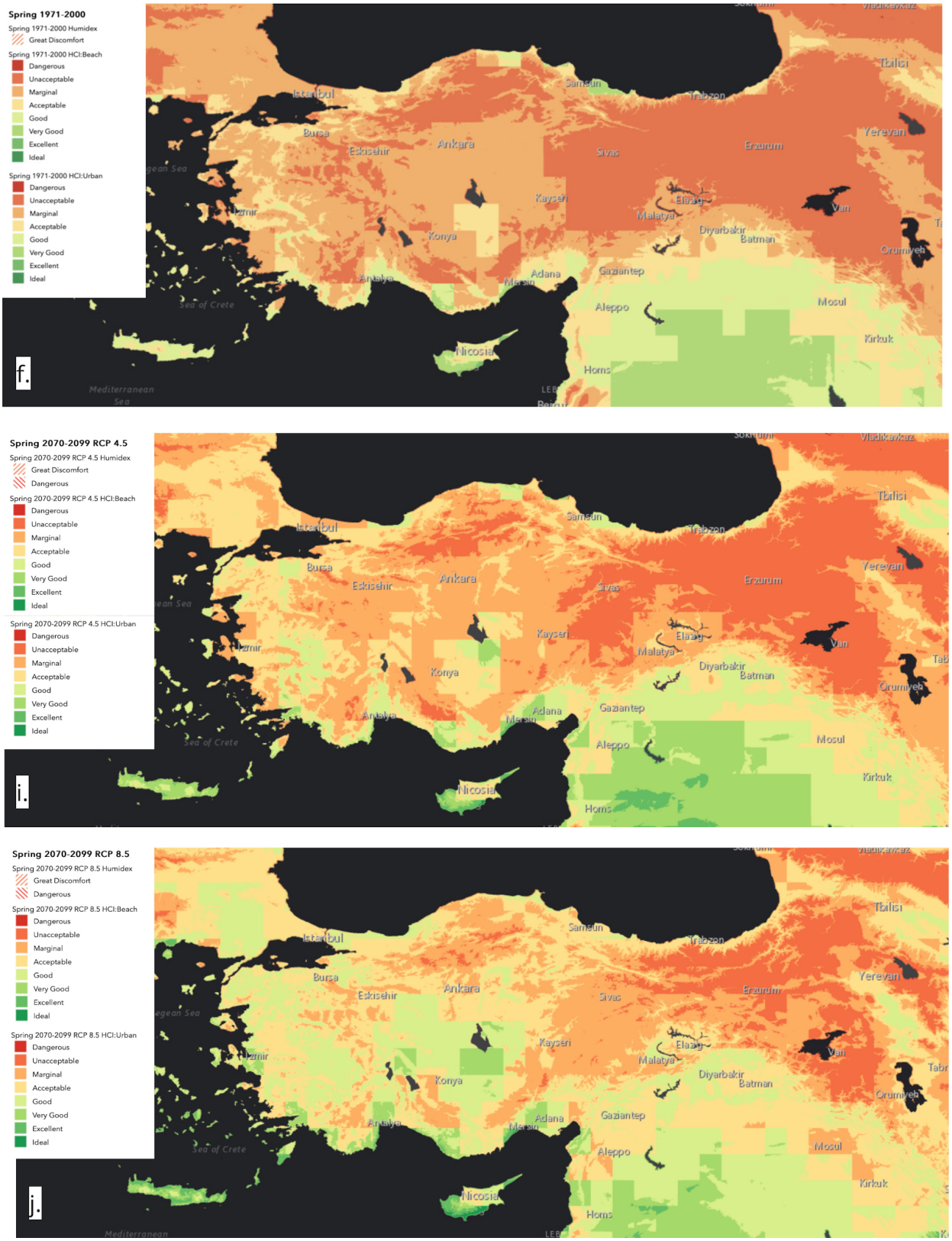

Figure 4.4. Spring season Holiday Climate Index (HCI) ratings and Humidex risks throughout Türkiye for the reference period of 1971-2000 (f.) and the projected period of 2070-2099 under RCP4.5 (i.) and RCP8.5 (j.)

The results for the fall and winter seasons can be found in our published work (Demiroglu et al., 2020), however they are not included in this dissertation since extreme heatwave events are mostly expected in summer and spring seasons. The results show higher Humidex risks for the summer seasons while the HCI scores show more comfortable climatic conditions for the summer seasons compared to the spring seasons. At the same time, spring seasons show more discomfort according to the HCI ratings but without any Humidex risk. Summer season results show that many cities will experience severe discomfort with Dangerous and Great Discomfort Humidex risks becoming common for most of the country. The Aegean, Mediterranean and Southeastern Anatolia regions will experience the most severe impacts. Spring season HCI scores show that the Northeastern Türkiye will experience the most challenging conditions. All these findings highlight the urgent need for smart solutions addressing human health concerns under extreme heat, as well as climate adaptation and mitigation strategies across Türkiye for the future.

4.1.2. HCI:Beach Performance in Türkiye

HCI:Beach results are seen as a thin strip on the coasts of Türkiye, therefore it might be difficult to see the detailed results on the pages of this dissertation. For the most detailed outputs of this study, one might visit iklimBU's web page and zoom in his/her region of interest (Bogazici University Centre for Climate Change and Policy Studies, n.d.). Here, the most preliminary findings of the study will be mentioned. Türkiye, having hot and sunny beaches in the Mediterranean and Aegean coasts, attracts tourists during the summer season for beach vacation. Summer season for the period 2021-2050 under RCP4.5 HCI:Beach outputs give Excellent and Ideal conditions for most of the Mediterranean and Aegean coasts while Humidex results show Great Discomfort for Çanakkale, Muğla, Antalya and Mersin coasts. Marmara Sea coasts of Balıkesir, Bursa, and Samsun coasts also give Great Discomfort Humidex risks. RCP8.5 results for the same period show extended Humidex risks for the same coasts and HCI:Beach outputs give increased areas with Very Good and Good conditions. When we look at the results for the far future, we see that the coasts having the Humidex risks are increased even under the RCP4.5 scenario while the HCI results show mostly Very Good ratings for most of the Mediterranean and Aegean coasts. Some coasts of İzmir and Aydın even fall to Good conditions. HCI:Beach outputs under RCP8.5 for the far future now give Acceptable to Good comfort levels for many beaches in the Mediterranean and Aegean coasts and reveal significantly increased Humidex risks for almost all of the coasts of Türkiye, including Giresun, Samsun, Sinop, Kastamonu, Zonguldak in the Black Sea Region, basically every coast in the Marmara Sea, Çanakkale, Balıkesir, Muğla in Aegean Region, Antalya, Mersin, Adana, Antakya in the Mediterranean Region. Most of these coasts display Great Discomfort and Dangerous cumulative

Humidex risks for the end of the century with the business as usual scenario, which again underlines the importance of taking precautions to protect the lives of people.

4.1.3. The case of Antalya

Here, a specific focus is given to the city Antalya, which is among the most visited touristic destinations in the Mediterranean and in the world, especially for Sun, Sea and Sand tourism due to its 640 km shoreline with various beach facilities (World Travel and Tourism Council, 2019). Antalya offers 300 sunny days a year to its visitors in the coastal regions, highest precipitation falls between December and January, daily summer temperatures are around 30-34 °C, while the maximum temperatures exceed 40 °C with an annual relative humidity of 64% (ANTAB, 2024). Antalya has been specifically selected for this study since the city sits in between both high HCI scores and Humidex risks while having the highest population density during the summer months when the possibility of heat related health issues is highest. Figure 4.5 presents a closer look to the city Antalya with the averaged HCI and Humidex results for the summer months for the reference period 1971-2000, 2021-2050 under RCP4.5 and 2021-2050 under RCP8.6. As can clearly be seen, the Humidex results show Great Discomfort for both of the scenarios. This Humidex outputs are similar to what happened in France and in Europe in the summer of 2003, when more than 70,000 people died. As will be discussed in the following sections, there are various solutions to the situation in terms of specific cities and therefore when there were other cases with similar temperatures in the following years, France and Europe did not experience this many fatalities. Figure 4.6 shows another closer look to the city Antalya with the averaged HCI and Humidex results for the summer months for the reference period 1971-2000, but for the far future this time, 2070-2099 under RCP4.5 and RCP8.6. The end of the century under RCP4.5 shows extended areas of Great Discomfort Humidex rating. The most striking results, for which we must develop new solutions and strategies, are seen in 2070-2099 under the RCP8.5 scenario. Here we observe Great Discomfort and Dangerous Humidex levels, conditions that have never been experienced in the world yet. The solutions the smart cities have implemented until now to combat extreme heat will not be enough or sufficient for these outcomes. This is where it is strongly anticipated people will lose their lives, underscoring the urgent need to create and organize new solutions for smart cities to save lives. Although Antalya was selected for this dissertation, it is critical to emphasize that there are many other cities in Türkiye, particularly those in coastal regions, who will share a similar fate with Antalya in the future. Therefore, the solutions presented in this dissertation can be adapted and applied to these other cities as well.

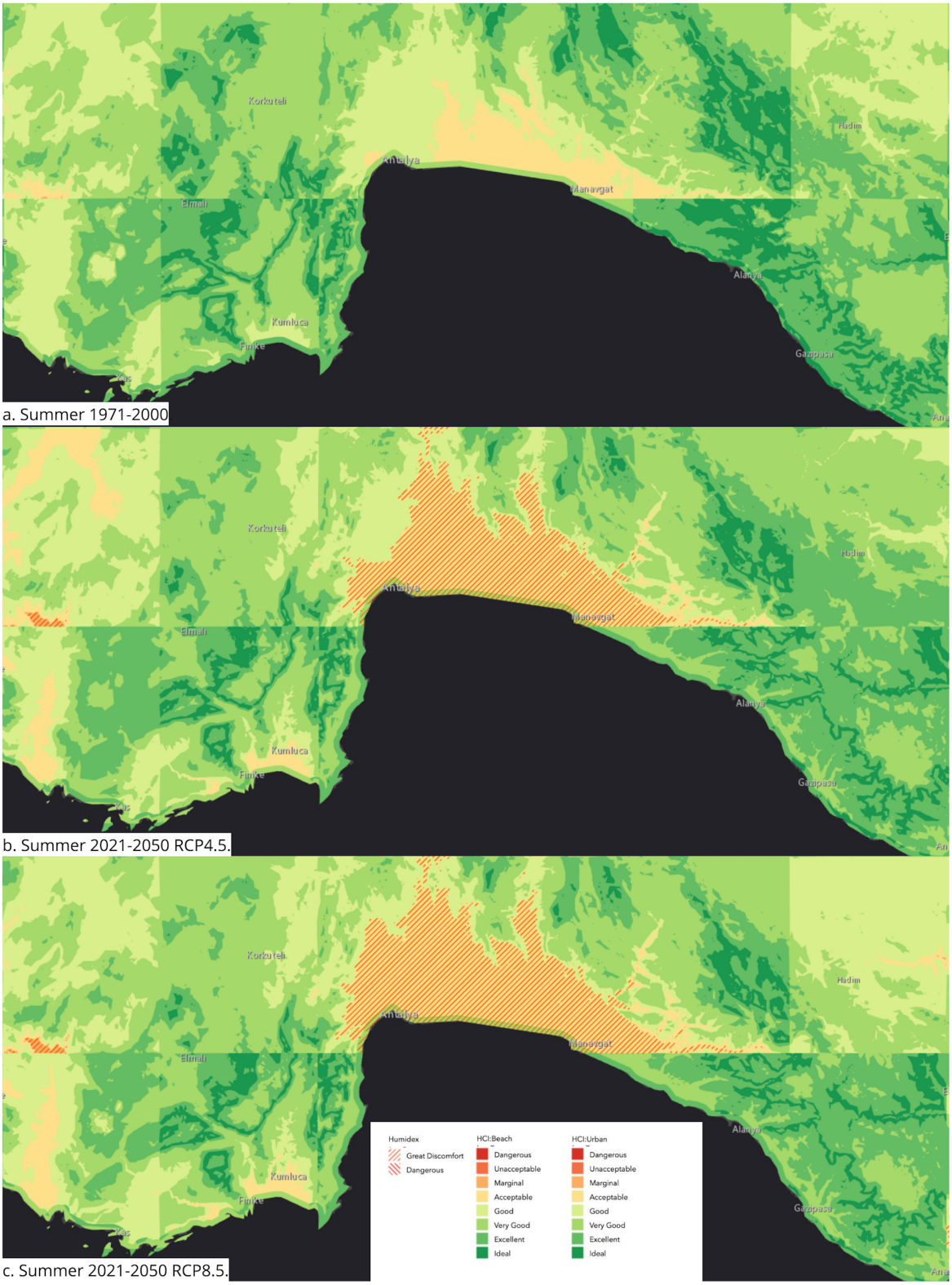

Figure 4.5. Summer season Holiday Climate Index (HCI) ratings and Humidex risks for Antalya for the reference period of 1971-2000 (a.) and the projected period of 2021-2050 under RCP4.5 (b.) and RCP8.5 (c.)

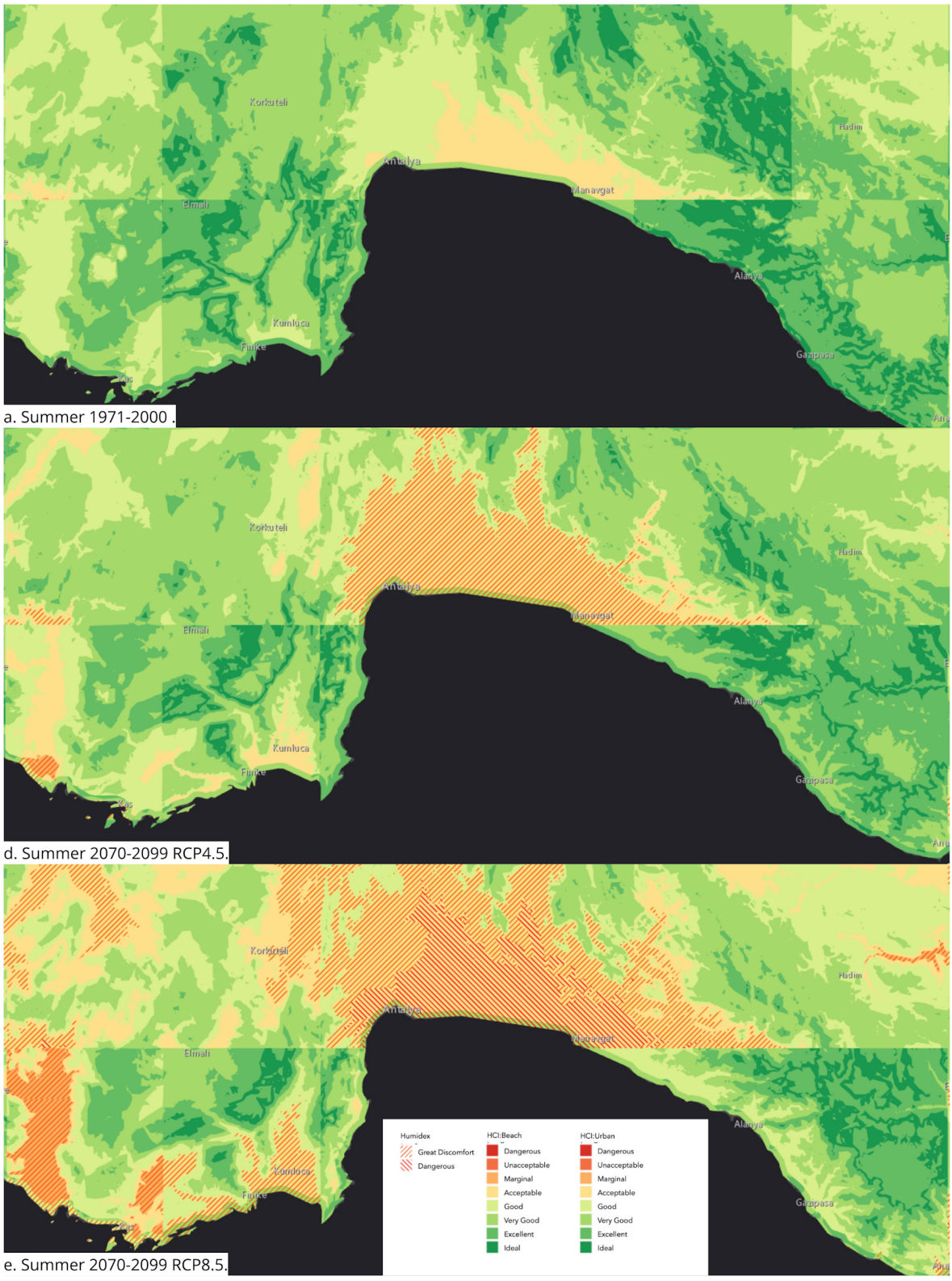

Figure 4.6. Summer season Holiday Climate Index (HCI) ratings and Humidex risks for Antalya for the reference period of 1971-2000 (a.) and the projected period of 2070-2099 under RCP4.5 (d.) and RCP8.5 (e.)

4.1.4. Taking one step further: Validation of HCI:Beach and introducing HCI:Beach-Med

Since the HCI:Beach index was recently developed, there were no validation studies in the literature for the Mediterranean. Therefore this study constitutes the first validation attempt by expanding our study a little further. Antalya was found to be appropriate for our purposes due to its significantly climate-dependent tourism economy as well as its data availability. Antalya has both high HCI scores and high Humidex risks as can be seen on Figures 4.5, 4.6, which is interpreted as the city has good climatic conditions for a beach holiday however there is high risk of being affected from heat related health hazards. The line graph in Figure 4.7 presents the comparison of HCI:Beach and Humidex ratings, which were calculated by the use of ERA5 reanalysis and MGM observation data for the period of 2007-2015, and the arrivals from the top source markets (namely from Germany, Netherlands, Russia, Sweden, UK and Ukraine) to Antalya. From the graph, the arrivals data seems to be better explained by the Humidex rather than HCI:Beach. HCI:Beach outputs display a steep fall for July-August months, which are actually the two peak months for total number of arrivals. Humidex outputs, on the other hand, show better agreement with the total number of arrivals.

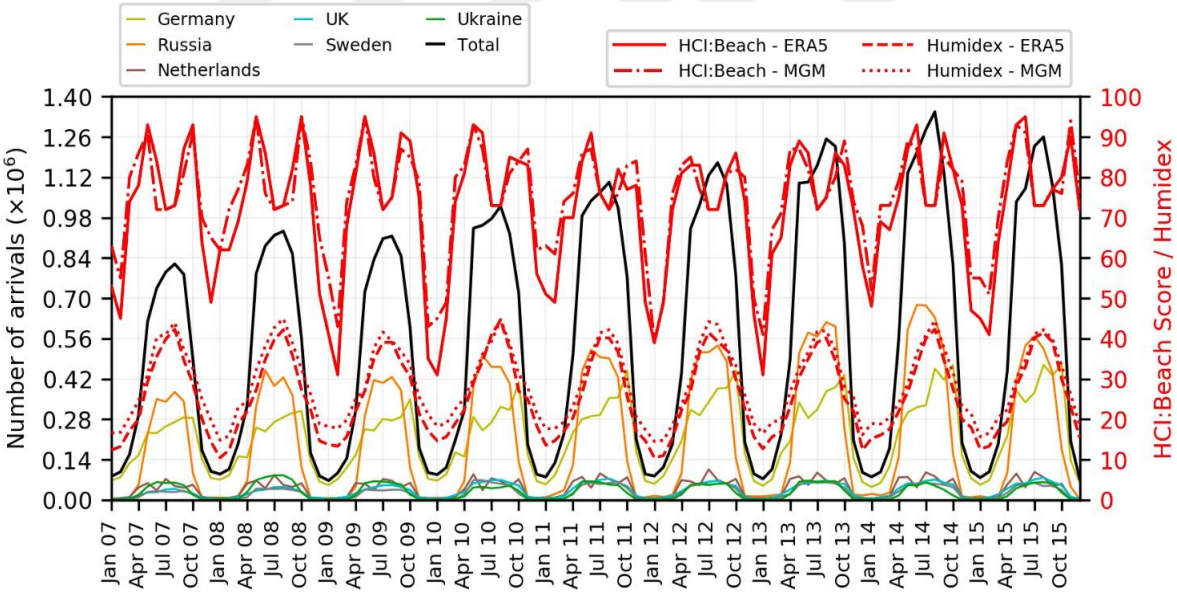

Figure 4.7. Comparison of HCI:Beach and Humidex ratings of Antalya with arrivals from top source markets.

Table 4.1 displays the regression analysis results which show that the number of total arrivals is best explained by Humidex and maximum temperature values. The coefficient of determination for thermal comfort rating ranks among the lowest and can even be regarded as insignificant considering the MGM data. This discrepancy arises from the Thermal Comfort rating scheme of HCI, which was designed based on Caribbean conditions, favoring a Humidex range of 28-31, while considering any rating above 39 as too hot for beach tourism (Rutty et al., 2020). However, when we look at Antalya

all of the observed Humidex ratings for July-August months between 2007-2015 surpass 39 threshold while the mean value is 40.7 during the maximum visitation.

Here, an opportunity emerges to optimize the HCI:Beach index with the case of Antalya and for the Mediterranean. When we look at the beach tourist surveys in Europe (presented in Table 1 in the study by Rutty et al., 2020), we see that the tourists specified optimal temperature span to be between 25-28 °C with a steady maximum of 32 °C. In 2017, the Copernicus Climate Change Service reanalyzed the relative humidity in Antalya for summer season in 2007-2015 and found it to be 54% (Copernicus Climate Change Service, 2017). Under this relative humidity, the fore-cited maximum temperature of 32 °C translates into a Humidex value of 41 (Government of Canada, 2020). Based on the information of these thresholds, a new Thermal Comfort rating scheme is proposed in Table 4.2 for the optimized HCI:Beach, namely HCI:Beach-Med. A regression analysis was then carried out to examine the relationship between HCI:Beach-Med and the arrivals data of Antalya. The analyses yielded much higher coefficients of determination as shown in Table 4.3. Here, we found that 74% of the variance in total arrivals is explained by HCI:Beach-Med, which is actually greater than the Caribbean (69%) (Rutty et al., 2020) and Canadian (73%) (Matthews et al., 2019) studies. Finally, by taking the coordinates of 36.885° N 30.7° E as the reference points representative of most visited beaches and tourist districts, the proposed HCI:Beach-Med is applied to both reference period and the future projections for Antalya. Tables 4.4 and 4.5 show the monthly HCI:Beach-Med, HCI:Beach and HCI:Urban scores with Humidex risks for both the historical and future periods. According to these results, the peak seasons of Antalya may move to the shoulder seasons especially under the RCP8.5 scenario. Antalya is found to be losing its Ideal conditions for both of the future periods and under both scenarios especially during July–August months since the climatic conditions become nullified in Thermal Comfort facet. Actually the city loses its Excellent conditions as well at the end of the century during these months under RCP8.5. During this period, the city's Humidex risk is found to be Dangerous. There is a need to develop thoroughly planned strategies to avoid catastrophic consequences. Overall, the city maintains Good to Excellent conditions between April and October.

Table 4.1. HCI:Beach Scores and Their Components as Estimators of Monthly Arrivals to Antalya (Türkiye) from the Top Source Markets (2007-2015).

		Germany	Russian Federation	Netherlands	United Kingdom	Sweden	Ukraine	Total
Cloud Cover	r	-0.665	-0.777	-0.633	-0.732	-0.733	-0.795	-0.81
	r^2	0.442	0.603	0.401	0.525	0.538	0.633	0.657
Relative Humidity	r	-0.438	-0.485	-0.393	-0.446	-0.443	-0.561	-0.524
	r^2	0.192	0.235	0.154	0.191	0.196	0.315	0.274
Precipitation	r	-0.533	-0.632	-0.568	-0.608	-0.608	-0.654	-0.654
	r^2	0.284	0.4	0.323	0.37	0.37	0.428	0.428
Wind Speed	r	-0.416	-0.35	-0.388	-0.407	-0.402	-0.336	-0.379
	r^2	0.173	0.122	0.151	0.166	0.161	0.113	0.144
Maximum Temperature (ERA5)	r	0.816	0.879	0.772	0.868	0.855	0.896	0.929
	r^2	0.667	0.773	0.595	0.754	0.73	0.803	0.864
Maximum Temperature (MGM)	r	0.814	0.863	0.757	0.848	0.834	0.889	0.916
	r^2	0.662	0.745	0.573	0.719	0.696	0.791	0.839
Humidex Score (ERA5)	r	0.818	0.888	0.775	0.878	0.863	0.892	0.935
	r^2	0.67	0.788	0.6	0.771	0.744	0.795	0.875
Humidex Score (MGM)	r	0.822	0.874	0.764	0.861	0.846	0.888	0.925
	r^2	0.675	0.764	0.583	0.741	0.715	0.789	0.856
Thermal Comfort Rating (ERA5)	r	0.581	0.339	0.482	0.436	0.469	0.39	0.396
	r^2	0.338	0.115	0.223	0.19	0.22	0.152	0.157
Thermal Comfort Rating (MGM)	r	0.247	0.081 ****	0.211 ***	0.073 ****	0.085 ****	0.041 ****	0.02 ****
	r^2	0.061	0.007 ****	0.044 ***	0.005 ****	0.007 ****	0.002 ****	0.000 ****
Aesthetic Rating	r	0.594	0.584	0.49	0.584	0.603	0.599	0.621
	r^2	0.352	0.341	0.24	0.341	0.364	0.358	0.386
Precipitation Rating	r	0.461	0.498	0.491	0.511	0.496	0.517	0.529
	r^2	0.213	0.248	0.241	0.261	0.246	0.267	0.28
Wind Rating	r	0.401	0.281*	0.38	0.375	0.362	0.265**	0.322*
	r^2	0.161	0.079*	0.144	0.141	0.131	0.070**	0.104*
HCI:Beach Score (ERA5)	r	0.686	0.547	0.605	0.612	0.633	0.588	0.604
	r^2	0.471	0.3	0.366	0.375	0.4	0.346	0.365
HCI:Beach Score (MGM)	r	0.577	0.39	0.527	0.49	0.498	0.427	0.455
	r^2	0.333	0.152	0.278	0.24	0.248	0.182	0.207

Unless otherwise stated, p <0.001, * p <0.005, ** p <0.01, *** p <0.05, **** p >0.05

Table 4.2. Humidex-based Thermal Comfort Rating Scheme of HCI:Beach-Med.

Min	Max	Rating
-9999	9.99	-10
10	14.99	-5
15	23.99	0
24	24.99	1
25	25.99	2
26	26.99	3
27	27.99	4
28	28.99	5
29	29.99	6
30	30.99	7
31	31.99	9
32	40.99	10
41	42.99	9
43	43.99	7
44	44.99	6
45	9999	0

Table 4.3. Regression Results on the Effects of Monthly HCI:Beach-Med Scores to Visitor Arrivals (2007-2015) to Antalya. All results are significant at $p < 0.001$ level.

Source Market	r	r^2
Germany	0.77	0.59
Russian Federation	0.82	0.67
The Netherlands	0.70	0.48
United Kingdom	0.81	0.65
Sweden	0.82	0.66
Ukraine	0.83	0.69
Total	0.86	0.74

Table 4.4. Projected HCI:Beach-Med, HCI:Beach, HCI:Urban Scores and Humidex Risks of Antalya.

Index	Period	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
HCI:Beach-Med	1971-2000	19	23	23	36	54	76	91	91	91	91	70	33
	RCP 4.5 2021-2050	23	23	23	40	62	88	91	89	89	91	70	33
	RCP 8.5 2021-2050	23	23	26	36	56	88	92	89	89	88	56	33
	RCP 4.5 2070-2099	23	23	26	40	58	88	91	85	85	88	58	36
	RCP 8.5 2070-2099	33	30	36	52	70	86	85	71	71	86	80	40
HCI:Beach	1971-2000	19	15	23	36	66	82	81	71	71	83	80	35
	RCP 4.5 2021-2050	23	15	23	44	72	84	71	71	71	81	80	39
	RCP 8.5 2021-2050	23	15	26	38	66	84	72	71	71	76	64	39
	RCP 4.5 2070-2099	23	15	26	46	70	84	71	71	71	72	64	44
	RCP 8.5 2070-2099	33	22	36	62	78	76	71	71	71	68	76	54
HCI:Urban	1971-2000	37	33	37	46	68	67	71	53	53	71	73	43
	RCP 4.5 2021-2050	37	39	39	50	79	70	55	53	53	69	64	47
	RCP 8.5 2021-2050	37	37	42	46	70	70	52	53	53	60	54	47
	RCP 4.5 2070-2099	37	39	42	50	64	70	55	53	53	60	54	58
	RCP 8.5 2070-2099	43	42	46	66	67	57	55	53	53	52	52	62
Humidex	1971-2000	12	10	12	16	24	31	37	40	40	35	27	17
	RCP 4.5 2021-2050	13	12	13	18	26	33	39	42	42	36	29	20
	RCP 8.5 2021-2050	13	12	14	18	25	33	39	43	43	37	29	20
	RCP 4.5 2070-2099	14	12	15	19	27	33	40	43	44	39	30	20
	RCP 8.5 2070-2099	16	14	16	21	30	37	44	48	48	42	34	23

Table 4.5. HCI and Humidex color scale.

0-19	Dangerous	<20	No discomfort
20-39	Unacceptable	20 - 29	Little discomfort
40-49	Marginal	30 - 39	Some discomfort
50-59	Acceptable	40 - 45	Great discomfort
60-69	Good	>45	Dangerous
70-79	Very Good		
80-89	Excellent		
90-100	Ideal		

4.2. Extreme Temperature Indices

In this section, the results for the selected extreme indices of ETCCDI, namely Maximum of TX, Minimum of TN, Warm Nights, Tropical Nights and Warm Spell Duration are presented since these are the ones that are useful for interpreting spatial patterns of changes of extreme temperatures. The results for the rest of the temperature indices and precipitation indices can be viewed in our published work (Ozturk et al., 2021).

Figure 4.8 displays spatial patterns of changes of TXx, namely the annual maximum of daily maximum temperature, for the period 2071-2100 with respect to the period 1971-2000, utilizing outputs from two global climate models under two emission pathways. The model MPI exhibits more optimistic projections compared to the model HadGEM for both scenarios, though this does not diminish the inherent danger. Under RCP4.5, MPI projects a 1-3 °C increase across most of Türkiye, whereas under RCP8.5, it projects a 4-6 °C increase. On the other hand, HadGEM projects a 3-5 °C increase under RCP4.5 and a 7-9 °C increase under RCP8.5 for the majority of the country. Notably, the entire Aegean region is projected to experience an increase of more than 9 °C, with Muğla potentially facing increases exceeding 10 °C. Antalya is also projected to see an increase in the annual maximum of daily maximum temperature exceeding 10 °C, emphasizing the necessity for preemptive measures to mitigate the risk of substantial fatalities. The region between Hakkari, Şırnak, and Van is projected to experience an increase exceeding 11 °C. It is crucial to emphasize that the RCP8.5 projections from MPI should not be interpreted as indicating an absence of risk for human mortality due to extreme heat. As previously noted, humidity levels of approximately 95% or higher pose significant danger even under current conditions. Therefore, a 5-6 °C increase in MPI projections also presents a severe risk to human life.

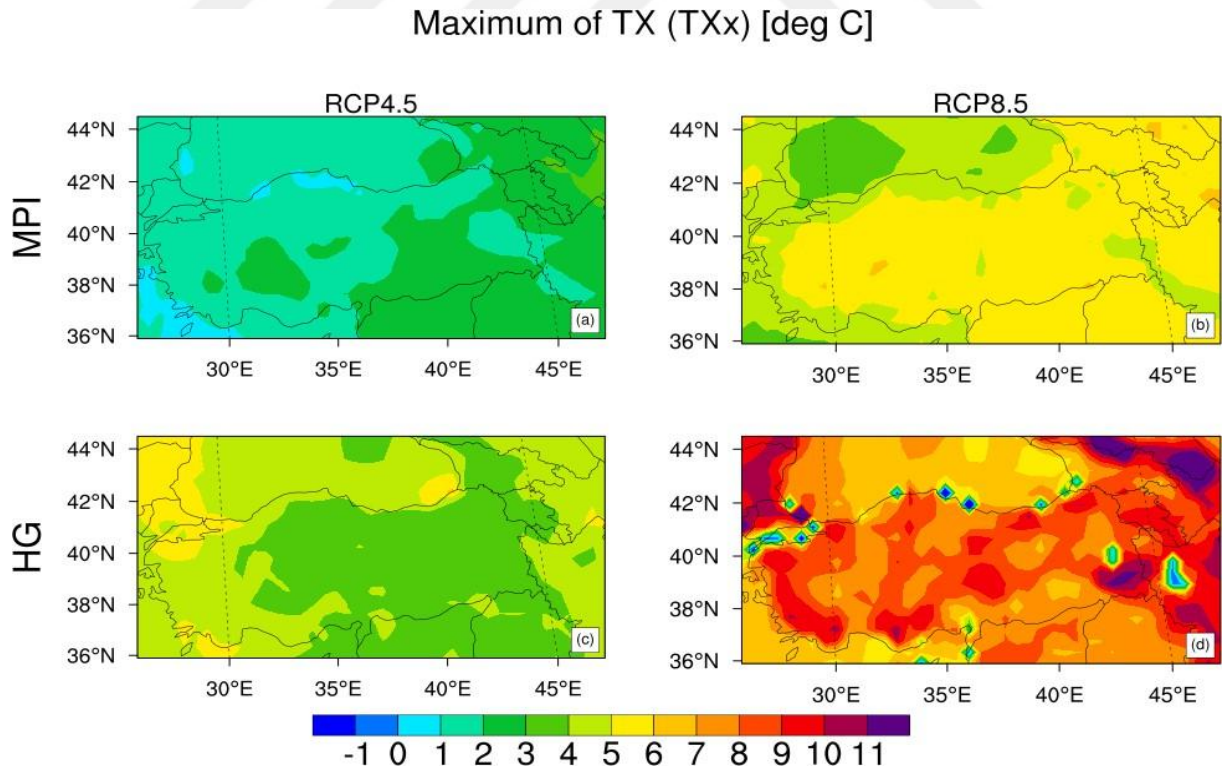

Figure 4.8. Temporally averaged changes in TXx for the period of 2071–2100 shown as differences in °C with respect to the reference period of 1971–2000 for the model MPI-ESM-MR with RCP4.5 (a) and with RCP8.5 (b) and for the model HadGEM2-ES with RCP4.5 (c) and with RCP8.5 (d)

Figure 4.9 shows the spatial patterns of temporally averaged changes in TNn, specifically the annual minimum of daily minimum temperature, for the period of 2071-2111 with respect to the period 1971-2000, using two global climate models under two emission scenarios. The MPI model continues to present more optimistic results compared to HadGEM for both scenarios. However, MPI still shows a 3-5 °C increase for most of the country, even under the RCP4.5 scenario, while some regions in Manisa, İzmir, Aydın, Muğla, and Antalya appear to have an increase of about 4-5 °C. Under the business-as-usual scenario, MPI displays more than a 5 °C increase for most parts of the Aegean and Mediterranean regions of Türkiye. HadGEM outputs for RCP4.5 show a 3-6 °C increase across the country, while the regions that show an increase more than 5 °C are in Antalya, Mersin, Adana. When examining HadGEM outputs for the RCP8.5 scenario, a significantly different color scheme is observed compared to the others. The annual minimum of daily minimum temperature increases by more than 5 °C for almost the entire country, with small regions in the Marmara, Mediterranean, East Anatolian, and Black Sea regions showing an increase of more than 11 °C. These results indicate that not only the annual maximum of daily maximum temperature but also the annual minimum of daily minimum temperature increases throughout the country, even under the optimistic scenario and MPI global climate model. This undeniably raises the risks of human health hazards due to extreme heat and underscores the importance of taking precautions to save lives.

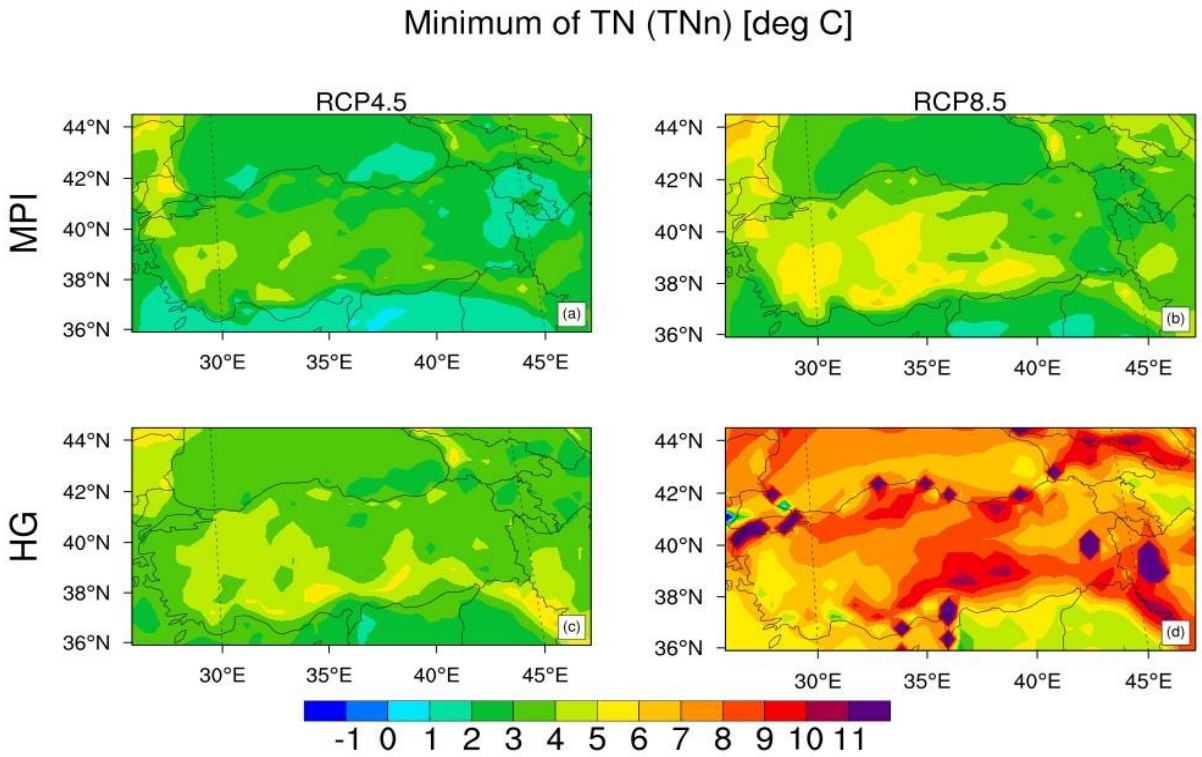

Figure 4.9. Temporally averaged changes in TNn for the period of 2071–2100 shown as differences in °C with respect to the reference period of 1971–2000 for the model MPI-ESM-MR with RCP4.5 (a) and with RCP8.5 (b) and for the model HadGEM2-ES with RCP4.5 (c) and with RCP8.5 (d).

Figure 4.10 presents spatial changes in the annual count of days when the daily minimum temperature exceeds 20°C, displayed as differences in days for two global climate models under two scenarios for the period 2071-2100 with respect to the reference period of 1971-2000. MPI outputs for the RCP4.5 scenario show almost no difference for most parts of the country, with only coastal regions experiencing an increase of about 10 to 30 days. Under the RCP8.5 scenario, the increase in coastal regions exceeds 50 days, and for some cities such as Antalya, Mersin, Adana, and Hatay, the increase in TR reaches 80 days. Some inland cities in the Aegean and Central Anatolian Regions appear to have an increase of between 10 to 50 days. The HadGEM model for the RCP4.5 scenario provides somewhat similar outputs to the MPI model under the RCP8.5 scenario, only the coastal regions experiencing an increase of about 50 days are extended. Again, the HadGEM model under the business-as-usual scenario presents the most pessimistic outputs, with an increase of between 90 to 120 days for most coastal regions. The increase in TR exceeds 170 days for Hatay, Adana, and Mersin. Most of the Central Anatolian Region shows an increase of more than 40 days, while most of the Eastern Anatolian Region shows an increase of 0-10 days. These results indicate that the annual count of days when the daily minimum temperature exceeds 20°C will increase for the coastal regions even under the optimistic scenario and with the MPI global climate model. In other words, even the nights in the coastal regions will become hotter in the future under any scenario and any global model.

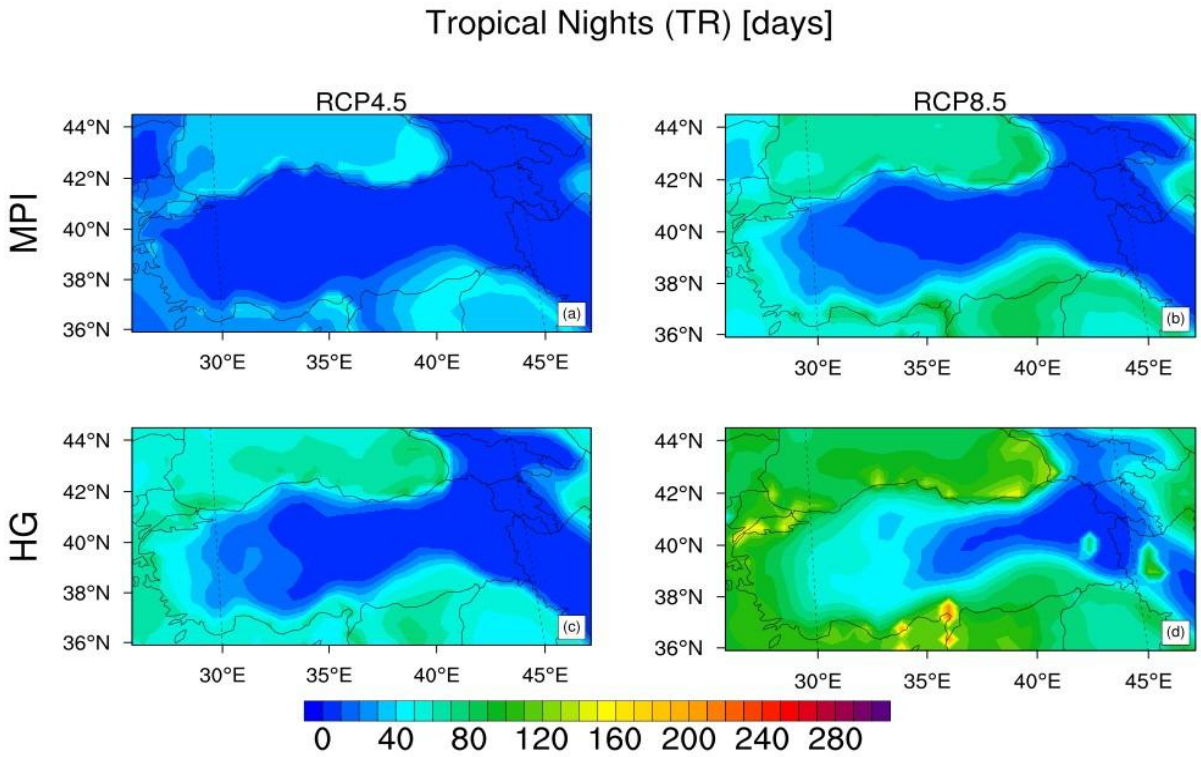

Figure 4.10. Temporally averaged changes in TR for the period of 2071–2100 displayed as differences in days with respect to the reference period 1971–2000 for the model MPI-ESM-MR with RCP4.5 (a) and RCP8.5 (b) and for the model HadGEM2-ES with RCP4.5 (c) and RCP8.5 (d).

Figure 4.11 displays the spatial patterns of temporally averaged changes in TN90p, which is the exceedance rate of days when the daily minimum temperature is above the 90th percentile, shown as differences in percentages for two models under two scenarios for the period 2071-2100 compared to the period 1971-2000. It is observed that the inland regions experience a greater increase compared to coastal regions for both models under both scenarios, similar to previous results. Here, MPI outputs under the RCP4.5 scenario show an increase of about 30-40% in TN90p for inland regions, while for coastal regions the increase is around 20-30%. Under the RCP8.5 scenario, most of the country shows an increase of 50-60%, with most coastal regions showing an increase of 40-50%, and the Southeastern Anatolian Region, along with Van, Ağrı, and Iğdır from the Eastern Anatolian Region, showing an increase of 60-70%. HadGEM model outputs under the RCP4.5 scenario are similar to MPI model outputs under the RCP8.5 scenario. However, the HadGEM outputs under the RCP8.5 scenario indicate significantly more severe outcomes. Almost the entire country experiences an increase of more than 70%. The Eastern and Southeastern Anatolian Regions, as well as almost the entire coastline of the country, show an increase exceeding 80%. These findings indicate that the annual frequency of days with daily minimum temperatures above the 90th percentile will substantially increase, especially in the inland regions, even under the optimistic scenario and MPI global climate model.

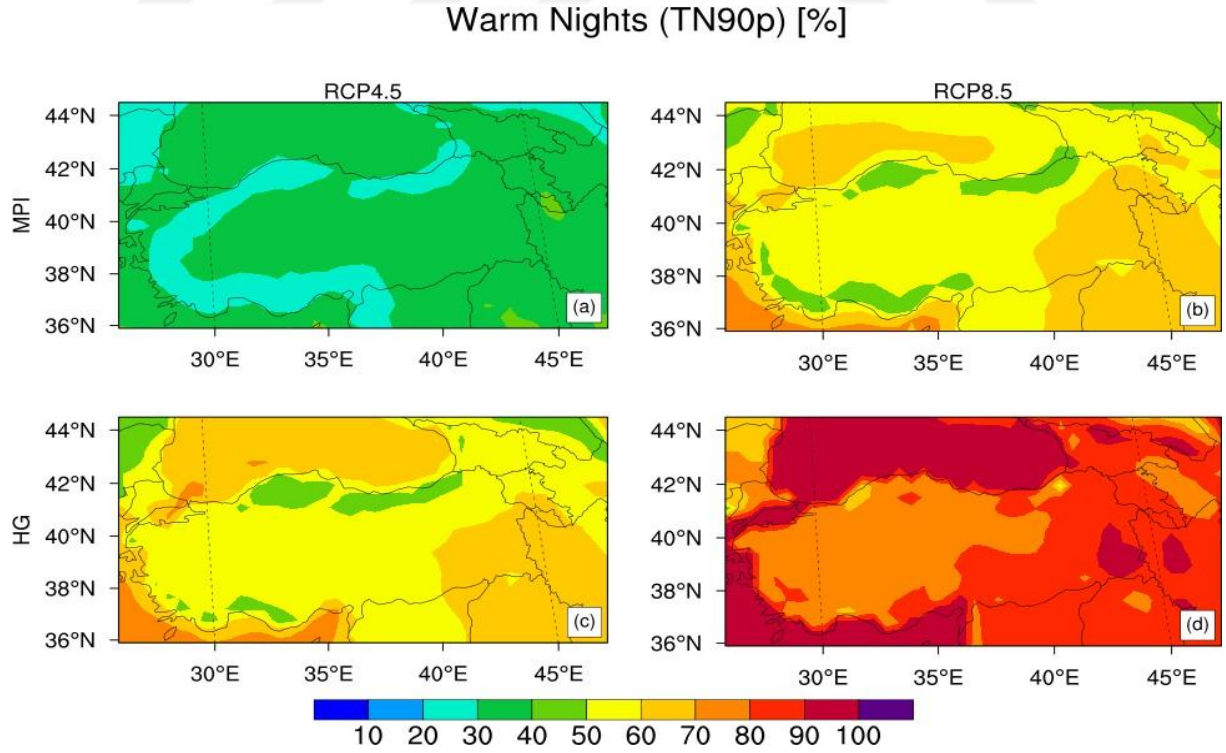

Figure 4.11. Annual frequency of TN90p temporally averaged over the period of 2071–2100 as absolute values of the exceedance rate in % for the model MPI-ESM-MR with RCP4.5 (a) and RCP8.5 (b) and for the model HadGEM2-ES with RCP4.5 (c) and RCP8.5 (d). By definition, the exceedance rate averages to approximately 10% over the reference period.

Figure 4.12 presents the spatial patterns of temporally averaged changes in WSDI, which is the annual count of days with at least six consecutive days when TX is above the 90th percentile, displayed as differences in days for the period 2071-2100 compared to the reference period 1971-2000 for two models under two scenarios. In the first graph, showing MPI outputs under the RCP4.5 scenario, the greatest increase in WSDI is observed in the Southeastern Region of Türkiye, with more than 50 days, while the smallest increase is observed in the Marmara and Black Sea Regions, with 0-20 days. The increase in the Aegean and Mediterranean Regions remains below 50 days. Under the RCP8.5 scenario, most parts of Türkiye south of the 40°N latitude show an increase of around 100 days, while north of this latitude, in the Marmara and Black Sea Regions, the increase in WSDI is between 30-60 days. Once again, the HadGEM model under the RCP4.5 scenario produces similar outputs to the MPI model under the RCP8.5 scenario, with the Marmara and Black Sea Regions now showing an increase of more than 50 days. The most severe projections are made using the HadGEM model under the RCP8.5 scenario, where almost the entire country shows an increase exceeding 150 days. The Aegean and Mediterranean coastlines appear to have an increase reaching 300 days, which is particularly alarming for human health.

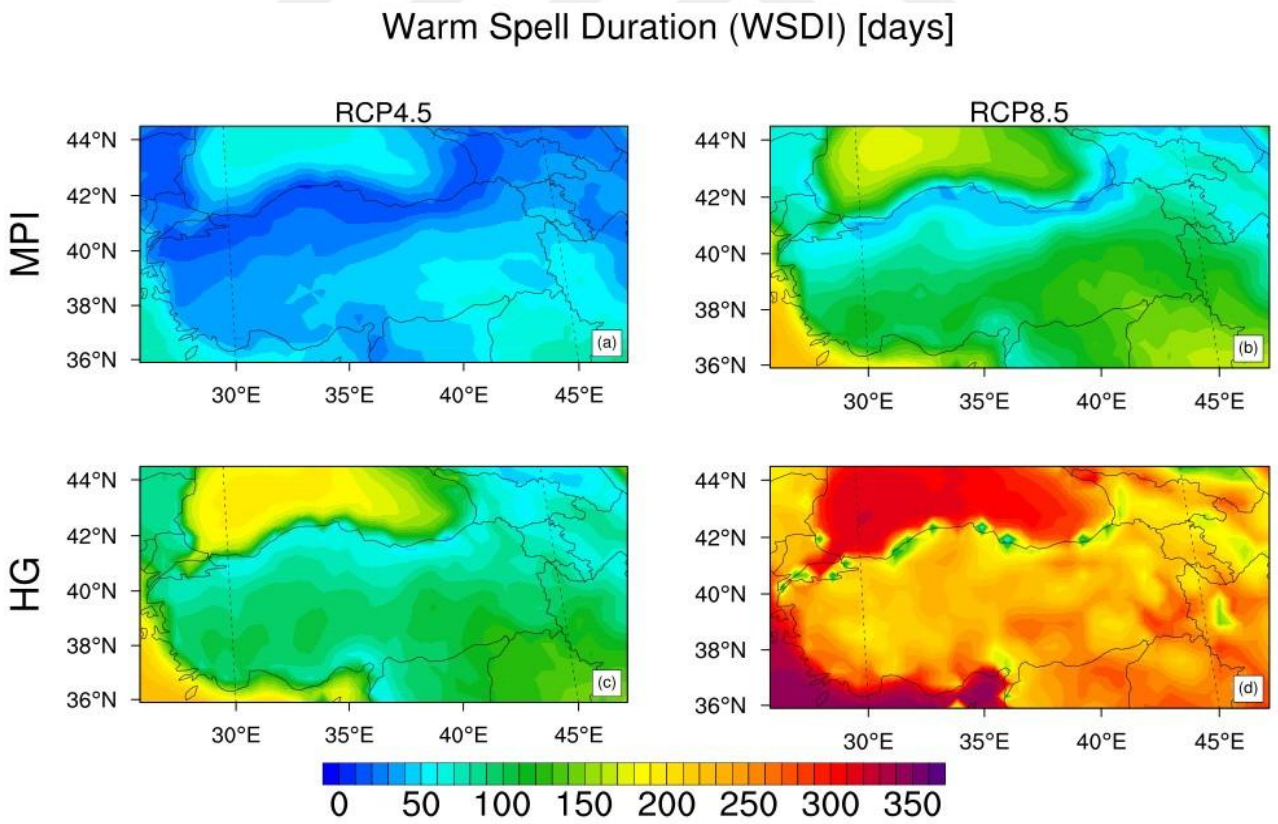

Figure 4.12. Temporally averaged changes in WSDI for the period of 2071–2100 displayed as differences in days with respect to the reference period 1971–2000 for the model MPI-ESM-MR with RCP4.5 (a) and RCP8.5 (b) and for the model HadGEM2-ES with RCP4.5 (c) and RCP8.5 (d).

The findings of the future projections of extreme event indices support our understanding that the risk to human health, including the potential for fatalities due to extreme heat, will increase in the future. It is imperative to emphasize that such fatalities are already occurring today in Türkiye and globally. The findings of this dissertation compellingly indicate that the situation is likely to worsen considerably in the future. Therefore, we must immediately begin taking precautionary measures to avoid an excess number of deaths.

5. SOLUTIONS FOR SMART CITIES

The findings of this study indicate a substantial increase in expected mortality rates due to the projected significant increase in extremely hot days in the future. There are various preventive solutions that can be applied to mitigate the excess number of fatalities. Some solutions have already been successfully implemented in several cities and therefore they actually have been proven to work. Paris provides a pertinent example in this regard. As mentioned in detail in Section 2.1, Paris experienced approximately 4900 deaths during the 2003 European heatwave, due to the extreme temperatures that soared to 40.4 °C and stayed above 35 °C for several days. The impact was exacerbated by unusually high nighttime temperatures, resulting in severe public health consequences. Since then, the city has improved its preparedness against heatwaves and has taken response measures, therefore the mortality rates during the 2018 and 2019 heatwaves in Paris were significantly lower despite their severity and intensity.

Moscow also increased preparedness against extreme heatwaves after the catastrophic 2010 event, which was considered as by far the worst extreme heatwave event that Europe has experienced since at least 1950. Although the city and the country has not encountered a similar heatwave in terms of either duration or severity since then, the measures they have taken were similar to those implemented in Paris. Another example is India. Although the country is used to major heatwave events with increasing trend, after the 2015 extreme heatwave event which caused more than 2500 deaths they have implemented successful solutions to mitigate the fatalities in future events. Other countries such as Australia, Japan, China, the USA are also taking precautions because it is proven by experience that these precautions succeed to decrease the mortality rates. Even though the countries are geographically and climatically different from each other, the measures and precautions they have taken are quite similar. Moreover, all these solutions are remarkably cost-effective, simple to implement and compatible with the features of smart cities as explained in detail in Section 2.2. These solutions that can easily be implemented in Türkiye are explained below.

5.1. Solutions for Cities in Türkiye

5.1.1. Heat Action Plans (HAPs)

The development of heat action plans is essential for countries that are under the risk of extreme heatwaves in the future. Basically, HAPs are pre-planned and outlined strategies and responses for

extreme heatwave events for cities. The first and likely the most important component of HAPs are the Early Warning Systems (EWS), also called Heat Health Warning Systems in the literature. EWSs are considered as the main response to extreme heatwave events worldwide (Samuel et al., 2013). They function according to the information provided by the Meteorological Departments of countries (the General Directorate of Meteorology for Türkiye) and they inform and alert the public as well as the local authorities for impending heatwaves. Various channels must be utilized to communicate this information such as radios, television channels, media, SMS alerts and social media. Leveraging advanced weather forecasting and EWSs, smart cities can foresee extreme heat events in advance and proactively communicate with residents to encourage energy conservation and provide information on staying safe.

In the case of Türkiye, announcements regarding extreme heatwaves could also be disseminated via mosques, similar to the practice of the azan. Although there is no comprehensive study for the exact number and locations of mosques in Türkiye, it is reasonable to assume that Türkiye has at least one mosque in each of its villages and mostly more than one in each district (mahalle) of big cities. Since the vulnerable groups include mostly the elderly, and since the ones that live alone might not be able to use other communication channels, utilizing the mosques for announcements could be an effective solution for both urban and rural areas. Furthermore, social cohesion is also required and crucial for the effective communication of the early warnings. If the community knows in which apartment an elderly lives, who might be unaware of the warnings, then the community can inform that individual and if necessary assist him/her in ways that will be explained in the next sections. Although this proposal may appear to conflict with the Law on the Protection of Personal Data (Kişisel Verilerin Korunması Kanunu, KVKK), the critical point is that the community does not need to know the specific identity of the elderly, which would maintain their privacy. The community should only know that there is an elderly living in that specific apartment, who might need help in case of an extreme heatwave. This way, with the social inclusion of the most vulnerable group, the elderly, the communication of early warnings would be maximized in Türkiye.

Secondly, HAPs require inter-agency coordination between various governmental departments, such as health departments, the authorities for disaster management (the Ministry of the Interior Disaster and Emergency Management Presidency in Türkiye), and municipalities. Governance of both the country and the cities play a critical role while combating an extreme heatwave event. As explained in Section 2.2, the success factors of smart governance include collaboration, communication, accountability, transparency, service and application integration. These features significantly enhance the effectiveness of HAPs.

Thirdly, HAPs require capacity building which would include educational programs for health sector workers, special training programs for especially the paramedics and emergency medical technicians, who are usually the first responders to heat related illnesses. Capacity building also includes enhancing the skills and abilities of local authorities in order to better manage heat related health problems and implement strategies to mitigate heat effects and fatalities. Establishing Non-Governmental Organizations (NGOs) dedicated to improve organizational capacity specifically for responding to heatwave events would be a highly effective strategy. In these NGOs trained local volunteers can help with distributing water, checking on the vulnerable populations, such as the elderly (whose addresses the volunteers know) or the ones with pre-existing health conditions, assist them with heat safety information.

5.1.2. Cooling Centers and Shelters

To mitigate the mortality rates during extreme heatwaves, smart cities have started establishing cooling centers and shelters (Bedi et al., 2022; White-Newsome et al., 2014). While this strategy is one of the most promising for saving significant number lives, it is surprisingly inexpensive and applicable to any city in Türkiye, as it does not require the construction of new buildings and infrastructure. Cities can make use of their own facilities and already existing buildings that have air conditioning, such as libraries, malls, schools, lecture halls in universities, community centers, etc.

It is evident that air conditioning provides the strongest protection against health risks due to extreme heat. During an extreme heatwave event, these air-conditioned places can be used as temporary cooling centers, sheltering significant number of people, especially the vulnerable populations such as the elderly, young children and those with pre-existing health conditions, who might not be able to cool themselves at home. The certain number of people at each cooling center, in other words the capacity, should be arranged so that the maximum temperature, despite the crowd, is guaranteed to stay below 30 °C.

Ensuring that people stay hydrated is crucial, therefore, constant water distribution is essential. These buildings and facilities should also provide food during the time they serve as cooling centers. All unnecessary lighting, which increases the temperature and creates redundant load on electricity grids, especially small spotlights or decorative lamps, must be turned off.

Since people might have to spend the night or stay inside the center for a few days until the danger is over, security must be ensured against theft, harassment, and conflicts, therefore the

presence of the police and security guards is essential. Moreover, paramedics and the first-aid teams that are specifically trained for heat related health problems must be present at all times. Facilities are expected to be crowded, causing boredom or stress for people waiting inside. It is inevitable that there will be discomfort, but such measures will save lives.

Creating a mobile application to help people find the nearest cooling center could be highly effective. The application should display real-time information about the available capacity at each center to prevent overcrowding and guide users to alternative centers if necessary. Additionally, the application could provide information on needed items for each center, allowing users to bring essential supplies with them when they go.

As mentioned earlier, during an extreme heatwave event the efficiency of the electricity production decreases and at the same time, due to the intense air conditioning use, the load on the grids increases, which creates double burden and leads to electricity cuts. Türkiye is expected to experience these cuts at the end of the century as the results of HCI and Extreme Event Indices studies indicate. This is the situation where the cities in Türkiye, especially cities like Antalya, as can be seen in Figure 4.6, have to invest and allocate some financial resources. These resources are required to install solar panels on buildings that will serve as temporary cooling centers during heatwaves. Although there will be electricity cuts on extremely hot days, these are precisely the days when solar energy production is at its maximum. Installing solar panels provides dual benefit since they would also decrease the electricity usage on regular days and therefore help mitigate the GHG emissions and consequently the climate change. India has started employing solar-powered air conditioning systems after their experience of 2015 extreme heatwave event, when temperatures exceeded 45 °C (Pattanaik et al., 2017). Solar powered fans and ventilation would also help in circulating the air and maintaining flow. Moreover, deploying energy storage systems, such as batteries, that can store energy from solar panels, or the regular grid is a smart solution for storing excess energy during periods of low demand and releasing it during peak demand. This would help ensure a consistent power supply.

To reduce the electricity overload on grids during extreme heatwave events, demand response programs can be implemented. There are smart cities that have already adopted these programs (Derakhshan et al., 2016) and these programs encourage citizens to reduce their electricity usage during peak demand periods by offering them incentives to minimize their non-essential electricity usage, to shift their energy-intensive activities to off-peak hours, and to voluntarily reduce overall energy consumption.

More ambitious solutions can be found in the literature. For example, several review papers in leading energy journals discuss passive cooling technologies for buildings (Dimoudi and Androutsopoulos, 2006; Chan et al., 2010; Pacheco et al., 2012; Samuel et al., 2013). One such technology is nocturnal radiation, also known as nighttime radiative cooling, which requires covering the roof of a building with a specific coating material so that the emission of infrared radiation increases compared to the standard roofing materials. Since covering the roof with solar panels offers far more advantages, this solution is not suitable for a country like Türkiye, which can spare limited amount of financial resources on this issue. Another technology is evaporative cooling roof system, which makes use of water on the roof of a building. Water may be circulated or sprinkled on the roof by the use of sprinklers, drip systems or other mechanisms to ensure a consistent layer of water and when it evaporates it takes away some of the heat from the building, similar to the process of sweating. The cities of Türkiye might apply this strategy without implementing any systems but only sprinkling water by the use of a hose on the side surfaces of the cooling centers, not on the roofs, since this strategy requires almost no financial resources. However, if the humidity is high, then the water cannot evaporate effectively from the building, just as it cannot evaporate from the skin, which is a critical concern of this dissertation. Therefore, this strategy also should not be prioritized in Türkiye. Other passive cooling technologies offered in the literature include ventilation, shading and although these might help to some extent for the homes of individuals, they should not be considered for cooling centers. It is recommended that Türkiye invests in this regard in solar panels .

5.1.3. Public Awareness Campaigns

Another important aspect that will save as many lives as the HAPs and the cooling centers is, public awareness campaigns. In order to improve public health response in case of an extreme heatwave, the citizens have to be firstly informed on the seriousness of the issue. Educational programs on television, on the radio, magazines, newspapers, alerting people of all ages on social media, and by using all available means, individuals have to be made sure to understand that this is the new natural disaster of our era. Once this awareness is achieved, citizens have to be instructed on what to do during a heatwave via Public Service Announcements (PSA), again by using all available communicative channels. PSAs should consist of short, direct videos on television and social media, or brief radio spots and should be broadcast repeatedly over many years. It is unfortunate that the general public tends to learn slowly; without having experienced a similar event before, it takes time for them to understand the gravity of the situation, as evidenced by the 1999 earthquake, which resulted in over 18,000 fatalities (Kasapoğlu and Ecevit, 2003), despite many scientists warning and alarming people beforehand.

The educational programs should first emphasize on staying indoors during an extreme heatwave event. Closing the curtains and staying hydrated is essential. Many Turkish people will prefer to keep their televisions on continuously, even though they are strongly advised to do otherwise, since they will be worried and will want to be informed about the updates. Therefore, , they should actually be encouraged to keep the televisions on national channels such as Turkish Radio and Television Corporation (TRT) channels, to stay informed. However, they should be constantly reminded to turn off or avoid using unnecessary energy-consuming devices, such as washing machines, dryers, dishwashers, vacuum cleaners, and non-essential lighting. PSAs that humorously encourage meticulous housewives to postpone housework only for a few days would be useful.

People with air conditioning in their homes should be informed that frequently turning their air conditioners on and off throughout the day with the temperature set to 18°C (so that they believe they can get faster and more effective cooling) is much more energy-consuming than keeping the unit running continuously for about 18 hours a day around 24 °C. People should be encouraged to sacrifice some comfort to save lives by setting the temperature to a minimum of 26 °C, which would still provide home comfort similar to pre-disaster conditions, and save energy, provided that they keep the air conditioners running continuously for about 18 hours a day. The community must be informed about the nearest cooling centers, and the exact addresses of the elderly individuals or those with pre-existing health conditions, who might be in need of assistance to arrive to those centers. Again, the specific identities of these people are not needed and should remain private so that this proposition is still in compliance with KVKK. Social cohesion and community engagement will contribute to save many lives.

These public awareness campaigns should also be conducted through NGOs, and they can provide longer lessons, teachings to the public compared to PSAs. In many cities of Türkiye, there are Public Education Centers (PEC), such as Istanbul Metropolitan Municipality Art and Vocational Training Courses (İSMEK); Izmir Metropolitan Municipality Culture and Art Education Center, Muğla Metropolitan Municipality Culture and Education Center, Antalya Metropolitan Municipality Education Center (ANTEM), etc., that are dedicated to provide vocational training and education in various fields for the general public. These are already in existence, they only have to include one more course such as ’Heatwave Safety Tips’ to help people cope with and stay safe during extreme heat. These tips include staying hydrated, staying in home, staying out of heat by arranging activities at cooler times of the day, keeping your house cool, using fans and coolers, using sun screens, hats, umbrellas if going outside is unavoidable, wearing lighter and looser clothes, learning how to get help, noting the contact information and the address of the nearest health care center. Additionally,

the information about the cooling centers and the individuals that might need assistance during a heatwave can also be included in these courses as well.

5.1.4. Health Sector Preparedness

As discussed earlier in Section 2.1, during extreme heatwaves hospital admissions due to heat related health problems increase significantly. Firstly, healthcare workers must be trained to recognize, diagnose and immediately treat heat stress related conditions such as dehydration, heat exhaustion, heat syncope, electrolyte imbalance, heat cramps and heatstroke. To be able to treat heat illnesses, improving the related equipment, stocking rehydration salts and other medical supplies and ensuring to have cooling systems in hospitals would be another smart approach.

Secondly, although the patients might panic since they do not feel well, some of the heat related conditions may be treated at home, therefore establishing telemedicine services to provide medical consultation for citizens whose conditions are not so severe to necessitate leaving their homes would also help reduce the overcrowding in hospitals.

Thirdly, improving the surveillance and reporting systems to better monitor the number of patients and fatalities, and announcing these figures transparently to the public -instead of manipulating the number of deaths for political interests- would actually encourage people to take the issue more seriously and therefore would lead to a better response in future cases.

5.1.5. Infrastructure and Urban Planning

When it comes to solutions that would help in the long run, smart cities have to invest in infrastructure and urban planning in order to reduce heat island effect. Urban Heat Island (UHI) effect simply refers to the exacerbated temperatures in cities compared to the surrounding countryside due to excess usage of artificial surfaces such as asphalt, cobblestones, concrete. These surfaces cause a different radiation balance in cities because solar radiation is absorbed more and reflected less with these surfaces compared to the green areas, which results in significantly higher discomfort in cities. It is stated in the literature that, the night-time temperature in the city can be 10 °C more than the surrounding countryside (Rožnovský et al., 2017).

In order to decrease the UHI effect the existing greenery in the city must be protected and there must be a constant effort to increase the number of trees, parks, and green areas. A study researching

on improving the thermal comfort in smart cities through spatial analysis of heat with in-situ measurements in the study area of Seoul found that increasing the green areas by 1%, decreases the sensible heat by 4.9 W/m2 (Kwon et al., 2019). This strategy has several benefits: in addition to decreasing the UHI effect, it provides more shaded areas for people to take shelter in and it helps mitigate the climate change by enhancing the carbon sinks. The importance of green areas for the future wellness of human beings cannot be overstated.

Another method of cooling cities and decreasing UHI effect is investing in the roofs of the buildings. The aforementioned ambitious solutions, such as nocturnal radiation, might not intrigue a developing country with financial concerns like Türkiye, however there is one affordable smart solution, and it is simply painting the roofs of the buildings to a reflective white paint. This simple smart solution would increase the albedo of the city, although it will not contribute to mitigating the climate change overall (since it neither mitigates emissions nor enhances sinks), it will help reducing the UHI effect. It is critical to emphasize that the cooling centers must invest in solar panels and actually the more solar panels established in the city, the better. This solution should only be applied to the regular buildings where solar panels are not considered.

One popular discussion on the issue is the installation of green roofs, which are nature-based solutions which might play an important role in regulating indoor temperatures. Although research on green roofs is ongoing, a 2020 microsimulation study examining their effect on fatalities due to extreme heat events in four European cities—Szeged (Hungary), Alcalá de Henares (Spain), the Metropolitan City of Milan (Italy), and Çankaya municipality in Ankara (Türkiye)—found variable results in reducing heatwave-induced mortality across cities (Marvuglia et al., 2020). The study showed that Szeged, Alcalá de Henares, and Çankaya saw substantial reductions in heatwave-induced mortality, while the Metropolitan City of Milan experienced almost no mitigation effect. Although there are other studies promoting vegetative green roofs (Santamouris, 2014), the installation of green roofs are not cost-friendly and therefore not easily applicable to residential buildings (Blackhurst et al., 2010). Moreover, sustaining these green roofs during extreme events including extreme precipitation and heatwaves which are highly expected in the last 30 years of the century, will be increasingly difficult and expensive. Green areas are an indispensable part of smart cities; however, if Türkiye is to invest in rooftop initiatives, the budget should be allocated to solar panels first. If, however, there are buildings with wide roofs which stay in the shade due to surrounding buildings or nearby trees, and therefore solar panels are not applicable or not efficient enough, then green roofs can be considered to reduce the UHI effect and increase the air quality in the city. If Türkiye still suffers from economic problems during the last 30 years of the century, the country may prefer to

invest in greenery focused on ground-level areas, where costs are lower.

5.1.6. Policy and Research

The current policies of smart cities worldwide to cope with heatwaves involve investing in several smart technologies. The first is energy efficiency measures (Pacheco et al., 2012), including energy efficient appliances, lighting, and building designs that reduce overall electricity demand. The second is investment in renewable energy resources, particularly solar and wind, to create a more resilient and sustainable power supply by diversifying energy sources. The third is smart grid technology investments (Tuballa and Abundo, 2016), which enable more efficient and dynamic management of electricity distribution, while also allowing for better monitoring, control, and optimization of the power grid, helping to balance electricity supply and demand.

Another policy that does not require investment in technology is to collaborate with utility companies to develop and implement strategies for managing electricity demand and ensuring the power grid's resilience during extreme events.

An additional policy that the government should implement is a 'lockdown' or 'stay-at-home order' during an extreme heatwave event, similar to the measures taken during the COVID-19 pandemic. If individuals are unable to protect their life for various reasons, the state should enforce regulations comparable to those implemented during the pandemic.

There should be ongoing research throughout the century into the climate change crisis and the extreme events associated with it. It should be emphasized that the extreme heatwave events will not be the only extreme events that will claim lives in the future. However, since the technology will advance, the scenarios will get more realistic as the future approaches, recent research will be increasingly valuable. Therefore, the government should continue to encourage master's and Ph.D. students of this country to investigate solutions to these challenges by providing scholarships, as exemplified by this dissertation, which is supported by the YÖK 100/2000 scholarship program.

5.1.7. Community Engagement

In order to prevent excessive deaths in extreme heatwaves, the community's collective action, unity, and voluntary participation in life-saving initiatives within the framework of social responsibility can be called community engagement. The sense of solidarity and unity keeps the

morale of the community high in difficult times, such as natural disasters, and also enables individuals to make some sacrifices for one another. In fact, the actions people can take to help each other in the city is rather simple in extreme heatwaves compared to other disasters such as earthquakes, extreme precipitation leading to floods, extreme drought, wildfires, sea level rise, etc. People should make sure to stay hydrated and offer water to the ones who are not feeling well. If they have air conditioning in their homes, they can invite others that lack such capabilities. Even if both have air conditioning, they should be encouraged to gather in one home to reduce the burden on the electrical grid. People should know in which apartment an elderly lives, who might be in danger and in need of assistance to a cooling center. The volunteer networks for distributing water, assisting with transportation to cooling centers, providing medical assistance to those with heat-related conditions, and establishing neighborhood support systems would all contribute to reducing mortality rates during a deadly heatwave event. Therefore, the national televisions, such as TRTs should make continuous announcements about the community engagement actions that individuals can take to help each other. Additionally, all television channels should air programs aimed at boosting morale and supporting people's mental well being.

On a regular day, people should inform each other on the dangers of heatwaves, they should notify each other about the courses in PECs, they can teach each other how to use the developed application in order to find the nearest cooling center.

As shown in the integrative framework of smart cities in Figure 2.6, all these simple and smart solutions require the collaborative work of governance, people and communities, alongside well-planned policies on the investment in technologies of solar panels and mobile apps, They also should utilize the built infrastructure and include continuous efforts to increase green areas for the natural environment . All these measures would collectively create smart cities and make a significant impact on the death tolls during extreme heatwave events.

5.2. Preparation opportunities specific for Antalya

As the outputs of this study indicates, Antalya is one of the cities that is projected to face the worst extreme heat events in the future. The central districts of Muratpaşa, Kepez, Aksu, Döşemealtı, Serik, together with Konyaaltı, Manavgat have been shown to be under most risk, while Kaş, Kale, Finike, Kumluca have been shown to experience Great Discomfort Humidex classifications for the end of the century. Therefore, the aforementioned solutions should be prioritized in Antalya and the municipality should invest in this area more compared to the other cities in Türkiye. It is likely that

extreme heat events will be the worst disasters that the city will encounter in the future.

Antalya has one of the longest coastlines in Türkiye with approximately 640 kilometers (Turkish Ministry of Culture and Tourism, 2024) to the Mediterranean Sea. While cities like Muğla have longer coastlines, reaching around 1,100 kilometers due to their highly indented structure due to several curves and bays, Antalya's coastline is more continuous and direct. This means, not only the temperatures are so high in Antalya, but also the humidity is in dangerous levels even today in the city due to its narrow expanse running parallel to the sea and not venturing far inland. All these reasons make Antalya very vulnerable in terms of all the concerns of this dissertation.

The first smart solution for Antalya municipality would be investing more in their weather forecasting systems so that they can have better EWS. In his 2022 article, Murat Türkeş says "Predicting what the weather will be like in the upcoming days is no longer enough; impact-based forecasts that inform the public about what the weather will do are vital to save lives and livelihoods and being prepared, being able to act at the right time and place can save lives now and in the future, and protect the livelihoods of communities everywhere" (Türkeş, 2022). The WMO has announced a few important strategical approaches in order to improve the implementation and effectiveness of EWSs; focusing investments on translating early warning information into early action, monitoring the financial flows to understand where funding is allocated (ensuring transparency and accountability) to meet EWS implementation requirements, and developing greater consistency in monitoring and evaluation to better determine the effectiveness of EWSs (World Meteorological Organization, 2024). Since Antalya is more vulnerable compared to the most other cities in Türkiye, it is meaningful for the Antalya municipality to invest more in EWSs and their communication to the public. Following the recommendations of WMO to enhance the efficiency and implementation of EWSs would help better managing the impacts of extreme heatwave events.

The next smart solution specific for Antalya would be identifying the locations and the buildings which can serve as cooling centers for each district, as soon as possible. High quality and energy efficient air conditioning investment for the identified centers is a must. Furthermore, in-situ assessments on how many people each center can accommodate for how many days are necessary. Then, when it comes to decide on where to install the solar panels, further research is required to determine which buildings are appropriate for solar panels. There are several steps to follow before selecting the roofs and buildings the solar panels can be installed. Firstly, the orientation and the location of the roof must face direct sun light for most of the day, avoiding shade from nearby buildings, trees, or mountains. Secondly, the roof area must be large enough to ensure the investment

in solar panels is worthwhile, and the electricity that can be produced from the panels in case of a power outage during an extreme heatwave event can be compensated enough to keep people inside alive. Thirdly the roofing material has to be solid and durable enough to enable the installation and accommodation the solar panels for many years. Fourthly, the building itself should be structurally strong and steady enough so that the investment in solar panels would be justified. It is important to note that Türkiye is situated along earthquake fault lines and Antalya has one of them passing through the eastern part of the city. If a building was constructed after the 1999 İzmit earthquake, which led the authorities to issue new and stricter building regulations, that might offer some reassurance, still earthquake resistance analysis together with in-situ research would serve better for the intentions of this study.

Below, a list of the buildings that can potentially serve as a cooling center during an extreme heatwave event in Antalya is provided. It should be noted that this study has not verified whether these buildings are currently equipped with air conditioning, as even if they do have air conditioning systems in place, they may not be sufficient for the demands discussed in this dissertation. Regardless of their current air conditioning capabilities, each center needs to be assessed to determine whether new, more powerful, and energy efficient air conditioning units are required.

1. **Muratpaşa**

a. Terracity Shopping Center

Address: Fener, Tekelioğlu Street, 07160 Muratpaşa

b. MarkAntalya Shopping Center

Address: Tahılpazarı, Kazım Özalp Street, 07040 Muratpaşa

c. Antalya Culture and Arts

Address: Elmalı, Binbaşı Cengiz Toyunç Street, 07100, 07040 Muratpaşa

d. Atatürk Cultural Center

Address: Meltem, Sakıp Sabancı Boulevard, 07030 Muratpaşa

e. Doğan Hızlan Library

Address: Meltem, Sakıp Sabancı Boulevard, 07030 Muratpaşa

f. Antalya Tekelioğlu Provincial Public Library

Address: Üçgen, 96th Street, 07040 Muratpaşa

g. Muratpaşa Ahmet A.Sönmez District Public Library

Address: Zümrütova, 07160 Muratpaşa

2. **Kepez**

a. Antalya Library

Address: Gülveren, 3700 Street, 07220 Kepez

b. Cemil Meriç Library

Address: Fabrikalar, Dokumaparki, Namık Kemal Boulevard, 07100 Kepez

c. Erdem Beyazıt Culture Center

Address: Yeni Emek, Sakarya Boulevard, 07060 Kepez

d. Antalya Metropolitan Municipality Yenimahalle Neighborhood House

Address: Yeni, 2450th Street, 07060 Kepez

e. GSB Özgecan Aslan Youth Center

Address: Kültür, 3806th Street, 07090 Kepez

3. **Döşemealtı**

a. Döşemealtı Municipality Culture and Social Service Center

Address: Yeşilbayır, Adnan Menderes Street, 07190 Döşemealtı

b. Antalya Science University Library

Address: Çıplaklı, Akdeniz Boulevard, 07190 Döşemealtı/Antalya

4. **Konyaaltı**

a. Mediterranean University Central Library

Address: Pınarbaşı, Mediterranean University, Dumlupınar Boulevard, 07070 Konyaaltı

b. Konyaaltı Municipality Nazım Hikmet Fair and Congress Center

Address: Pınarbaşı, 734th Street, 07070 Konyaaltı

c. Konyaaltı Municipality Women's Art and Education Center

Address: Uluç, 1164th Street, 07070 Konyaaltı

d. Konyaalti Social Services Center

Address: Gürsu, Atatürk Boulevard, 07070 Konyaaltı

e. Mozaik Cultural Center

Address: Pınarbaşı, 739th Street, 07070 Konyaaltı

5. **Kemer**

a. Kemer Centrum Shopping Center

Address: Yeni, Atatürk Boulevard, 07980 Kemer

b. Kemer Municipality Culture Center

Address: Merkez, Street, 07980 Kemer

6. **Serik**

a. 100. Yıl Sports Hall

Address: Merkez, Burmahancı Street, 07500 Serik

b. Serik Public Library

Address: Orta, 1033rd Street, 07500 Serik Korkuteli

c. Recep Gurbuz Indoor Sports Hall

Address: Kiremitli, Paris Street, 07800 Korkuteli

7. **Elmalı**

a. Elmalılı Muhammed Hamdi Yazır Cultural Center

Address: Karyağdı, 36 Daireler Street, 07700 Elmalı

b. Elmali Municipality Cinema Hall

Address: Gündoğan, Hükümet Street, 07700 Elmalı

8. **Kumluca**

a. 50. Yıl Cultural Center Cinema

Address: Narenciye, Kültür Park,, 07370 Kumluca

b. Kumluca Cultural Center

Address: Bağlık, Kiremithane Street, 07350 Kumluca

9. **Finike**

a. Finike Culture and Art House

Address: Kale, Şerbetçi Boulevard, 07740 Finike

b. Finike Indoor Sports Hall

Address: Yeni, 517th Street, 07750 Finike

c. Finike District Public Library

Address: Yeni, Şerbetçi Boulevard, 07740 Finike

10. **Demre**

a. Demre Municipality Culture and Arts Hall

Address: Büyükkum, 07570 Demre

b. Demre Indoor Sports Hall

Address: Gökyazı, Çevre Yolu Street, 07570 Demre

11. **Manavgat**

a. Novamall Shopping Hall

Address: Sorgun, 8096th Street, 07600 Manavgat

b. Mall of Side

Address: Ilıca, Kumköy, Cumhuriyet Boulevard, 07600 Manavgat

c. Manavgat Atatürk Cultural Center

Address: Yukarı Pazarcı, 07600

d. ManavgatManavgat National Library

Address: Yukarı Hisar, Hastane Street, 07600 Manavgat

e. Manavgat District Public Library

Address: Yukarı Pazarcı, 4075th Street, 07600 Manavgat

12. **İbradi**

a. İbradi District Public Library

Address: Aşağı, Millet Street, 07680 İbradı

13. **Akseki**

a. Yeğen Mehmet Paşa Public Library

Address: Hacı İlyas, Ömer Duruk Street, 07630 Akseki

14. **Alanya**

a. Alanyum Shopping and Entertainment Center

Address: Cumhuriyet, Keykubat Boulevard, 07400 Alanya

b. Time Center Shopping Mall

Address: Konaklı, 100th Street, 07400 Alanya

c. Atatürk Sports Center

Address: Saray, 07400 Alanya

d. Emine Hacıkura Library

Address: Güller Pınarı, Recepli Street, 07460 Alanya

e. Alanya Municipality Cultural Center

Address: Saray, İsmet Hilmi Balcı Street, 07400 Alanya

f. Alanya District Public Library

Address: Kadıpaşa, Bostancıpınarı Street, 07400 Alanya

15. **Gazipaşa**

a. Antalya Metropolitan Municipality Gazipaşa Cultural Center

Address: Pazarcı, 7888+73, 07900 Gazipaşa

b. Gazipark AVM Life Center

Address: Beyobası, Kümeli Evler, 07900 Gazipaşa

From this list, the most promising places to be used as cooling centers are the shopping malls and the sports halls, since they are larger and can hold more people, they were built more recently compared especially to the old municipality libraries, they have better infrastructure and wider roof surface area to accommodate solar panels and most of them currently have strong air conditioning systems. Investing in energy storage systems both from solar energy and from conventional electricity energy particularly for malls and sports halls would be another smart approach. For the libraries and shopping centers security measures are essential to protect books and products.

6. DISCUSSION

This study has conducted two climate projections to assess thermal comfort and extreme heat-related indices, aiming to provide insights into the potential future impacts of extreme heatwaves on cities in Turkey. The findings of both projections indicate alarming trends, underscoring the urgent need for proactive planning to mitigate excessive fatalities in the future. One key finding of this study is that the outputs of the HadGEM2-ES global climate model project more severe climatic conditions for the future study period (2071–2100) across all ETCCDI indices compared to the MPI-ESM-MR model under both RCP4.5 and RCP8.5 scenarios.

The literature suggests that for CORDEX Region 13 (Middle East and North Africa), which includes Turkey, the regional climate model RegCM has been demonstrated to produce outputs that align more closely with observational data when driven by MPI-ESM-MR data rather than HadGEM2-ES data (Endris et al., 2016; Ozturk et al., 2018). This may suggest a higher likelihood of the less dire projections of MPI-ESM-MR being realized in comparison to those of HadGEM2-ES. Nevertheless, the projections from MPI-ESM-MR still indicate conditions severe enough to pose significant risks, including loss of life. Therefore, comprehensive action plans to address extreme heatwave events remain imperative, even under the less dire projections of MPI-ESM-MR.

This dissertation, aimed to find smart solutions against future deadly heatwaves, found the most promising solution in the solar paneled buildings which can serve as cooling centers and shelters during extreme heatwave events. The research on the role of cooling centers have been expanding during the last decades (Widerynski et al., 2017; Bedi et al., 2022; Hondula et al., 2024). One such study investigating the lessons learned from the 1995 extreme heatwave event in the Midwestern United States (Palecki et al., 2001), found that the extreme heatwave in Chicago in 1999 resulted in 80% less mortality compared to the 1995 mostly because people went to air-conditioned areas such as malls and movie theaters to escape heat. Moreover, an early warning system implemented, and cooling centers opened after the 1995 event, before the 1995 event, which lead to the significant decrease in the death toll (Palecki et al., 2001). Another study researching on 2003 France heatwave and the risk factors for older people living at home employed interviews with family members of the deceased and concluded that utilization of a cool space by the elderly during the extreme heat resulted in reduced mortality (Vandentorren et al., 2006).

A study investigating the impact of heatwaves on public health in Europe found that individuals at lower risk of heat-related illness are more likely to utilize cooling centers compared to vulnerable groups. The study highlighted the need for targeted public awareness campaigns to inform and encourage the participation of vulnerable populations (Kovats et al., 2006). Several other studies have similarly emphasized the importance of such campaigns to ensure that cooling centers function at full capacity and effectively reduce mortality during extreme heat events. For instance, in Canada, which has implemented cooling centers as part of its heat action plans, a study was conducted involving interviews with 238 patients from Montreal with chronic cardiac and pulmonary conditions. The findings revealed that 25% of the respondents indicated they would not seek shelter in cooling centers during a prolonged heatwave, citing reasons such as reluctance to sleep in an unfamiliar environment and not perceiving themselves as ill enough to require such precautions (Kosatsky et al., 2009). Furthermore, a study by Alberini et al. (2011), which surveyed residents from five different cities in Canada, found that more than half of the respondents were unaware of the existence of cooling centers. Similarly, a study conducted in New York revealed that vulnerable groups did not perceive themselves as at risk and expressed reluctance to visit cooling centers, citing concerns about being surrounded by elderly individuals and the desire to avoid leaving their homes unattended for extended periods (Lane et al., 2014). All these studies underscore the critical role of public awareness campaigns in assessing the efficacy of cooling centers. It is unfortunate that the full gravity of the issue is often only recognized after significant mortality rates, as was the case during the 2003 heatwave in France. The delayed recognition of the severity of heat-related health risks highlights the urgent need for proactive education and outreach to ensure vulnerable populations are aware of and make use of cooling centers before the onset of extreme heat events.

An additional study, reflecting on the lessons learned from the 2003 heatwave in France three years after the event, underscores the importance of social preparedness as a priority, followed by addressing the thermal quality of the built environment. This includes enhancing thermal insulation in individual buildings and increasing urban vegetation to mitigate the urban heat island effect. The study further highlights the critical need for robust electricity supply infrastructure (Salagnac, 2011). It is noted that while there has been a significant increase in air conditioning sales, this rise has predominantly occurred in non-residential buildings. In 2003, electricity demand increased by 4.2% compared to the same period in 2002, driven largely by the heightened demand for electrically powered cooling systems, which are increasing in number after the event. The national electricity provider, Electricité de France, acknowledged that the scale of the 2003 heatwave's impact had never been anticipated or even envisaged prior to the event.

In order to cope with electricity-related problems during extreme heatwave events, France's action plans include reducing exports and increasing electricity imports from foreign subsidiary companies, along with implementing electricity consumption reduction measures for major industrial clients. Temporary exemptions were granted in France to allow the operation of six power plants (four nuclear and two traditional thermal plants) beyond the maximum temperature limits to meet the high demands during heatwaves (Salagnac, 2011). Although France's heatwave action plan incorporates the use of cooling centers—such as naturally cool rooms like cellars, historic stone buildings like churches, and artificially cooled spaces like malls, museums, and libraries—it does not include investments in solar panels. Solar panels would be highly beneficial for generating electricity during extreme heatwave events. Moreover, this solution offers a win-win scenario by reducing greenhouse gas emissions and mitigating climate change, while providing electricity without the risks associated with operating power plants beyond their maximum temperature limits. This approach would be smarter for Turkey and other countries as well. One smart approach that France plans to implement involves reinforcing insulation and improving equipment maintenance to enhance building performance. The goal is to increase the proportion of "heatwave-resilient buildings" within the national building stock. Under their action plans, a two-week heatwave event classified as third-degree on a four-level alert scale occurred in June 2005 across eight French regions and no excess mortality was recorded (Salagnac, 2011), underscoring the effectiveness and importance of such action plans.

To understand the perspectives and approaches of key stakeholders on this issue, several stakeholders in Antalya were contacted, including mayors, deputy mayors, department heads, public health directors from seven different district municipalities, emergency room doctors from Medical Park Antalya Hospital Complex (the largest private hospital in the region), and Antalya City Hospital. Among them, an interview was conducted with Ceren Şahin, who is an Environmental Engineer and the Director of the Climate Change and Zero Waste Department at Muratpaşa Municipality in Antalya.

Ms. Şahin was asked whether a preparation or an action plan exists for extreme heatwaves in Muratpaşa and whether the municipality would be open to such planning. She stated that while the Climate Change and Zero Waste Directorate, along with other relevant departments, implements various projects to mitigate the effects of climate change, no specific plan currently addresses heatwaves. However, Mayor Ümit Uysal emphasizes the importance of planned and result-oriented actions in tackling climate change. Therefore, the municipality would likely be receptive to developing and evaluating plans specifically targeting heatwaves. Additionally, in 2022, the

municipality joined the Covenant of Mayors initiative and prepared a Sustainable Energy and Climate Action Plan, which outlines strategies to mitigate climate-related challenges, including heatwaves. This demonstrates a proactive stance by the municipality.

Regarding the existence of studies on early warning systems and the potential support for such initiatives, Ms. Şahin highlighted that Mayor Uysal underscores the importance of planned measures concerning the climate crisis and water management. Consequently, early warning systems would likely be positively received and could be implemented in collaboration with other municipalities.

Ms. Şahin was also asked about the feasibility of utilizing air-conditioned spaces such as shopping malls, libraries, and sports centers as cooling centers during extreme heatwaves. She noted that Muratpaşa Municipality does not currently have such an initiative in place. However, given the municipality's openness to innovative solutions for mitigating climate change effects, such measures could be considered in the future.

Regarding the installation of solar panels on rooftops, Ms. Şahin stated that the municipality supports energy efficiency and the use of renewable energy sources. As part of its Institutional Energy and Climate Action Plan, Muratpaşa Municipality aims to reduce emissions from municipal activities by 40% by 2030. Within this framework, renewable energy projects, including solar panel installations, are actively encouraged and supported.

Finally, when asked about the allocation of municipal budgets for such projects in the future, Ms. Şahin emphasized that Muratpaşa Municipality prioritizes environmental and climate-focused initiatives. The municipality has already invested in various sustainability projects, such as the Environmental Neighbor Card (Çevreci Komşu Kart) program, which incentivizes recycling and has achieved significant success. The allocation of funds for such initiatives reflects the municipality’s commitment to environmental sustainability, and it is likely that similar projects will continue to receive financial support in the future.

In summary, the interview with Ms. Şahin provided valuable insights into the current initiatives and future directions of Muratpaşa Municipality in addressing the challenges posed by climate change, particularly in relation to heatwaves. Although there is no specific plan in place for heatwave preparedness, the municipality has shown a proactive and open stance towards addressing climate-related challenges, as evidenced by its participation in the Covenant of Mayors and the implementation of the Sustainable Energy and Climate Action Plan (SECAP). Furthermore, while

current efforts do not include the establishment of cooling centers or the deployment of early warning systems, there is a clear willingness to explore such solutions in collaboration with other municipalities. The municipality's support for renewable energy projects, such as rooftop solar panel installations, and its commitment to funding future environmental initiatives suggest a strong alignment with sustainable development goals. These findings contribute to understanding the capacity of local governments to adapt to climate change and the importance of planning, cooperation, and innovation in building urban resilience in the face of extreme weather events.

7. CONCLUSION AND RECOMMENDATIONS

In this study the performance of Holiday Climate Index in Türkiye is calculated to investigate the future climatic comfort of the country in terms of both urban and beach tourism. In order to do this, firstly the outputs of the MPI-ESM-MR global climate model were dynamically downscaled by the use of RegCM4.4 regional climate model under RCP4.5 and RCP8.5 scenarios for near future period of 2021-2050 and far future period of 2070-2099 compared to the reference period of 1971-2000. Given the alarming findings, the study further continued to investigate future extreme events in Türkiye by employing the indices developed by Expert Team on Climate Change and Detection and Indices. Here, the outputs of two global climate models, HadGEM2-ES and MPI-ESM-MR, were dynamically downscaled by the use of RegCM4.4 regional climate model under RCP4.5 and RCP8.5 scenarios for the period of 2071-2100 compared to the reference period of 1971-2000. Both the findings of HCI and extreme event projections for the final three decades of the century have shown that there will be extreme heatwaves of such severity that they are known to cause excess number of fatalities, especially among the elderly, young children and those with pre-existing health conditions.

The findings and indications of the projection studies are well-limited due to the methodological constraints. High computation power and storage requirements constitute the technical limitations which prevents much higher resolution data. Further research should utilize the more recent scenarios of IPCC, employ more GCM-RCP couples together with their ensembles in order to provide alternative solution sets. Further statistical downscaling techniques, similar to the lapse rate corrections utilized in HCI study, can be improved and become more sophisticated in order to take the seasonal temperature deviations in different regions into account.

After showing with climate simulations that extreme heatwaves in Türkiye will reach deadly levels in the future, this study aims to bring smart solutions to this situation on a city basis.. As discussed earlier, healthy and young human beings can survive under 35 °C wet bulb temperature for five hours. Although this survival limit of 35 °C wet bulb temperature has been being used in several articles, studies employing lower limits have also begun to appear in the literature. These relatively new studies say that the former 35 °C limit was defined with a model treating the body as an unclothed object that does not move (Wong, 2024), without integrating variations in human physiology (Vanos et al., 2023), and also by over-relying on the public-health bodies (Sherwood and Huber, 2010), therefore the limit is actually lower. To illustrate, the study by Vanos and coworkers (2023) attempted to employ physiological and biophysical principles for young and older adults and their research

concluded that 35 °C wet bulb temperature vastly underestimates the risks in hot dry conditions and updated survivability limits are 25.8–34.1 °C for young people, 21.9–33.7 °C for old people. Since these limits and similar others are defined rather newly, in this study it is preferred to put emphasis on the commonly used 35 °C wet bulb temperature. However, this ongoing research already show that the gravity of the situation is even worse than this study highlights. It should not be forgotten that the actual problem is the climate change crisis and extreme heatwaves are only one of the problems that come with it, and it is most probable that even the business as usual scenario is underestimating the risks that the climate change will pose in the future. The focus of this dissertation is only to provide a remedy for a symptom, not a cure for the actual disease, the climate change crisis. However, if the suggestions in this study are followed, they will also help mitigate the climate change.

This study places particular emphasis on Antalya, as it is among the most vulnerable cities and experiences a significant population increase during the summer due to both residents and tourists. The impact of previous heatwave events, along with the changes observed following the implementation of action plans, underscores that adopting the solutions proposed in this study could lead to a reduction in fatalities. Notably, given Antalya's prominence as a tourist destination, hotels could potentially serve as cooling centers or shelters, provided that hotel owners are willing to cooperate. Research suggests that even allowing individuals to stay in hotels for a few hours could effectively lower core body temperature and heart rate, thereby enhancing survival rates (Meade et al., 2023). Furthermore, the feasibility of utilizing basement spaces as cooling areas could be explored. However, it is recommended that more extensive public awareness campaigns be implemented, as individuals often perceive themselves as healthy and not at risk, leading them to decline even readily available cooling options, such as visiting shopping malls.

Although this study places a focus on Antalya, the HCI outputs and the extreme event indices indicate that numerous cities across Türkiye will experience life-threatening heatwaves in the future. To mitigate high mortality rates, other cities in Turkey should follow similar adaptive measures. It is critical to emphasize that the solutions proposed in this dissertation for extreme heat events are both straightforward and cost-effective. These practical and efficient measures, such as ensuring adequate hydration, staying indoors, and developing public awareness campaigns to inform individuals that if cooling their bodies at home is not feasible, they should utilize cooling centers, do not necessitate the construction of new buildings for the purposes of this study.

The most expensive investments this study recommends are on the solar panels, which would save hundreds of lives since they provide energy security and reduce the dependence on the

conventional electricity grid during deadly heatwaves. Furthermore, they have many more benefits to the country aside from saving lives. They will help reduce the overall fossil fuel consumption for energy, help mitigate the GHG emissions, help the economy in the long run since they cost less compared to the conventional electricity, help creating new employment for manufacturing, installation and maintaining purposes, and help protecting the environment.

Another approach of increasing green areas in the cities, is to reduce urban heat island which also has many other benefits for the country. Protecting the existing greenery and continuous efforts to increase the number of trees and parks will help reduce urban air pollution, help carbon sequestration and therefore contribute mitigating the climate change effects, provide areas for citizens to find tranquility in the city, help enhance the biodiversity in the city, reduce the flooding risks during extreme precipitation events, provide access to nature therefore improve the well-being of community, and promote sustainable urban life by creating climate and heatwave resilient cities.

Other smart solutions such as improving the weather forecasting systems to implement EWSs, developing an app for citizens to search the nearest cooling centers and the materials needed in these centers, establishing courses in municipality educational centers to educate community, promoting NGOs working with volunteers in order to help and assist the vulnerable populations, are all easily applicable and economically viable for a country like Türkiye. All these simple solutions will, without a doubt, contribute saving hundreds of lives in the city and thousands of lives in the country.

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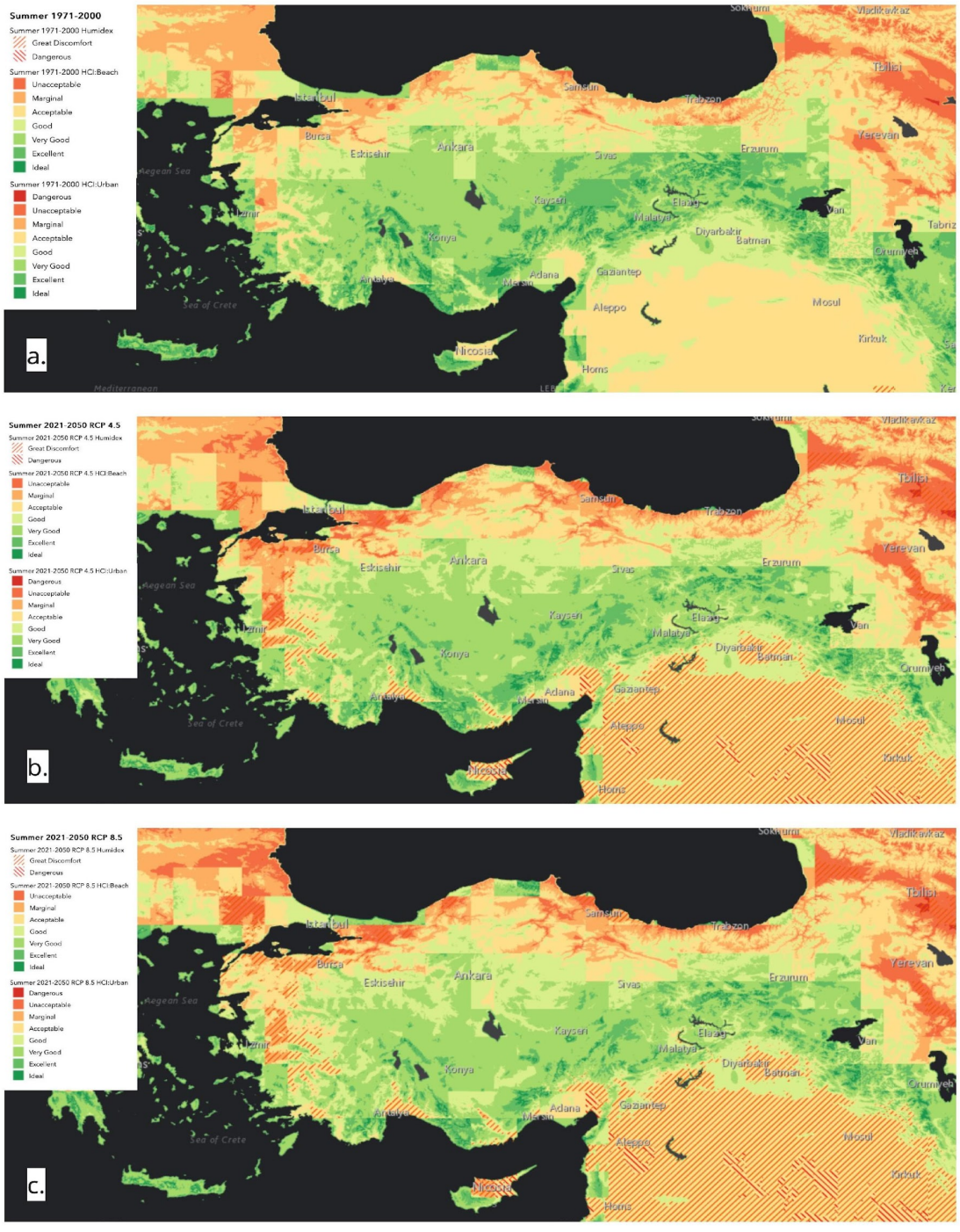
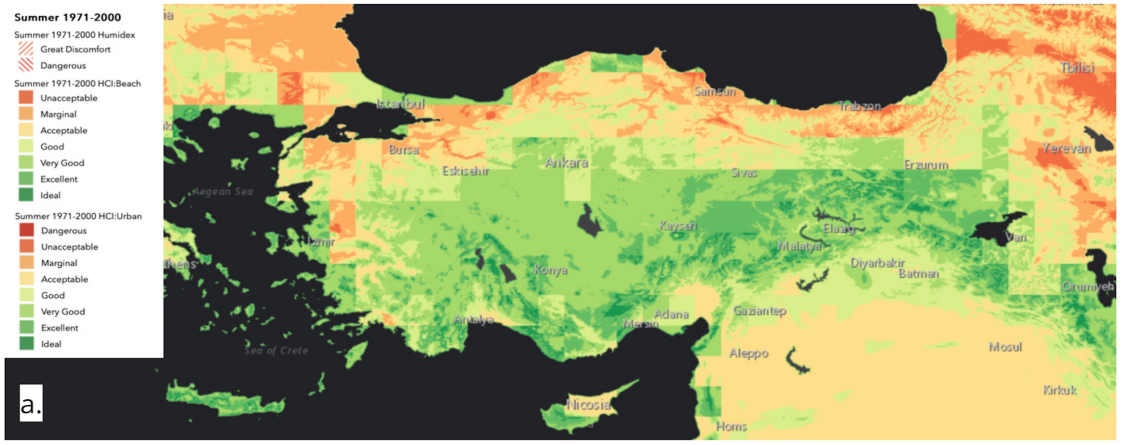
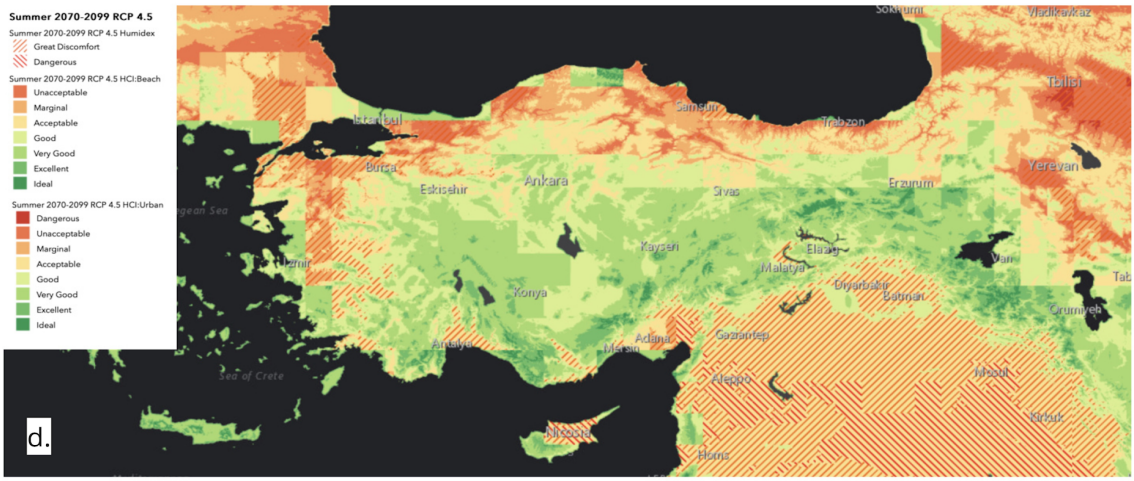
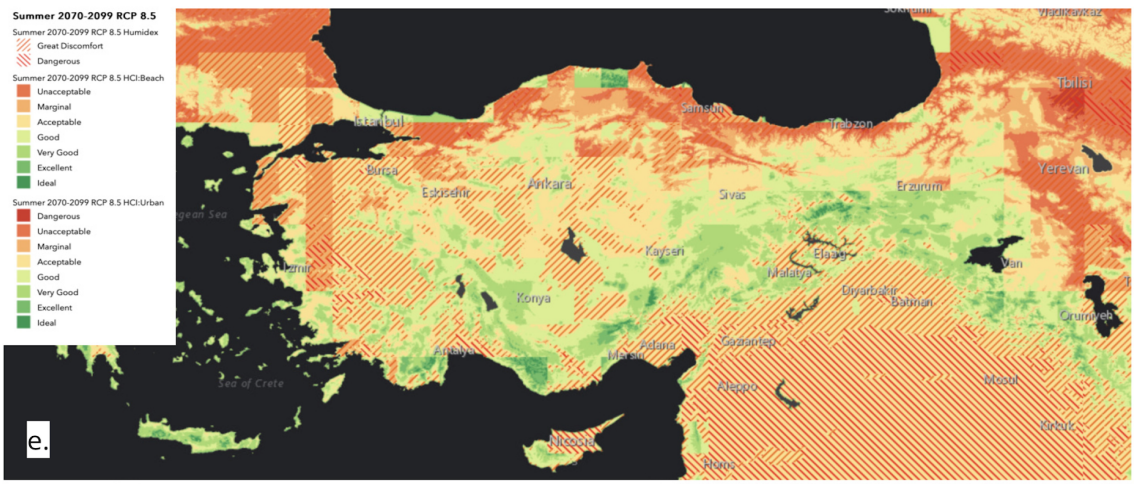
APPENDIX A: SUMMER SEASON HCI RATINGS AND HUMIDEX RISKS THROUGHOUT TÜRKİYE FOR THE REFERENCE PERIOD OF 1971-2000 (a.) AND THE PROJECTED PERIOD OF 2021-2050 UNDER RCP4.5 (b.) and RCP8.5 (c.)



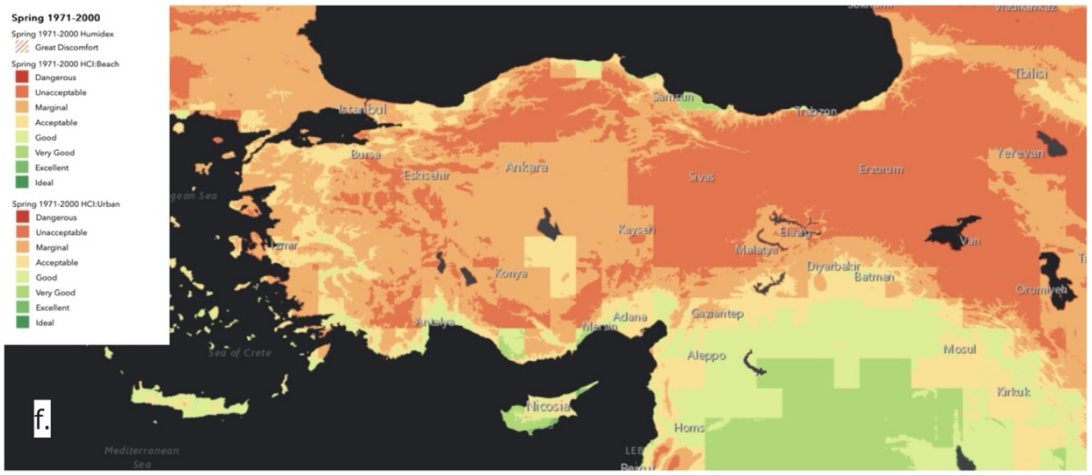
APPENDIX B: SUMMER SEASON HCI RATINGS AND HUMIDEX RISKS THROUGHOUT TÜRKİYE FOR THE REFERENCE PERIOD OF 1971-2000 (a.) AND THE PROJECTED PERIOD OF 2070-2099 UNDER RCP4.5 (d.) and RCP8.5 (e.)

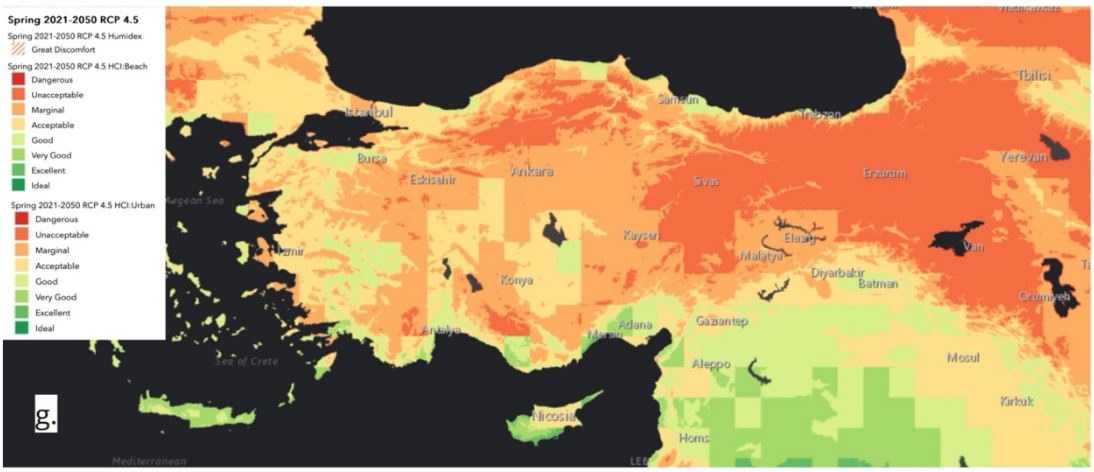


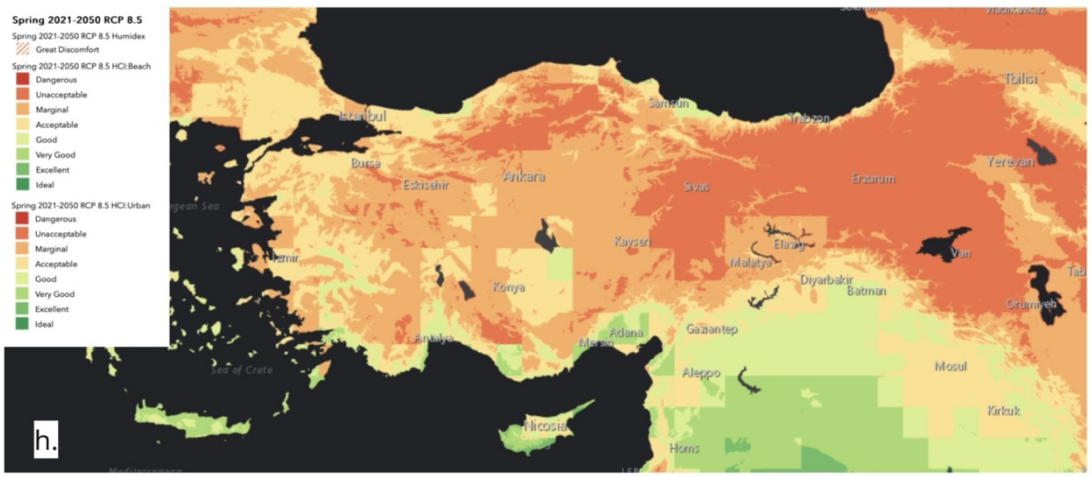




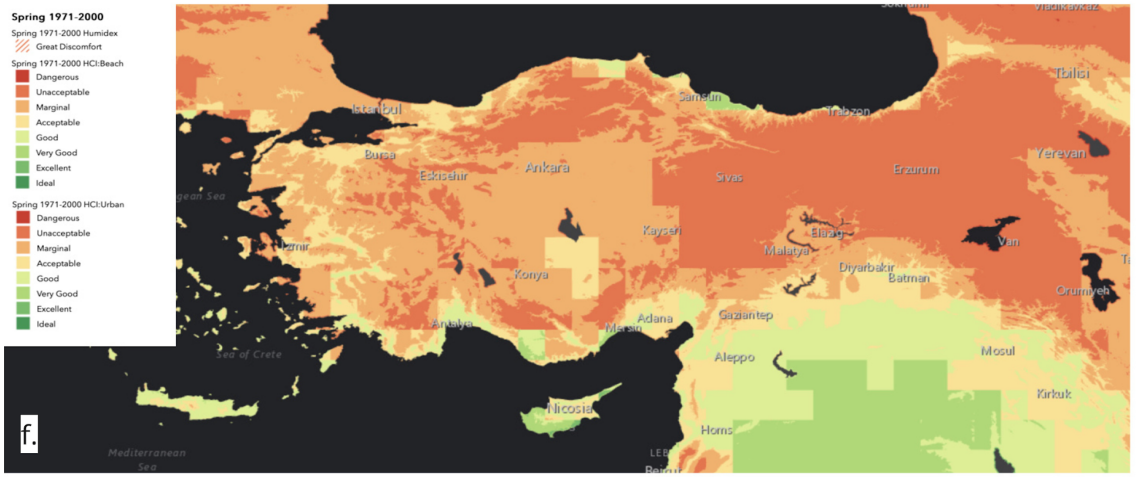
APPENDIX C: SPRING SEASON HCI RATINGS AND HUMIDEX RISKS THROUGHOUT TÜRKİYE FOR THE REFERENCE PERIOD OF 1971-2000 (f.) AND THE PROJECTED PERIOD OF 2021-2050 UNDER RCP4.5 (g.) and RCP8.5 (h.)

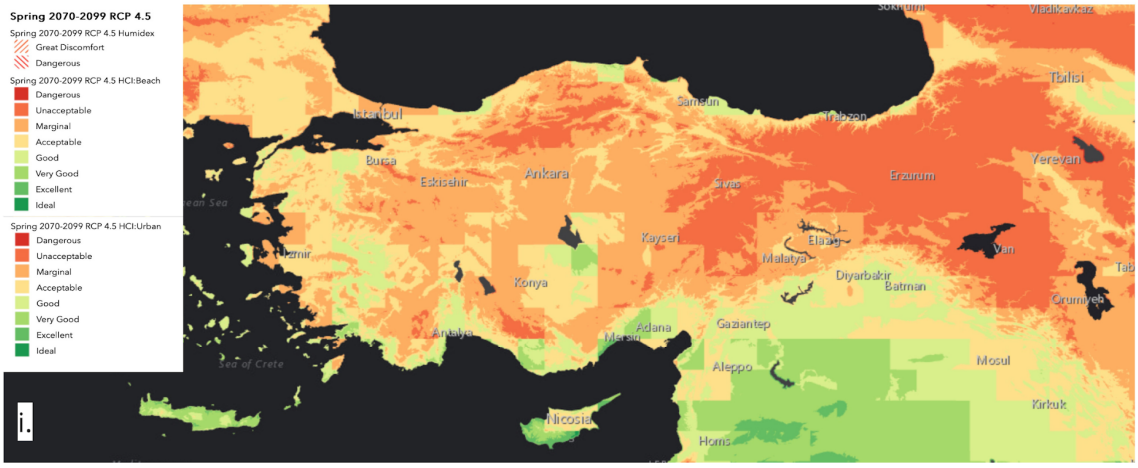


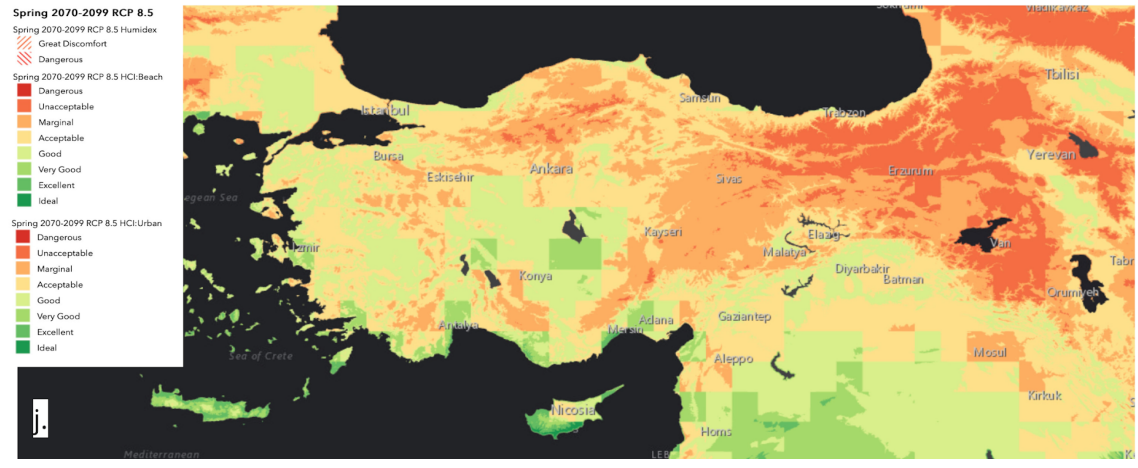




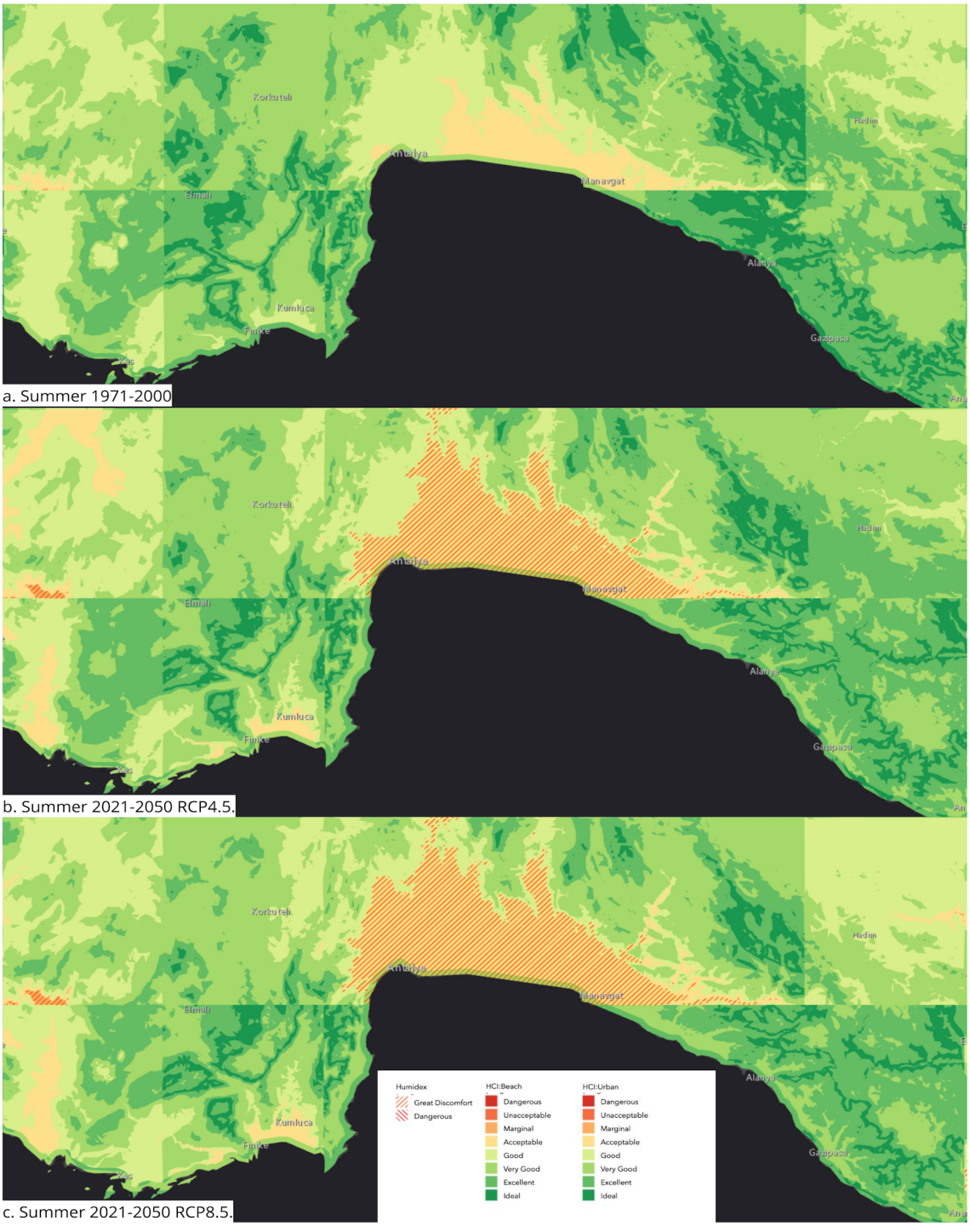
APPENDIX D: SPRING SEASON HCI RATINGS AND HUMIDEX RISKS THROUGHOUT TÜRKİYE FOR THE REFERENCE PERIOD OF 1971-2000 (f.) AND THE PROJECTED PERIOD OF 2070-2099 UNDER RCP4.5 (i.) and RCP8.5 (j.)







APPENDIX E: SUMMER SEASON HCI RATINGS AND HUMIDEX RISKS FOR ANTALYA FOR THE REFERENCE PERIOD OF 1971-2000 (a.) AND THE PROJECTED PERIOD OF 2021-2050 UNDER RCP4.5 (b.) and RCP8.5 (c.)

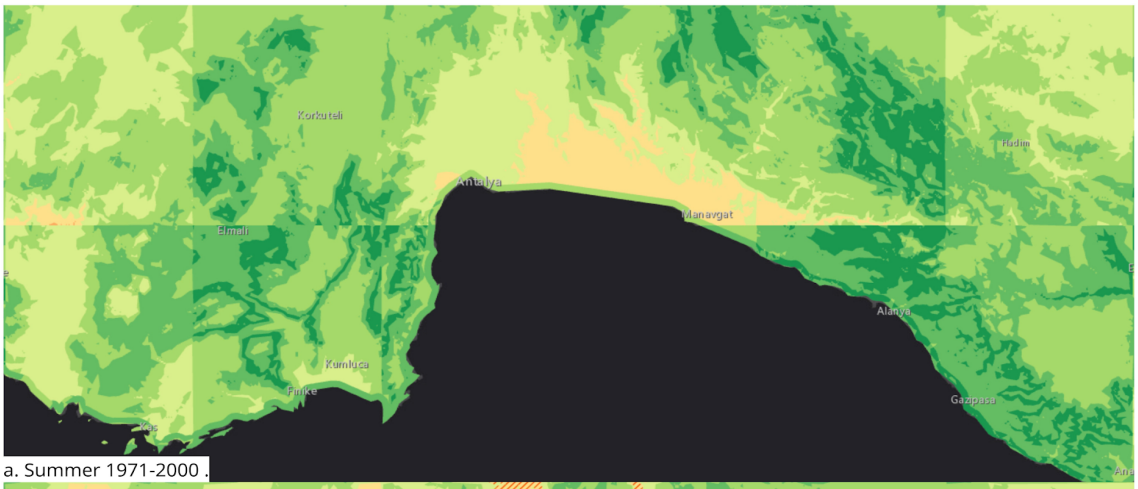


a. Summer 1971-2000

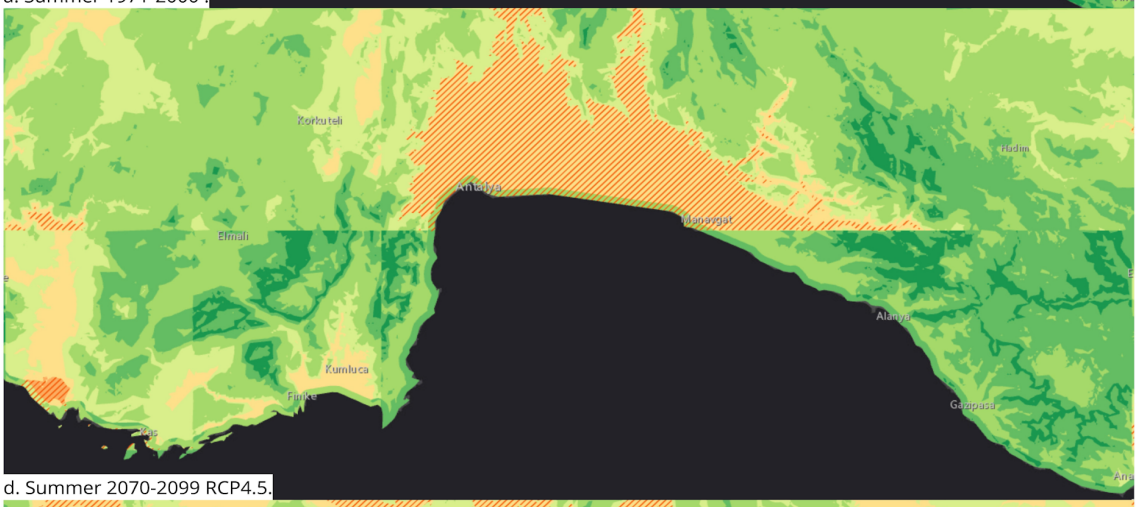
b. Summer 2021-2050 RCP4.5.

c. Summer 2021-2050 RCP8.5.

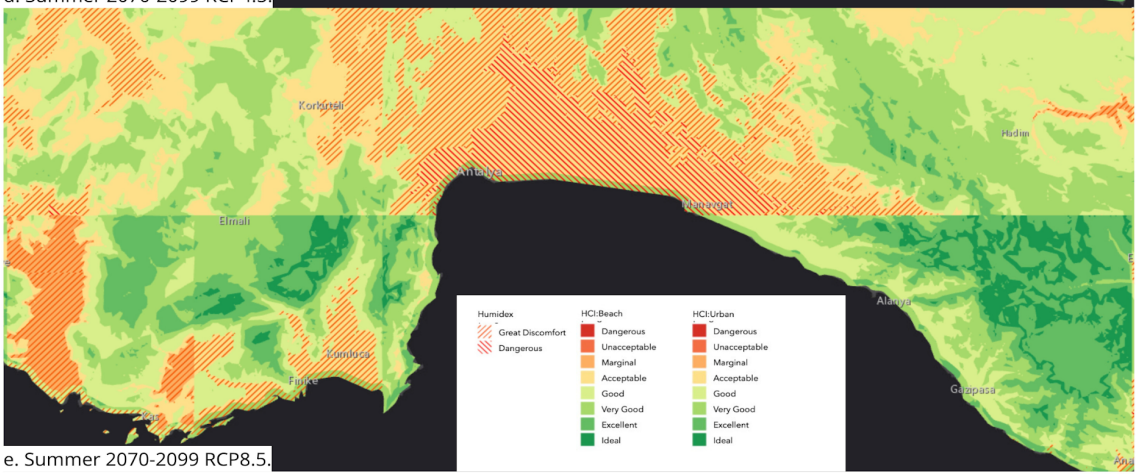
APPENDIX F: SUMMER SEASON HCI RATINGS AND HUMIDEX RISKS FOR ANTALYA FOR THE REFERENCE PERIOD OF 1971-2000 (a.) AND THE PROJECTED PERIOD OF 2070-2099 UNDER RCP4.5 (d.) and RCP8.5 (e.)



a. Summer 1971-2000 .

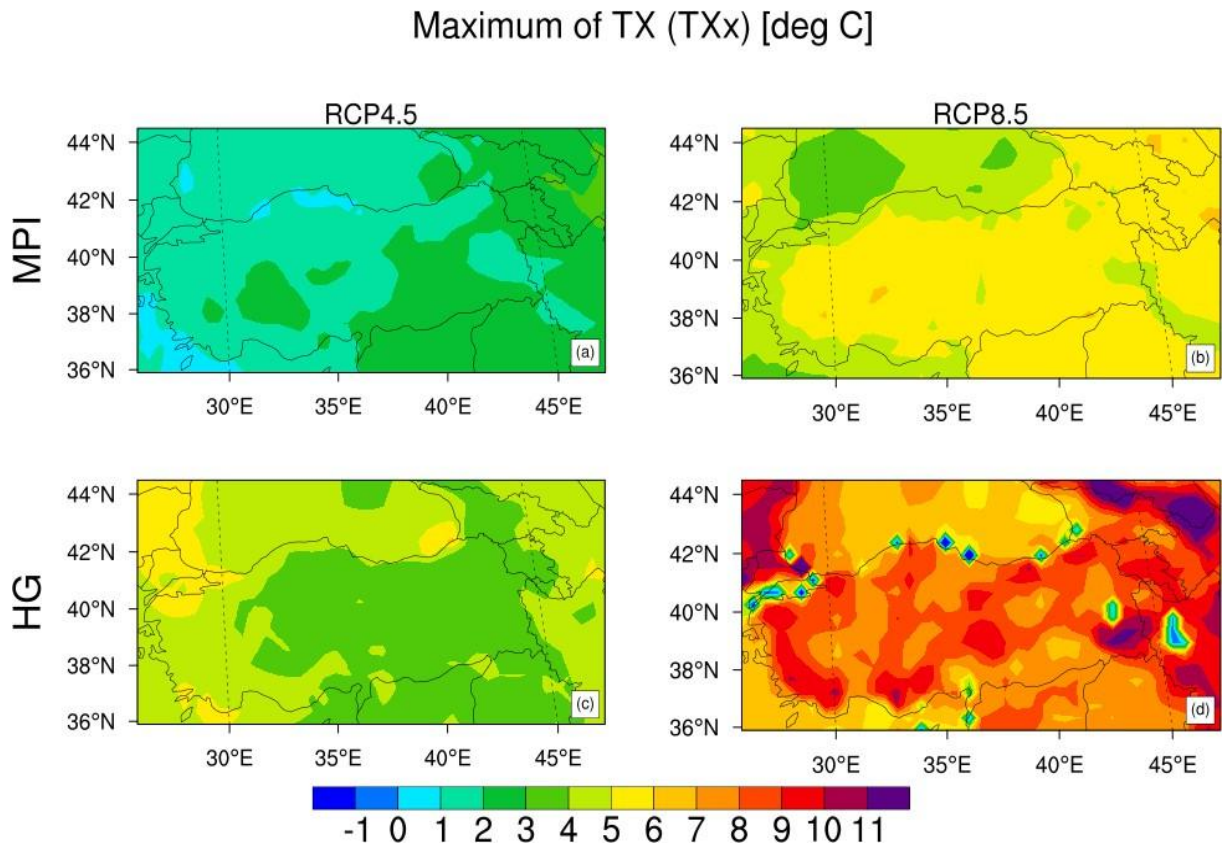


d. Summer 2070-2099 RCP4.5.

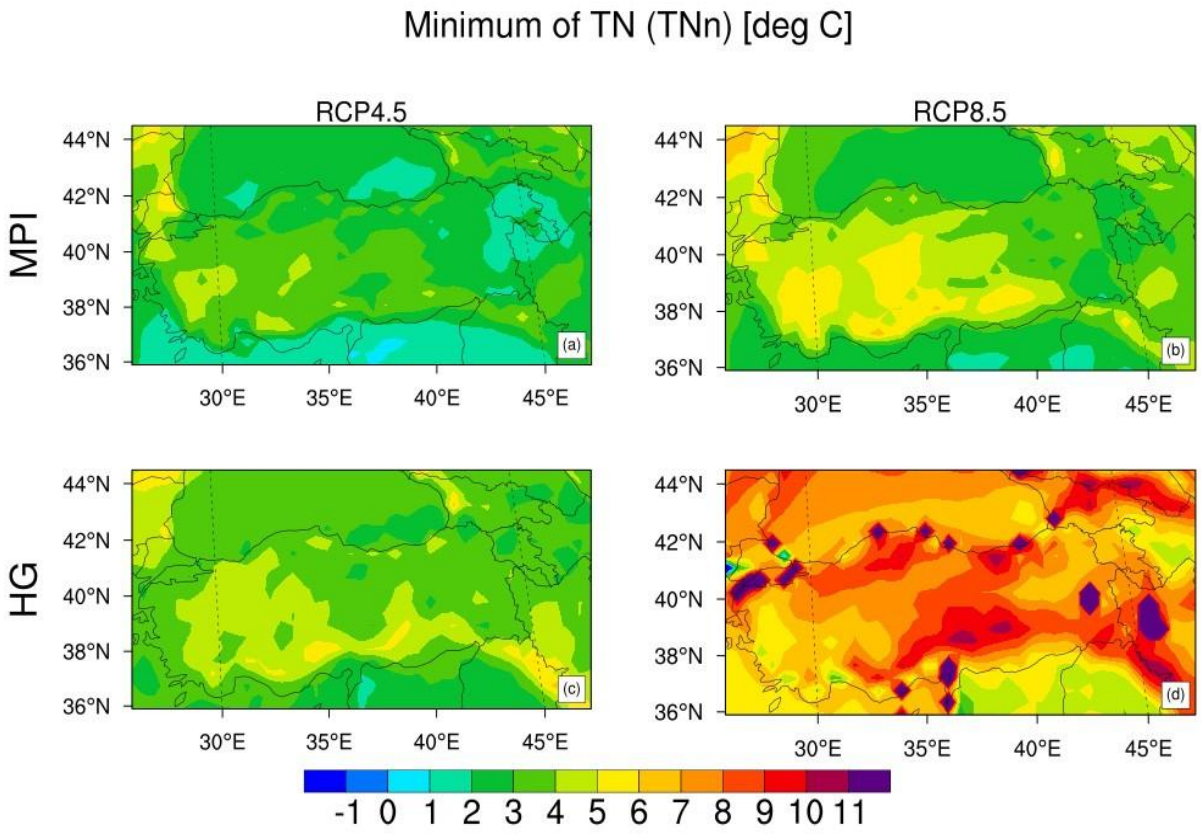


e. Summer 2070-2099 RCP8.5.

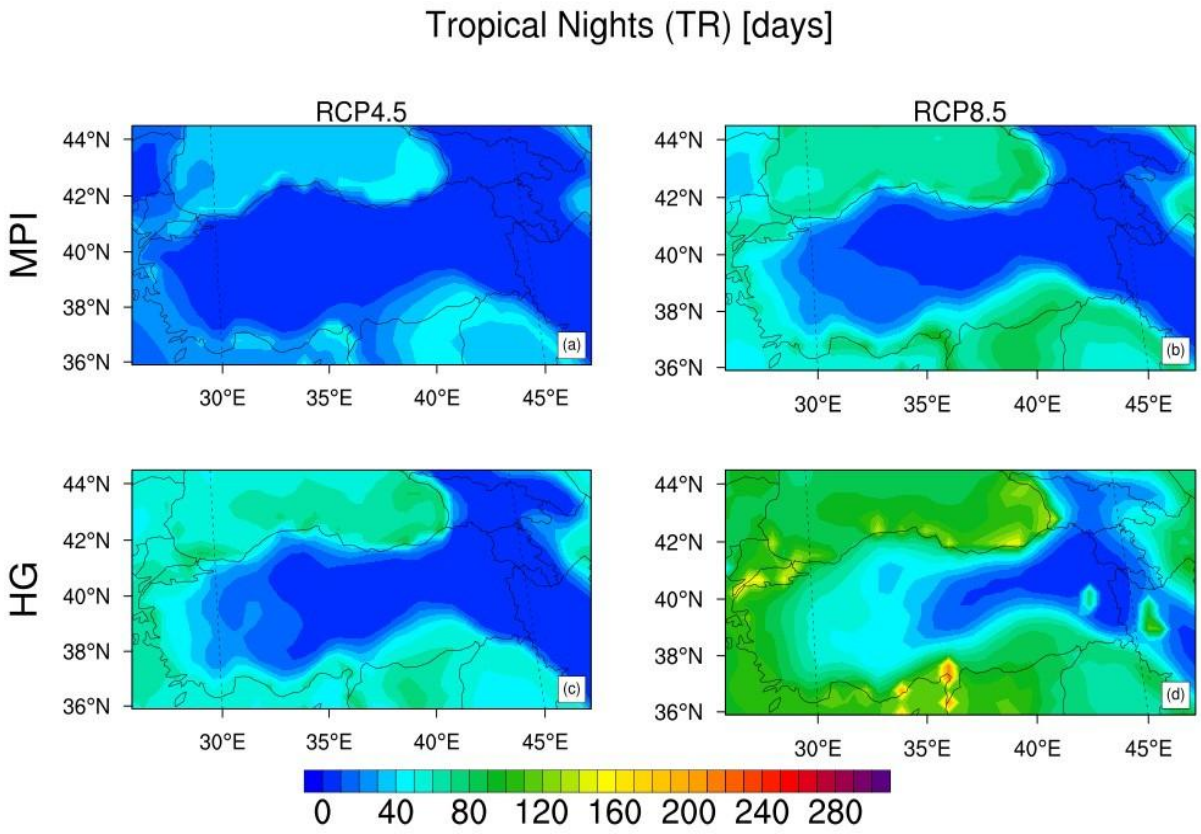
APPENDIX G: THE TEMPORALLY AVERAGED CHANGES IN TXx FOR THE PERIOD OF 2071-2100 SHOWN AS DIFFERENCES IN °C WITH RESPECT TO THE REFERENCE PERIOD OF 1971-2000 FOR THE MODEL MPI-ESM-MR WITH RCP4.5 (a.) AND WITH RCP8.5 (b.), FOR THE MODEL HadGEM2-ES WITH RCP4.5 (c) AND WITH RCP8.5(d)



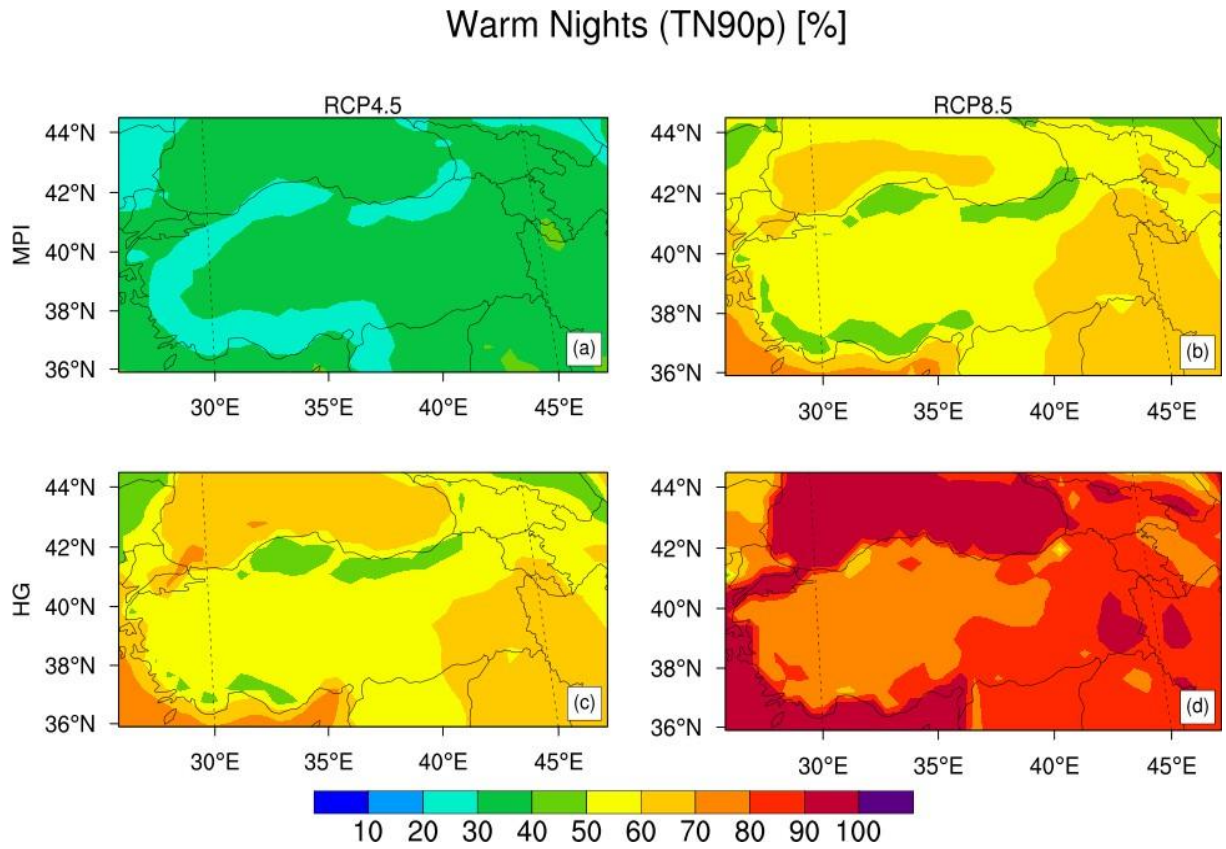
APPENDIX H: THE TEMPORALLY AVERAGED CHANGES IN TNn FOR THE PERIOD OF 2071-2100 SHOWN AS DIFFERENCES IN °C WITH RESPECT TO THE REFERENCE PERIOD OF 1971-2000 FOR THE MODEL MPI-ESM-MR WITH RCP4.5 (a.) AND WITH RCP8.5 (b.), FOR THE MODEL HadGEM2-ES WITH RCP4.5 (c) AND WITH RCP8.5(d)



APPENDIX I: THE TEMPORALLY AVERAGED CHANGES IN TR FOR THE PERIOD OF 2071-2100 DISPLAYED AS DIFFERENCES IN DAYS WITH RESPECT TO THE REFERENCE PERIOD OF 1971-2000 FOR THE MODEL MPI-ESM-MR WITH RCP4.5 (a.) AND WITH RCP8.5 (b.), FOR THE MODEL HadGEM2-ES WITH RCP4.5 (c) AND WITH RCP8.5(d)



APPENDIX J: ANNUAL FREQUENCY OF TN90P TEMPORALLY AVERAGED OVER THE PERIOD OF 2071-2100 AS ABSOLUTE VALUES OF THE EXCEEDANCE RATE IN % WITH RESPECT TO THE REFERENCE PERIOD OF 1971-2000 FOR THE MODEL MPI-ESM-MR WITH RCP4.5 (a.) AND WITH RCP8.5 (b.), FOR THE MODEL HadGEM2-ES WITH RCP4.5 (c) AND WITH RCP8.5(d).



APPENDIX K: THE TEMPORALLY AVERAGED CHANGES IN WSDI FOR THE PERIOD OF 2071-2100 DISPLAYED AS DIFFERENCES IN DAYS WITH RESPECT TO THE REFERENCE PERIOD OF 1971-2000 FOR THE MODEL MPI-ESM-MR WITH RCP4.5 (a.) AND WITH RCP8.5 (b.), FOR THE MODEL HadGEM2-ES WITH RCP4.5 (c) AND WITH RCP8.5(d)