Cumulative Dissertation

A Comprehensive Analysis of Severe Flood Events in Turkey

Event Documentation, Triggering Mechanisms and Impact Modelling

submitted to University of Potsdam

Faculty of Science

Institute for Environmental Science and Geography

for obtaining the doctorate degree of doctor rerum naturalium

(Dr. rer. nat.)

in Natural Hazards Research

by

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submitted on 20th April 2021

defended on 06th September 2021

Potsdam, 2021

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Published online on the
Publication Server of the University of Potsdam:
https://doi.org/10.25932/publishup-51785
https://nbn-resolving.org/urn:nbn:de:kobv:517-opus4-517853

"*First principle: never to let one's self be beaten down by persons or by events.*"

–Marie Curie

Author Declaration of Originality

I, Gamze Koç, hereby declare that this thesis is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at University of Potsdam or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in conception or in style, presentation and linguistic expression is acknowledged.

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Location, Date: Potsdam, 20.04.2021

Acknowledgements

The PhD was a unique journey full of adorable and hard moments, ups and downs and I would like to acknowledge everyone who was always near me during this journey.

First of all, I would like to state that being a part of the "ALErT: Anatolian pLateau climatE and Tectonic hazards" project which was funded as a part of the European Union Marie Curie Actions program "Initial Training Networks – ITN (FP7-PEOPLE-2013-ITN / 607996)" was a peerless opportunity for me that made this study possible. I would like to acknowledge the support of all ITN-ALErT members for their collaboration throughout the project.

I want to express my deepest gratitude to my supervisor Prof. Dr. Annegret H. Thieken for her valuable teachings, stimulating advices and everlasting support. I learnt a lot from her during this journey.

I also extend my sincere thanks to my second supervisor Prof. Dr. Attila Çiner for his willingness to help me any time I needed it. It would not have been possible without his support.

In addition, I would like to send my special thanks to Prof. Dr. Johann Stötter for agreeing to be an external reviewer, to Prof. Dr.-Ing. Bruno Merz for agreeing to be the chairman, and to Prof. Dr.-Ing. Axel Bronstert and Prof. Dr. Manfred Strecker for agreeing to be a part of the examination committee.

Furthermore, I would like to acknowledge the support of my mentor Dr. Theresia Petrow, my colleague Dr. Stephanie Natho and Dr. Peter Hoffmann (Potsdam Institute for Climate Impact Research – PIK). Their valuable comments and contributions helped me a lot to improve this research.

I want to thank my former colleagues Patric Kellermann, Sarah Kienzler and my friend Elif Türker Bakır for their great support which helped me a lot to get used to the new culture and my orientation in the beginning of my stay in Berlin.

My warmest thanks go to my best friends Görkem Sivri, Radka Burgertova, Milena Latinovic, Dadiyorto Wendi, Mustafa Yücel Kaya and Sema Bağci Kaya for their inexpressible support and for being my family in Berlin. I never felt alone with their warm friendship.

The greatest thanks go to my brother, my best friend and my colleague Ümit Koç for his never-ending support, invaluable help and motivation whenever I need.

Finally, I owe the greatest debt of gratitude to my beloved parents, Gülcan & Yılmaz Koç who always believed, unconditionally supported, encouraged and loved me. They did fear no sacrifice for my education abroad and did their best to raise an open-minded, well-educated and independent woman.

Contents

List of Figures

List of Tables

Abbreviations

AA	Anadolu Agency
ACP	Atmospheric Circulation Pattern
AFAD	Republic of Turkey Prime Ministry Disaster and Emergency Management Authority
ASM	Antecedent Soil Moisture
BTG	Major Soil Groups of Turkey
CBRN	Chemical Biological Radiological Nuclear
CCA	Climate Change Adaptation
CP	Circulation Pattern
CRED	Centre for Research on Epidemiology of Disasters
CLC	Corine Land Cover
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
EC	European Commission
ECLAC	United Nations Economic Commission for Latin America and Caribbean
EM-DAT	Emergency Events Database

ERA	European Centre for Medium Range Weather Forecasts Re-Analysis
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIS	Geographic Information Systems
HB-GWL	Hess and Brezowsky Großwetterlagen Catalogue
HFA	Hyogo Framework for Action 2005-2015
IDNDR	International Decade for Natural Disaster Reduction
IMF	International Monetary Fund
IN	Infiltration Number
IR	Infiltration Rate
IRDR	Integrated Research on Disaster Risk
IRU	International Relief Union
JRC	Joint Research Centre
MEVBIS	Meteorological Data Information Sales and Presentation System
MGM	Turkish State Meteorological Service
NGO	Non-Governmental Organization
PIK	Potsdam Institute for Climate Impact Research
PREC	Event Day Total Precipitation
RMSE	Root Mean Square Error
ROCKS	Road Cost Knowledge System
SFDRR	Sendai Framework Disaster Risk Reduction 2015-2030

SPRC	Source Pathway Receptor Consequence
TABB	Turkey Disaster Database
TCA	Total Catchment Area
TCMB	Central Bank of the Republic of Turkey
TEPGE	Turkey Agricultural Economic and Policy Development Institute
TÜIK	Turkish Statistical Institute
UDAP	National Earthquake Investing Programme
UA	Urbanized Areas
UN	United Nations
UN-GA	United Nations General Assembly
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations Office for Disaster Risk Reduction
USGS	United States Geological Survey
WB	Water Bodies

Abstract

Over the past decades, natural hazards, many of which are aggravated by climate change and reveal an increasing trend in frequency and intensity, have caused significant human and economic losses and pose a considerable obstacle to sustainable development. Hence, dedicated action toward disaster risk reduction is needed to understand the underlying drivers and create efficient risk mitigation plans. Such action is requested by the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR), a global agreement launched in 2015 that establishes stating priorities for action, e.g. an improved understanding of disaster risk. Turkey is one of the SFDRR contracting countries and has been severely affected by many natural hazards, in particular earthquakes and floods. However, disproportionately little is known about flood hazards and risks in Turkey. Therefore, this thesis aims to carry out a comprehensive analysis of flood hazards for the first time in Turkey from triggering drivers to impacts. It is intended to contribute to a better understanding of flood risks, improvements of flood risk mitigation and the facilitated monitoring of progress and achievements while implementing the SFDRR.

In order to investigate the occurrence and severity of flooding in comparison to other natural hazards in Turkey and provide an overview of the temporal and spatial distribution of flood losses, the Turkey Disaster Database (TABB) was examined for the years 1960-2014. The TABB database was reviewed through comparison with the Emergency Events Database (EM-DAT), the Dartmouth Flood Observatory database, the scientific literature and news archives. In addition, data on the most severe flood events between 1960 and 2014 were retrieved. These served as a basis for analyzing triggering mechanisms (i.e. atmospheric circulation and precipitation amounts) and aggravating pathways (i.e. topographic features, catchment size, land use types and soil properties). For this, a new approach was developed and the events were classified using hierarchical cluster analyses to identify the main influencing factor per event and provide additional information about the dominant flood pathways for severe floods. The main idea of the study was to start with the event impacts based on a bottom-up approach and identify the causes that created damaging events, instead of applying a model chain with long-term series as input and searching for potentially impacting events as model outcomes. However, within the frequency analysis of the flood-triggering circulation pattern types, it was discovered that events in terms of heavy precipitation were not included in the list of most severe floods, i.e. their impacts were not recorded in national and international loss databases but were mentioned in news archives and reported by the Turkish State Meteorological Service. This finding challenges bottom-up modelling approaches and underlines the urgent need for consistent event and loss documentation. Therefore, as a next step, the aim was to enhance the flood loss documentation by calibrating, validating and applying the United Nations Office for Disaster Risk Reduction (UNDRR) loss estimation method for the recent severe flood events (2015-2020). This provided, a consistent flood loss estimation model for Turkey, allowing governments to estimate losses as quickly as possible after events, e.g. to better coordinate financial aid.

This thesis reveals that, after earthquakes, floods have the second most destructive effects in Turkey in terms of human and economic impacts, with over 800 fatalities and US$ 885.7 million in economic losses between 1960 and 2020, and that more attention should be paid on the national scale. The clustering results of the dominant flood-producing mechanisms (e.g. circulation pattern types, extreme rainfall, sudden snowmelt) present crucial information regarding the source and pathway identification, which can be used as base information for hazard identification in the preliminary risk assessment process. The implementation of the UNDRR loss estimation model shows that the model with country-specific parameters, calibrated damage ratios and sufficient event documentation (i.e. physically damaged units) can be recommended in order to provide first estimates of the magnitude of direct economic losses, even shortly after events have occurred, since it performed well when estimates were compared to documented losses.

The presented results can contribute to improving the national disaster loss database in Turkey and thus enable a better monitoring of the national progress and achievements with regard to the targets stated by the SFDRR. In addition, the outcomes can be used to better characterize and classify flood events. Information on the main underlying factors and aggravating flood pathways further supports the selection of suitable risk reduction policies.

All input variables used in this thesis were obtained from publicly available data. The results are openly accessible and can be used for further research.

As an overall conclusion, it can be stated that consistent loss data collection and better event documentation should gain more attention for a reliable monitoring of the implementation of the SFDRR. Better event documentation should be established according to a globally accepted standard for disaster classification and loss estimation in Turkey. Ultimately, this enables stakeholders to create better risk mitigation actions based on clear hazard definitions, flood event classification and consistent loss estimations.

Zusammenfassung

In den letzten Jahrzehnten verursachten Naturgefahren hohe humanitäre und wirtschaftliche Verluste, wobei viele dieser Ereignisse durch den Klimawandel verstärkt werden und einen zunehmenden Trend in Häufigkeit und Schwere aufweisen. Daher sind gezielte Verfahren zur Reduzierung von Katastrophenrisiken erforderlich, um zugrundeliegende Treiber zu verstehen und effektive Risikominderungspläne zu erstellen. Solche Verfahren werden durch das Sendai-Rahmenwerk für Katastrophenvorsorge 2015-2030 (SFDRR) eingefordert. Das SFDRR ist, ein internationales Rahmenwerk, das 2015 verabschiedet wurde und prioritäre Maßnahmen festlegt, z.B. eine Verbesserung der Wissensgrundlagen zum Katastrophenrisiko. Die Türkei ist eines der SFDRR-Vertragsländer und wurde in der Vergangenheit von vielen Naturgefahren, insbesondere Erdbeben und Überschwemmungen schwer getroffen. Über die Hochwassergefahren und -risiken in der Türkei ist jedoch vergleichsweise wenig bekannt. In dieser Arbeit wird daher zum ersten Mal eine umfassende Analyse der Hochwassergefahren in der Türkei durchgeführt, von den auslösenden Ursachen bis hin zu den Auswirkungen. Ziel ist es, das Verständnis über Hochwasserrisiken zu verbessern, Studien zur Minderung des Hochwasserrisikos anzuregen und das Monitoring der Fortschritte und Zielerreichung bei der Umsetzung des SFDRR zu erleichtern.

Um das Auftreten und die Stärke von Überschwemmungen im Vergleich zu anderen Naturgefahren in der Türkei zu untersuchen und einen Überblick über die raumzeitliche Verteilung von Hochwasserschäden, wurde die Turkey Disaster Database (TABB) für den Zeitraum 1960 bis 2014 ausgewertet. Die TABB Datenbank wurde durch Vergleiche mit der Emergency Events Datenbank (EM-DAT),

der Dartmouth Flood Observatory Datenbank, wissenschaftlicher Literatur und Nachrichtenarchive überprüft. Zudem wurden die stärksten Überschwemmungen zwischen 1960 und 2014 identifiziert. Diese bildeten die Basis für eine Analyse der Auslösemechanismen (bspw. atmosphärische Zirkulationsmuster und Niederschlagsmengen) und verstärkende Wirkungspfade (z.B. topographische Eigenschaften, Größe der Einzugsgebiete, Landnutzung und Bodeneigenschaften). Dafür wurde ein neues Verfahren entwickelt, und die Ereignisse wurden mithilfe von hierarchischen Clusteranalysen klassifiziert, um die Haupteinflussfaktoren pro Ereignis zu identifizieren und zusätzliche Informationen über die dominanten Wirkungspfade bei schweren Überschwemmungen bereitzustellen. Die grundlegende Idee dieser Arbeit bestand darin, bei den Ereignisauswirkungen als Bottom-up-Ansatz zu beginnen und die Ursachen für Schadensereignisse zu identifizieren, anstatt eine Modellkette mit Langzeitreihen als Eingabe anzuwenden und darin nach potenziellen Schadensereignissen zu suchen. Bei der Häufigkeitsanalyse von hochwasserauslösenden Zirkulationsmustern wurde jedoch festgestellt, dass einige schwer Niederschlagsereignisse nicht in der Liste der schwersten Hochwasserereignisse waren, d.h., ihre Auswirkungen waren nicht in nationalen und internationalen Schadensdatenbanken dokumentiert, wurden jedoch in Nachrichtenarchiven erwähnt und vom türkischen staatlichen Wetterdienst gemeldet. Dieses Erkenntnis stellt den Bottom-up-Modelansatz in Frage und unterstreicht die Dringlichkeit einer konsistenten Ereignis- und Schadensdokumentation. Daher wurde im nächsten Schritt gezielt das Schadenmodell der Vereinten Nationen für Katastrophenvorsorge (UNDRR) für kürzlich aufgetretene starke Flutereignisse (2015-2020) angepasst, validiert und angewendet. Damit wurde ein konsistentes Hochwasserschadenmodell für die Türkei bereitgestellt, das es den Behörden ermöglicht, Verluste so schnell wie möglich nach Ereignissen abzuschätzen, zum Beispiel um eine bessere Koordination von finanziellen Hilfen zu gewährleisten.

Diese Arbeit zeigt, dass Überschwemmungen mit mehr als 800 Todesfällen und 885,7 Millionen US Dollar wirtschaftlichen Schaden zwischen 1960 und 2020 nach Erdbeben den zweit höchsten zerstörerischen Effekt in der Türkei in Bezug auf humanitäre und wirtschaftliche Auswirkungen haben. Daher sollte dieses Thema mehr Aufmerksamkeit auf nationaler Ebene erhalten. Die Cluster-Ergebnisse der dominanten hochwasser-auslösenden Mechanismen (z.B. Zirkulationsmuster, Starkniederschlag, plötzliche Schneeschmelze) erhalten wichtige Informationen zur Quell- und Pfad-Identifikation, welche als Basisinformation für Gefahrenidentifikation in der vorläufigen Risikoeinschätzung dienen kann.

Die Implementierung des UNDRR-Schadenmodells zeigt, dass das Modell mit länderspezifischen Parametern, kalibrierten Schadensgraden und ausreichender Ereignisdokumentation (d.h. physischer geschädigte Einheiten) empfohlen werden kann, um erste Schätzungen zur Höhe der direkten wirtschaftlichen Schäden bereitzustellen – auch unmittelbar nach Eintreten von Ereignissen, da die Modellschätzungen im Vergleich mit dokumentierten Verlusten gut übereinstimmten. Die präsentierten Ergebnisse können dazu beitragen, die nationale Schadensdatenbank der Türkei zu verbessern, und somit ein besseres Monitoring der nationalen Fortschritte und Erfolge im Hinblick auf die Ziele des SFDRR ermöglichen. Zusätzlich können die Ergebnisse für eine bessere Charakterisierung und Klassifizierung von Hochwasserereignissen verwendet werden. Informationen zu den zugrundeliegenden Einflussfaktoren und verstärkenden Wirkungspfaden unterstützen die Auswahl geeigneter Risikomanagementstrategien.

Alle Eingabevariablen dieser Arbeit wurden aus öffentlich verfügbaren Daten bezogen. Die Ergebnisse sind zugänglich und können für die weitere Forschung verwendet werden.

Insgesamt konnte festgestellt werden, dass die konsistente Erfassung von Schadensdaten und eine bessere Ereignisdokumentation mehr Beachtung finden muss, um die Implementierung des SFDRR verlässlich zu überwachen. Bessere Ereignisdokumentationen sollten nach einem weltweit anerkannten Standard für Gefahrenklassifizierung und Schadensabschätzung in der Türkei etabliert werden. Letztendlich ermöglicht dies den Verantwortlichen auf Basis von eindeutigen Gefahrendefinitionen, Hochwasser-Ereignisklassifizierungen und konsistenten Schadenschätzungen bessere Maßnahmen zur Risikominderung zu erarbeiten.

Chapter 1

Introduction

1.1 Motivation and Study Background

Overview on a global scale: natural disasters and milestones of international actions on disaster risk reduction

Over the past twenty years, the number of natural disasters has skyrocketed in comparison to previous years; 7,348 catastrophic events were recorded between 2000 and 2019, worldwide which caused 1.23 million fatalities and 2.97 trillion US$ economic losses (CRED and UNDRR, 2020). A comparative analysis revealed that societal and economic impacts of natural disasters have significantly increased within the last twenty years, when compared to the previous decades (1980-1999). While this situation could partly be explained by better data recording and better event documentation, much of it is explained by the considerable increase in the number of climate-related (i.e. hydrological, meteorological or climatological) disasters (CRED and UNDRR, 2020).

According to the Emergency Events Database (EM-DAT), floods were reported as the most common natural disaster all over the world, with 44% of total catastrophic events affecting 1.6 billion people (CRED and UNDRR, 2020). An increase is estimated in the frequency of potentially high impacts of natural hazards across the world due to a global temperature increase (CRED and UNDRR, 2020), increase in exposed premises based on population growth and wealth (Barredo, 2009; Barredo et al., 2012), and inflation change due to socio-economic factors (Barredo et al., 2012; Botzen et al., 2019). In parallel with this, a rise in the intensity and frequency of floods is expected (Dankers and Feyen, 2008; Blöschl et al., 2017; Kundzewicz et al., 2017; Didovets et al., 2019) due to shifts in rainfall and runoff patterns (Bronstert, 2003; Dobler et al., 2012; CRED and UNDRR, 2020) triggered by a warming climate. Hence, this estimation raises the importance of coordinated local and national strategies for disaster risk reduction (DRR) and climate change adaptation (CCA) for countries that have suffered severely from natural disasters.

Coordinated international actions on disaster risk reduction started in 1971 with the Office of the United Nations Disaster Relief Co-ordinator (UNDRO) to mitigate the natural disasters impacts (Allen et al., 1980). Before UNDRO, coordination of disaster relief assistance and financial aid was organized only after a specific event in the case of a natural disaster by the International Relief Union (IRU), which was established in 1927 (Allen et al., 1980). The UNDRO was mainly responsible for two broad aims: i) to mobilize, direct and coordinate external aid provided to disaster-stricken countries (relief coordination), and ii) to reduce the extent to which natural phenomena result in disasters, or eliminate the threat altogether through preventive measures, and to promote measures of preparedness in disaster-prone countries (prevention, pre-disaster planning and preparedness) (Allen et al., 1980; UNDRR, 2021). Given the increasing concern about the impact of disasters, the United Nations General Assembly (UN-GA) declared the International Decade for Natural Disaster Reduction 1990-1999 (IDNDR) in 1990 (UNDRR, 2021). With the IDNDR, the aim was to reduce, through concerted international action, especially in developing countries, loss of life, poverty damage and social and economic disruption caused by natural disasters (UNDRR, 2021). Accordingly, the First World Conference on Disaster Risk Reduction was hosted in Yokohama, Japan between 23 and 27 May 1994 in order to bring together government officials and other stakeholders (e.g. NGOs) to discuss how to strengthen the sustainability of development by managing disaster and climate risks (UNDRR, 2021). The

Yokohama Strategy – Plan of Action 1994 was built to set a basis for the strategy and provide guidelines for natural disaster prevention, preparedness and mitigation (IDNDR, 1994; UNDRR, 2021). International actions for disaster risk reduction and climate change adaptation continued with the 2nd World Conference on Disaster Reduction held in Kobe, Japan, between 18 and 22 January 2005 and adopted the Hyogo Framework for Action 2005-2015 (HFA). The HFA was developed together with governments, international agencies and other partners (e.g. NGOs) and aimed to focus more on early warning and preventive measures (UNDRR, 2021). The Hyogo Framework is important for being the first plan to explain and describe the work required from all different sectors to reduce disaster losses (UNISDR, 2007).

Finally, the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) is the most recent global framework adopted by the UN member states as a result of the 3rd World Conference on Disaster Risk Reduction, which was held in Sendai, Japan, between 14 and 18 March 2015 (UNDRR, 2021). The SFDRR consists of four priorities for action to improve the understanding of the underlying drivers, create a consistent risk mitigation plan and enhance the disaster preparedness for effective response (UNISDR, 2015c). Accordingly, to support the assessment of global progress by the SFDRR, seven global targets were agreed by the UN member states (UNISDR, 2015c, p. 12):

1. "*Substantially reduce global disaster mortality by 2030: aiming to lower the average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005–2015;*

2. *Substantially reduce the number of affected people globally by 2030: aiming to lower the average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015;*

3. *Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030;*

4. *Substantially reduce disaster damage to critical infrastructure and disruption*

of basic services, among them health and educational facilities, including through developing their resilience by 2030;

5. *Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020;*

6. *Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of the present Framework by 2030; and*

7. *Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030.*"

The SFDRR is very important for being the first framework to provide rough quantitative metrics as measures of success and suggest a qualitative risk assessment plan for different sectors in order to better monitor risk reduction studies (UNISDR, 2015c).

Although, many improvements have been made in terms of early warning, disaster preparedness and response with the international strategies mentioned above, recent statistics indicate that, since 2015, the number of natural disasters, especially flood events, has increased considerably (UN, 2020; CRED and UNDRR, 2020). Further, continued human and economic impacts from floods along with climate change is anticipated (Bronstert, 2003; Dankers and Feyen, 2008; Dobler et al., 2012; Hinkel et al., 2014; Kundzewicz et al., 2017; Blöschl et al., 2017; Vousdoukas et al., 2018; Didovets et al., 2019; Kirezci et al., 2020; CRED and UNDRR, 2020).

Within this context, the necessity of better understanding processes and mechanisms leading to flood impacts should be recognized by the countries that have suffered from flooding, and efforts to develop flood risk prevention studies should be increased. Hence, this thesis aims to contribute to these studies on a national scale specific to Turkey.

Understanding floods in Turkey: risk management on a national scale

Turkey is one of the countries threatened by flood hazards due to its climatic and topographic features. A study by Haldon et al. (2014) reveals that the Anatolian Peninsula, where Turkey is situated, has experienced great numbers of floods throughout its long history. The study presents the historic records of extreme weather events (i.e. floods, droughts, storms, heavy snows, etc.) between 300 and 1453 C.E. in Anatolia. Those records indicate that the northern and southern parts of Turkey have been suffering from floods for centuries (Haldon et al., 2014). When we look at the present disaster loss databases, it can be seen that Turkey remains exposed to the devastating effects of natural hazards, including floods (e.g. Gürer (1998); Ceylan et al. (2007); Gökçe et al. (2008); Gürer and Uçar (2009); EM-DAT (2021)), which caused enormous human and economic damages, especially in the last decade (Özcan, 2006; Özşahin, 2013; Öcal, 2019; EM-DAT, 2021; TABB, 2021). Most of the flood events were analysed as case studies in terms of their (hydro-)meteorological characteristics (i.e. atmospheric conditions, spatial variability of rainfall regimes) (e.g. Baltacı et al. (2015); Lolis and Türkeş (2016); Baltaci et al. (2019)) and rarely focused on human and economic impacts (e.g. Ceylan et al. (2007); Gürer and Uçar (2009)). However, up to now, there has been no study that reflects all the processes along the flood risk chain starting from flood-triggering precipitation through catchment properties (i.e. topography, drainage characteristics, and soil and land use properties) to direct economic losses on a national scale in Turkey.

As in the entire world, significant changes in climate conditions are also estimated in Turkey. The future projections show that a warmer climate will increase the intensity of precipitation on the western and northern coasts of Anatolia in the summer season (Demircan et al., 2017). Additionally, due to the increasing temperature, more sudden snowmelts and, in parallel with this, a temporal shift in snowmelt runoff are expected in the eastern part of Turkey (Bozkurt and Sen, 2013; Bozkurt et al., 2015; Demircan et al., 2017). In contrast to the northern and western coasts, a decreasing trend is expected with regard to the total amount of precipitation for the southern and inner parts of Anatolia; however, more intense and short-duration rainfall events, as well as more storms and hail, are expected (Demircan et al., 2017; Balov, 2020). These estimates also underline the importance of better understanding the flood risk on a national level and the urgent need for efficient risk management strategies on the local scale. Thus, the question arises as to what the legislative regulations are like for risk prevention and mitigation studies in Turkey.

Turkey has always actively participated in international frameworks (i.e. Yokohama Strategy, Hyogo Framework, Sendai Framework) and contributed with national reports as a UN member state (IDNDR, 1994; UNISDR, 2007, 2015c; AFAD, 2019). Until 2009, disaster risk management studies were conducted by different governmental offices (i.e. General Directorate of Civil Defence, General Directorate of Natural Disasters and General Directorate of Turkish Emergency Management). To gather all authorities and responsibilities related to natural disasters, such as disaster loss databases, disaster risk reduction and prevention studies and emergency management, under a single roof, the Republic of Turkey Prime Ministry Disaster and Emergency Management Authority (AFAD) was established in 2009 through a reunion of the General Directorate of Civil Defence, the General Directorate of Natural Disasters and General Directorate of Turkish Emergency Management (AFAD, 2019).

Following the international actions on disaster risk management, the Turkey Disaster Database (TABB) was set up by AFAD in 2009 by applying the United Nations Development Programme (UNDP) DesInventar database concept. In 2012, AFAD published the first Strategic Plan on Disaster and Emergency Management for the period 2013-2017 (AFAD, 2012). In the Strategic Plan 2013-2017, the focus was on mainly corporate infrastructure (AFAD, 2012). In 2015, progress in terms of the TABB database improvement was reported to the Global Assessment Report 2015 (UNISDR, 2015b). In March 2015, Turkey also signed the SFDRR and aimed to improve the national loss databases and reduce the human and direct economic losses due to natural hazards. Between 2016 and 2018, studies focused on increasing the public awareness, disaster risk reduction and prevention for earthquake disasters (AFAD, 2016a, 2017, 2018). The Strategic Plan on Disaster and Emergency Management 2019-2023 was published in 2019 based on the SFDRR targets to present the institutional goals in order to reduce the destructive impacts of natural hazards in Turkey (AFAD, 2019). The main objective of the Strategic Plan 2019-2023 was, as reported, "to develop policies on effective disaster and emergency management and to ensure coordination between the responsible institutions and the organizations" (AFAD, 2019, p. 18). The six main goals of the Strategic Plan on Disaster and Emergency Management 2019-2023 (Figure 1.1) can be summarized as (AFAD, 2019, p. 19):

1. "*To improve the coordination on disaster and emergency management*
2. *To ensure the adoption of an integrated risk-focused disaster management approach in all sectors*
3. *Effective management of the process during and after the disasters*
4. *To increase the public awareness for better disaster preparedness*
5. *To increase the effectiveness on an international level*
6. *To keep the continuous improvement and development*"

When the sub-goals of the strategic plan were examined in more detail, it became clear that only the earthquakes, landslides and Chemical-Bacteriological-Radiological-Nuclear (CBRN) disasters were explicitly mentioned (see AFAD (2019)). Despite their significant human and economic impacts, there is an important knowledge gap with respect to flood disasters in Turkey; no detailed sub-goals or funds on flood risk reduction or prevention studies are mentioned in the national strategic plan. Only the "Execution of the projects within the Turkey Meteorological and Hydrological Disasters Program (TUMEHAP)" was mentioned. However, no detailed action plan for flood risk reduction studies related to this statement was presented in the performance indicators list (AFAD, 2019, p. 87). This circumstance reveals the urgent need for a comprehensive analysis of flood events in

Figure 1.1: The six main goals of the Republic of Turkey Prime Ministry Disaster and Emergency Management Authority (AFAD) Strategic Plan on Disaster and Emergency Management 2019-2023 (AFAD, 2019).

Turkey, from triggering drivers to impacts. Therefore, the first motivation of this thesis is to enable a better understanding of flood disaster risk perceptions in Turkey to strengthen the disaster risk governance and manage disaster risk, reduce the direct economic loss and invest in disaster risk reduction for resilience, as well as to enhance disaster preparedness for effective response as outlined in the SFDRR's first prior action (UNISDR, 2015c).

According to the latest UN report as a five-year milestone of the SFDRR, the year 2023 will mark the midpoint of implementing the SFDRR. All SFDRR contracting states are therefore recommended to consider preparing a review of the implementation of the SFDRR at its midpoint in 2023 (UN, 2020). Likewise, another motivation of this thesis was to improve the understanding of flood processes and impacts in Turkey and to help facilitate the monitoring of the national progress and achievements toward the SFDRR targets with a comprehensive analysis for the first time in Turkey.

1.2 Objective of the Study and Research Questions

This thesis aims to present a comprehensive analysis of flood hazards on a national scale starting from triggering mechanisms to impacts by reflecting on the importance of event documentation. The objectives are addressed with the following research questions:

1. *Event documentation*: How important are floods in Turkey in comparison to other natural hazards as revealed in national and international loss databases? How does the national loss database - TABB indicate the societal and economic impacts of floods? And how sufficient is the TABB database to answer these questions with regard to data quality and accuracy aspects?

2. *Triggering mechanisms*: What are the triggering mechanisms and potential aggravating pathways of severe floods in Turkey?

3. *Impact modelling*: How can the UNDRR loss modelling (UNISDR, 2015a) be adapted for Turkey to estimate the direct economic losses due to severe floods in Turkey? How might these estimations contribute to improving event documentation, emergency response and recovery?

1.3 Study Design and Structure of the Thesis

In order to shed light on the research questions outlined in Section 1.2, the thesis was formulated into three main chapters (Chapters 2, 3, 4). In order to conduct a comprehensive analysis of floods and contribute the flood risk management studies, the goal was to understand the origins and impacts of floods, as well as the pathways that lead to intensifying the severe events. Therefore, this thesis is structured based on the Source-Pathway-Receptor-Consequence (SPRC) model (Figure 1.2).

Sources of a flood event are defined as its causes or origins, such as heavy rainfall, snowmelt, etc. It is very important within the context of a risk-based approach to define the full range of possible sources (Schanze, 2006; Samuels et al., 2010). Pathways of an event are defined as the routes that flood water takes from its source to reach the receptors, and it is essential to identify them for each specific area (Samuels et al., 2010) in order to understand the possible aggravating mechanisms. Receptors (also known as elements at risk, e.g. Mileti (1999); Plate (2002); Apel et al. (2009); Merz et al. (2010); Fuchs et al. (2019)) are defined as the entities that may be harmed by a flood, such as people, properties or habitat. Finally, consequences are defined as impacts such as economic, social and environmental damage that may result from a flood event. They might be categorized as either tangible (e.g. property damage, economic loss) or intangible impacts (e.g. human loss, health impacts).

The SPRC model was implemented to analyze the flooding systems in the United Kingdom by Sayers et al. (2002) for understanding the flood risk mechanisms. This model was frequently adopted and implemented later in coastal flooding (e.g. Narayan et al. (2011, 2012); Horrillo-Caraballo et al. (2013); Gallien et al. (2018); O'Donnell and Thorne (2020)) and it was indicated that it is possible to have multiple sources and pathways for a flood event (Kandilioti and Makropoulos, 2012).

In this thesis, the SPRC model was conceptualized to enable a better understanding of sources, different pathways and consequences of the floods in Turkey, and the bottom-up approach was followed for the study design (Figure 1.2). The bottom-up approach (also called 'scenario-neutral approach', Prudhomme et al. (2010); Knighton et al. (2017)) suggests starting at the event impacts (e.g. a disaster) and then trying to identify all the underlying variables that play a role in shaping the event outcomes, such as damages (Zscheischler et al., 2018). It was indicated by DiFrancesco et al. (2020) that, with the bottom-up approach, some of the limitations of the top-down approach, such as temporally or spatially downscaling of Global Climate Model (GCM) outputs, could be eliminated to approach flood risk assessment and therefore the use of this approach has increased recently (e.g. Brown et al. (2012); Serra-Llobet et al. (2016); Culley et al. (2016); DiFrancesco et al. (2020)) to understand the impacts of hazards and climate drivers of those hazards separately (Zscheischler et al., 2018). From this point of view, in this thesis,

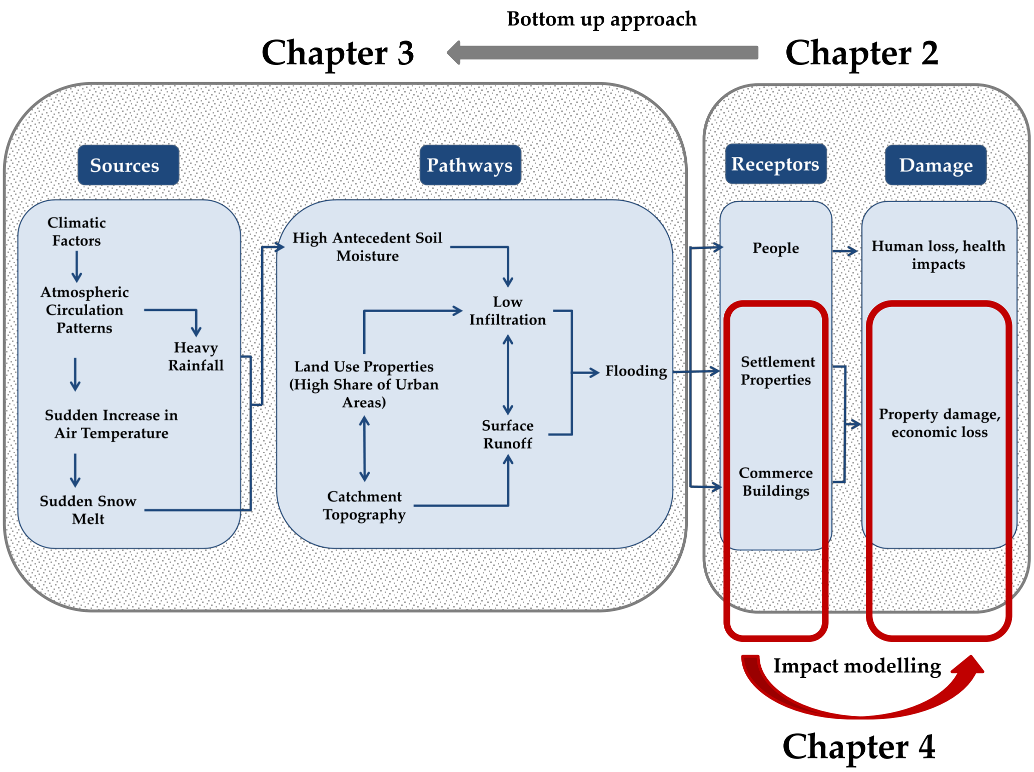


Figure 1.2: Conceptualized structure of the thesis based on the Source-Pathway-Receptor-Consequence (SPRC) model and the bottom-up approach

the structure was designed starting from the impacts (i.e. human and economic loss) of flood events in Turkey and aimed to identify the causes that created damaging events (Figure 1.2).

As the starting point, Chapter 2 discusses the importance of flood hazards in comparison to other natural hazards in Turkey based on national and international event documentation. The most severe flood events are retrieved starting from their impacts, such as number of fatalities, number of affected people and total economic losses, following the bottom-up approach. A comparative analysis of national and international loss databases is used to present this list of flood events.

Secondly, triggering mechanisms (i.e. atmospheric circulation and precipitation amounts) and aggravating pathways (i.e. catchment characteristics such as size, shape, topography, land use, soil properties) of those retrieved severe floods are then analyzed within Chapter 3. On this basis, a new approach is presented to identify the potential causal factors per event and provide additional information for determining the dominant flood occurrence pathways.

Chapter 4 addresses the biases caused by the data gaps in the event documentation as well as enhancing the flood loss documentation via impact modelling. Since the bottom-up approach starts from the impacts of an event, the quality and the accuracy of the event documentation has great importance. Therefore, Chapter 4 proposes recommendations to enhance the flood loss documentation in Turkey by calibrating, validating and applying the UNDRR loss estimation method to estimate the direct economic losses on the macro-scale, which can be used to fill gaps in event databases and support the coordination of financial aids after flood events.

Finally, the outcomes of the main sections (Chapters 2, 3, 4) will be summarized in Chapter 5. Chapter 5 provides an overall synthesis of the answers to the research questions outlined in Section 1.2.

1.4 Author Contributions

This thesis consists of three articles presented in Chapters 2, 3, 4. All studies that constitute the core of the thesis (Chapters 2, 3, 4) have been published in international peer-reviewed journals.

Chapter 2: Koç, G. and Thieken, A.H. (2018). 'The relevance of flood hazards and impacts in Turkey: What can be learned from different disaster loss databases?'. Natural Hazards (91), 375–408. doi: 10.1007/s11069-017-3134-6

Conceptualization: G.K. and A.H.T. ; Formal analysis: G.K.; Writing—original draft preparation: G.K.; Visualization: G.K.; Review and editing: G.K. and A.H.T.; Supervision: A.H.T.

Chapter 3: Koç, G., Petrow, T. and Thieken, A.H. (2020). 'Analysis of the Most Severe Flood Events in Turkey (1960–2014): Which Triggering Mechanisms and Aggravating Pathways Can Be Identified?' Water (12), 1562-1594. doi: 10.3390/w12061562

Conceptualization: G.K. , T.P. and A.H.T. ; Methodology: G.K.; Formal analysis: G.K.; Writing—original draft preparation: G.K.; Visualization: G.K.; Review and editing: G.K., T.P. and A.H.T.; Supervision: A.H.T.

Chapter 4: Koç, G., Natho, S. and Thieken, A. H. (2021). Estimating Direct Economic Impacts of Severe Flood Events in Turkey (2015-2020). International Journal of Disaster Risk Reduction (58), 102222. doi: 10.1016/j.ijdrr.2021.102222

Conceptualization: G.K., S.N. and A.H.T.; Model implementation: G.K.; Formal analysis: G.K.; Writing—original draft preparation: G.K.; Visualization: G.K.; Review and editing: G.K., S.N. and A.H.T.; Supervision: A.H.T.

Chapter 2

The relevance of flood hazards and impacts in Turkey: What can be learned from different disaster loss databases?

Published as: Koç, G., Thieken, A.H. (2018). 'The relevance of flood hazards and impacts in Turkey: What can be learned from different disaster loss databases?'. *Natural Hazards* (91), 375–408. doi: 10.1007/s11069-017-3134-6

2.1 Introduction

Over the past two decades, natural hazards have caused enormous human and economic losses in Turkey that occasionally amounted to 3–4% of the gross national product (Genç, 2007). Turkey is threatened by many hazards due to its climatic, tectonic and topographic features. Although disasters such as floods, landslides and wildfires are common in Turkey, earthquakes take the first place when evaluated in terms of their devastating effects. While there are numerous studies and a large body of literature on earthquake hazards and risks in Turkey (e.g. Gülkan et al. (1992); Bakır and Boduroğlu (2002); Özdemir and Yılmaz (2011)), relatively little is known about flood hazards and risks. Therefore, this study aims to investigate the emphasis of the floods in Turkey by analysing the TABB database, which is the only national disaster loss database for Turkey.

Since Turkey is in the favourable position of having had a national disaster database since 2009, i.e. the Turkey Disaster Database (TABB), there exists the unique opportunity to investigate flood impacts in Turkey in more detail, as well as to make a comparison with other data sources (e.g. EM-DAT, Dartmouth, literature).

In general, data on disaster events and their impacts are scarce in comparison with other scientific fields in natural hazard research, although the lack of reliable, consistent and comparable data is seen as a major obstacle for effective and long-term loss prevention (e.g. JRC (2013); UNISDR (2017a)). Disaster loss databases collect consolidate and organize loss data in a central repository (Gall, 2015), and as such, disaster loss databases represent an important tool to: identify high-risk hazards and highly vulnerable areas; prioritize disaster risk reduction studies; establish a baseline to follow progress in community resilience; evaluate the effectiveness of risk reduction measures; and carry out empirical research on climate change attribution of natural hazards (Glavovic and Smith, 2014). Currently, only a few data sets, in particular the Emergency Events Database—EM-DAT—hosted and maintained by the Centre for Research on the Epidemiology of Disasters (CRED) since 1988, are publicly accessible and have become widely used to provide information relevant for humanitarian aid at national and international levels and to describe trends in disaster losses (EM-DAT, 2016). However, there is some indication that EM-DAT does not reveal the full picture of natural hazards and risks due to the entry criteria of the EM-DAT database: for the alpine countries Austria, France, Germany, Italy, Slovenia and Switzerland, EM-DAT only contained 150 catastrophic events between 1950 and 2009 (Pfurtscheller and Thieken, 2013), while a national flood database listed no fewer than 4894 flood and debris flow events, as well as intermixture processes in Austria from 1972 to 2004 (Oberndorfer et al., 2007). This case in point reflects well the effect of the entry criteria of the EM-DAT which is identified as follows: 10 or more people reported fatalities; 100 or more people reported affected; declaration of a state of emergency; or call for international assistance. As with the EM-DAT, each database includes its own types of hazards, loss metrics (e.g. fatalities, effected and/or displaced populations) and spatial resolution, and covers different time periods. Despite these differences, many databases share the same underlying management structure (Gall, 2015).

The number of national, publicly accessible databases has considerably increased over the last decade reflecting the need and relevance of tackling disaster impacts at the local level (Gall, 2015). However, loss data are subjected to various biases (Gall et al., 2009). Common deficiencies in disaster loss databases are: the over- (or under-) reporting of certain hazard types (hazard bias); gaps in historical records (temporal bias); reliance on direct or indirect pecuniary losses (accounting bias); focus on high-impact or severe events (threshold bias); and overrepresentation of densely populated or easily accessible areas (geography bias) (Gall et al., 2009). To eliminate these biases and to provide high-quality loss data to decision makers, the public, planners, scientists and other end users, it is recommended to standardize some key areas related to loss data collection (Gall et al., 2009). Recently, IRDR (2014) proposed a common peril classification as well as human and economic impact indicators. With this classification system, it is aimed to provide a guideline on event classification and a unified terminology for operating loss databases. Local databases could have more detailed information and could be useful for regional studies on damage assessment. However, lack of common terminologies for perils, measurement methodologies and human loss indicators cause inability to compare the losses at global to local levels across hazards, place and time (IRDR, 2015). Therefore, to implement a common classification scheme in a national disaster loss database is an important step to overcome these challenges. Accordingly, it is aimed to analyse and review the Turkey Disaster Database—TABB—by implementing the IRDR Peril Classification System for better comparison with other international loss databases, i.e. EM-DAT, to address the following research questions: (1) How important are flood events in Turkey in comparison with other natural hazards as revealed in Turkey Disaster Database—TABB? (2) What are the

indications of the TABB database in terms of societal and economic impacts of floods? (3) Is the TABB database sufficient to answer these questions with regard to aspects of data quality and accuracy? As input for a more detailed event analysis, an additional aim is to retrieve the most severe flood events in Turkey for the time interval 1960–2014, using the human and economic losses as key indicators. For these objectives, TABB database was analysed and reviewed through comparison mainly with Emergency Events Database (EM-DAT), the Global Active Archive of Large Flood Events—Dartmouth Flood Observatory database, news archives and the scientific literature. It is also discussed how to complement the missing data by using different sources (e.g. news archives, scientific literature).
Loss data collection is gaining more and more attention, e.g. in the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) (UNISDR, 2015c) and the loss and damage programme of the UNFCCC (United Nations Framework Convention on Climate Change). Correspondingly, the study could offer a basis for developing guidelines and procedures on how to standardize loss databases and implement them in relation to other hazard events in order to monitor the progress of (flood) risk mitigation and adaptation in Turkey.

2.2 Study area, databases and methods

2.2.1 Study Area

Turkey is situated in Anatolia, bordering the Black Sea in the north, the Aegean Sea in the west and the Mediterranean Sea in the south. Turkey acts as a bridge-like between Europe and Asia with its positional properties. The total area of Turkey is 783,562 km^2 and it comprises seven geographic regions (Figure 2.1). The mean elevation is 1132 m and the elevation ranges 0 m (sea level) to 5137 m (Mountain Ararat). The Pontide mountain ranges (3937 m) in the north and the Tauride mountain ranges (3767 m) in the south (Figure 2.2) cause high precipitation in the Black Sea and the Mediterranean regions due to their orographic barrier effects and cause the fast runoff response due to their elevations. According to Turkish State

Meteorological Services report (1975–2015), the total annual precipitation ranges from 260 to 2248 mm in Turkey (MGM, 2015). Anatolia region has experienced

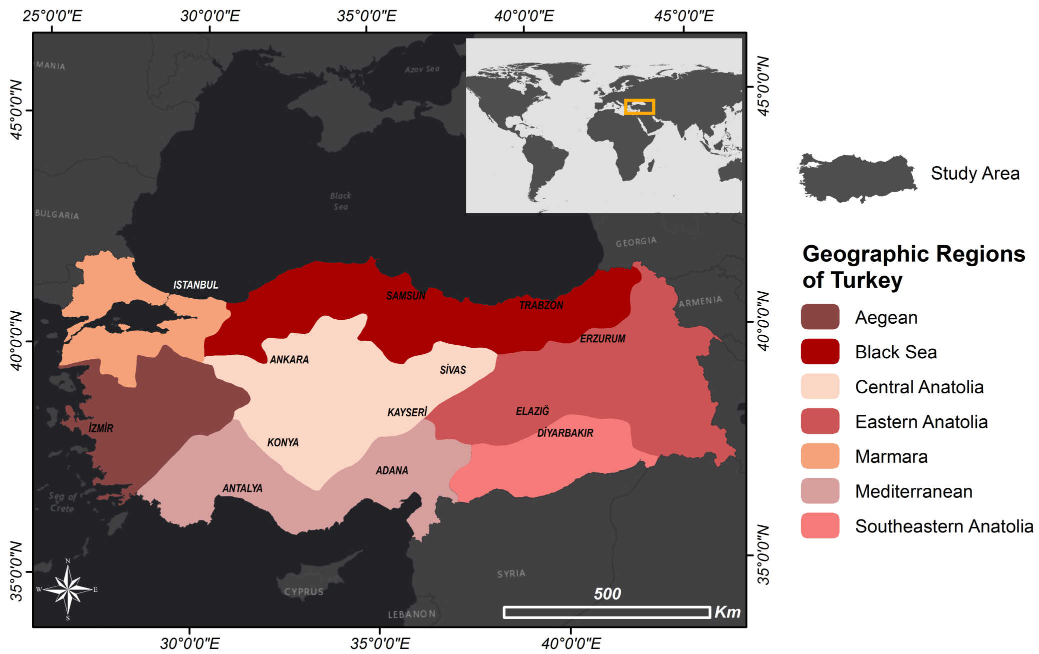


Figure 2.1: Study area and the geographic regions of Turkey

a great many floods throughout its long history. A study by Haldon et al. (2014) reveals a summary of historically recorded extreme climate related events in Anatolia, between 300 and 1453 C.E., and in this catalogue, historic records show that the northern and the southern part of Anatolia have been suffered from flood events several times (Haldon et al., 2014).

Over the last 50 years, Turkey has been severely affected by flood events as in the past. EM-DAT has reported 35 flood events between 1960 and 2014, which caused 773 fatalities, and the TABB database has reported 1076 flood events for the same period which caused 795 fatalities. These events, their societal and economic impacts were presented in more detail, in Sects. 2.2.3.1 and 2.2.3.2.

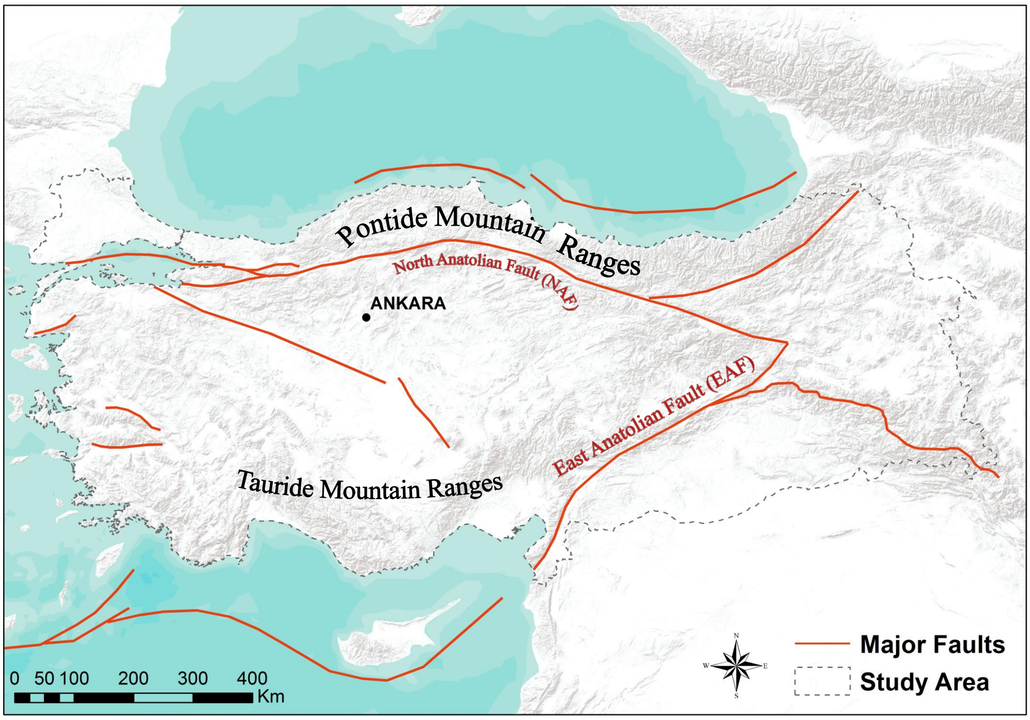


Figure 2.2: Physical map of Turkey

2.2.2 Databases and Methods

2.2.2.1 Turkey Disaster Database: TABB

In 1999, Turkey experienced a serious damaging earthquake in the Marmara region; 18,373 people lost their lives (TBMM, 2010), 43,953 people were affected (Özmen, 2000); and up to US$ 6.5 billion economic loss (USGS, 2000) occurred. After the Marmara earthquake, the collection of disaster losses for reducing the impacts of the disasters and for risk management studies became an important issue in Turkey. As a result of this rising awareness, the National Earthquake Investing Program (UDAP) was launched by the Republic of Turkey Prime Ministry Disaster and Emergency Management Authority (AFAD) in 2011 (AFAD, 2016b). The Turkey Disaster Database (TABB) was developed within the UDAP project in order to collect and summarize all corresponding documents and sources (e.g. dissertations, reports, books, photographs, videos) about both natural and anthropogenic disasters experienced so far. Applying the UNDP (United Nations Development Programme)

DesInventar database concept, TABB was set up in 2009 and has been hosted and maintained by the AFAD since then. The TABB is a publicly accessible database, which relies on secondary data sources (e.g. newspapers, NGO reports, government reports) and has no thresholds or entry criteria, such as a certain number of deceased or otherwise affected people (Table 2.2). In TABB, all events, for which an "AFAD information card" used in Turkish Emergency Management exists, are included. "AFAD information cards" are the documents which are prepared by local regional directorates and used for TABB database updating.

The TABB database includes 11 damage indicators (e.g. affected areas, total deaths, number of destroyed buildings) and 30 sub-classes (see Appendix A, Table A.1). However, although the AFAD is supposed access the detailed loss data for the natural hazards, considerable parts of the dataset are incomplete or missing. When the fill rate of each indicator in the TABB was analysed (Table 2.1), it is possible to see that approximately 98.35% of the total damage indicator information is incomplete/missing. Since incomplete damage indicators were filled in as "zero (0)", it is impossible to distinguish the value zero (0) from the missing data. Therefore, the share of missing data and the value zero (0) cannot be calculated.

Initially, a contract with a newsagent ensured that all newspapers between 1900 and 2014 were used to extract disaster loss information that was also geo-coded. An interview with AFAD representatives in June 2015 revealed that the TABB database was fundamentally updated in March 2015 and now contains 18,208 event data from 1923 to 2015. TABB was developed in two modules, which are called the "Document Module" and the "Analysis Module" (TABB, 2016). Users can access electronic documents concerning disasters by using the "Document Module" and can download the disaster data in .doc, .xls or .pdf formats by using the "Analysis Module".

2.2.2.2 Emergency Events Database: EM-DAT

EM-DAT (Emergency Events Database) is one of the most frequently used databases in the world that is global and publicly accessible, featuring both techno-

Table 2.1: Fill rate of the TABB database (1960–2014, downloaded in June, 2015)

Damage indicators of TABB database	Filled	Value zero (0)	Null (n/a)	% Empty
Total death	2079	16,129	0	88.58
Total injured	1774	16,434	0	90.26
Total missing	144	18,064	0	99.21
Number of destroyed building	144	18,064	0	99.21
Number of damaged building	2798	15,410	0	84.63
Affected	1766	16,442	0	90.30
Displaced	8	18,200	0	99.96
Evacuated	111	18,097	0	99.39
Total damage (US$)	15	18,193	0	99.92
Total damage (TL–Turkish Lira)	347	17,861	0	98.09
Destroyed agricultural area (Ha)	189	18,019	0	98.96
Cattle loss	63	18,145	0	99.65
Deaths (child 0-18)	77	18,131	0	99.58
Deaths (adult > 18)	59	18,149	0	99.68
Deaths (female)	85	18,123	0	99.53
Deaths (male)	74	18,134	0	99.59
Injured (child 0-18)	16	18,192	0	99.91
Injured (adult > 18)	42	18,166	0	99.77
Injured (female)	59	18,149	0	99.68
Injured (male)	50	18,158	0	99.73
Non-damaged public buildings	6	18,202	0	99.97
Lightly damaged public buildings	11	18,197	0	99.94
Moderately damaged public buildings	10	18,198	0	99.95
Heavily damaged public buildings	62	18,146	0	99.66
Run-downed public buildings	29	18,179	0	99.84
Non-damaged residence buildings	37	18,171	0	99.80
Lightly damaged residence buildings	9	18,199	0	99.95
Moderately damaged residence buildings	10	18,198	0	99.95
Heavily damaged residence buildings	68	18,140	0	99.63
Run-downed residence buildings	71	18,137	0	99.61
Non-damaged workplace buildings	4	18,204	0	99.98
Lightly damaged workplace buildings	7	18,201	0	99.96
Moderately damaged workplace buildings	7	18,201	0	99.96
Heavily damaged workplace buildings	11	18,197	0	99.94
Run-downed workplace buildings	0	0	18,208	100
Total number of events	18,208			

logical and natural disasters. Initially supported by the WHO (World Health Organization) and the Belgian government, EM-DAT has been maintained and hosted since 1988 by the Centre for Research on the Epidemiology of Disasters (CRED). EM-DAT's main objective is to provide information relevant for humanitarian aid at national and international levels. It further aims to rationalize decision-making for disaster preparedness and to provide data for vulnerability assessments. EM-DAT contains essential data on the occurrence and impacts of more than 21,000 damaging events from all over the world from 1900 to the present. Various sources, including: UN agencies; non-governmental organizations; insurance companies; research institutes; and press agencies, are used to populate the database (EM-DAT, 2016). However, an event is only included in EM-DAT if one of the following criteria is fulfilled: (1) 10 or more people died in the event; (2) 100 or more people were affected by the event; (3) a state emergency was declared; or (4) there was a call for international assistance (Table 2.2).

EM-DAT classifies disasters based on the IRDR peril classification and hazard glossary (IRDR, 2014). It describes an event with five levels of peril classification (disaster group, disaster subgroup, disaster type, disaster sub-type and disaster sub-sub-type). Information on total deaths, number of injured people, number of affected people, number of homeless people, total affected and total damage is also provided by EM-DAT.

It is possible to reach the disaster data by using the "Database" section in the EM-DAT website (EM-DAT, 2016). This section is formed as a dynamic search tool, and it is possible to download generated profiles for different regions, summary tables, maps and trends information easily. However, access to the raw data is only possible through a data request procedure. Each request is reviewed individually by the EM-DAT team, and access to the data is only granted on a case-by-case basis (EM-DAT, 2016).

2.2.2.3 Other Data Sources

2.2.2.3.1 Dartmouth Flood Observatory: Global Active Archive of Large Flood Events Dartmouth Global Flood Archive has been composed by Robert Brakenridge in 1993 and maintained by the University of Colorado, USA, with the intent to: (1) acquire and preserve a digital map record of the Earth's changing surface water for public use, including changes related to floods, droughts, wetlands, shorelines, lakes and reservoir, (2) to conduct remote sensing-based water measurement and mapping in "near real time", (3) to support and encourage operational uses of remote sensing-based surface water information for humanitarian purposes and (4) to conduct scientific research making use of these data products (Dartmouth, 2016). The Flood Observatory has been funded by: NASA, the US Geological Survey, the World Bank, the Development Bank of Latin America, the UN-ISDR, and from the European Commission's Global Disaster Alert and Coordination System (GDACS) at its Joint Research Centre (Italy), since 1993. The data for the Dartmouth Archive cover flood data from 1985 to the present day, and the available data are derived from governmental, instrumental, remote sensing sources and the news (Table 2.2). This platform is an "active" platform, and the event information is added instantly. Spatial resolution of the Dartmouth Archive is in "country scale", and it is downloadable in: (1) an online .html table of recent events, only, (2) Excel .xls and .xml files for all events, (3) a GIS (MapInfo format) file set and (4) a .shp format file set directly. Each event includes detailed locations, date, duration, total death, displaced, damage (USD), main cause, severity, affected area (km^2) and magnitude information (Dartmouth, 2016).

For a better comparative overview of the TABB database in this study, disaster data from EM-DAT and the Dartmouth Flood Archive were retrieved and downloaded in June 2015.

2.2.2.3.2 Literature and News Archives Literature review is an essential phase for advancing a research, and it could supply critical information to identify knowledge gaps. TABB is the only disaster loss database for Turkey, and it is important

Table 2.2: Comparative summary of Turkey Disaster Database (TABB), Emergency Events Database (EMDAT) and Dartmouth Flood Observatory database.

	TABB	EM-DAT	Dartmouth
Spatial coverage	National	Global	Global
Spatial resolution	Regional	Country	Country
Parameters	*Please see Appendix A, Table A.1	Injuries, fatalities, affected, homeless, insured damages, reconstruction costs, total damages	Locations, date, duration, total death, displaced, damage (USD), main cause, severinity, affected area (km^2) and magnitude
Time interval	1923-present	1900-present	1985-present
Update intervals	Irregular intervals	Every 3 months	Instantly (based on events)
Thresholds	No thresholds	$\geq$ 10 fatalities $\geq$ 100 affected Declaration of state of emergency Call for international assistance	–
Data accessibility	Downloadable (.xls, .doc, .pdf), (singly for each hazard type)	Downloadable (.xls)	Downloadable (an online.html table of recent events, only; Excel.xls and .xml files for all events; a GIS (MapInfo format) file set and a .shp format file set)
User access	Public	Public	Public
Sources	Universities, local administrations, state institutions and organizations, non-governmental organizations, news agencies	United Nations, National Governments, NGO's, Inter-Governmental Organizations, Reinsurance Companies, Press, etc.	Governmental sources, instrumental sources, remote sensing sources, news
Priority source(s)	News agencies	UN agencies	News and governmental sources
Host institution(s)	Republic of Turkey Prime Ministry Disaster & Emergency Management Authority	Centre for Research on the Epidemiology of Disaster, Catholic University of Louvain	University of Colorado, USA
Web page	tabb.afad.gov.tr	www.emdat.be	floodobservatory.colorado.edu

to examine the knowledge gaps in order to review the disaster data better, in regard to accuracy and data quality aspects. Accordingly, available and related literature and also the news archives were reviewed for obtaining information, which could be critical to determine the knowledge gaps in the TABB database.

Literature and the news archives could provide diverse amount of information, concurrent with their respective specific objectives and governing institutions. Each study is important to complete the knowledge gaps for the flood events information (e.g. number of events, fatalities, economic losses). For example, a study by Gürer and Uçar (2009) indicates 2089 total flood events, but for the years 1960–2009 and 1919 events were reported which caused 1050 fatalities, 3.1 billion US$ economic loss and 1.9 million ha of flooding area (Gürer and Uçar, 2009). Another study regarding the spatial distribution of the floods in Turkey by Özcan (2006) presents that 52% of all flood events occurred in the Black Sea, Mediterranean and Marmara regions (Özcan, 2006). Different studies observing flood events in Turkey, however, showed that the Black Sea, Eastern Anatolia and Mediterranean regions were at higher flood risk (Gürer and Uçar, 2009) and that most of the human deaths due to floods occurred in the Eastern Black Sea basin (Beyhun et al., 2005). The spatial distribution of flood events shows that the Black Sea Region, Eastern Anatolia and Mediterranean Sea regions experienced a higher frequency of flood events. However, although the Eastern Black Sea region had a comparatively low number of flood events, these events had more destructive effects than in the other regions (Gürer and Uçar, 2009). Ceylan et al. (2007) used 237 climatological stations records between the years 1940 and 2005 in order to analyse the spatial and temporal distribution of flood events in Turkey. Also, seventeen major flood events and their losses were listed in this study. According to major floods list, 1768 flood events were reported, in which 1344 people died (Ceylan et al., 2007). The spatial distribution of flood events shows that the occurrence of events is not distributed uniformly. Congruently, valleys in the Black Sea, Marmara and Aegean regions are under particular threat (Kömüşçü and Çelik, 2013; Yüksek et al., 2013; Çıtıroğlu and Baysal, 2011). For the western part of Turkey, heavy rainfall with a combination of geomorphological features plays a main role in flood events. Additionally, for the events reported in the Central Anatolian region and the eastern part of Turkey, snow accumulation and sudden snowmelt is the main reason for flooding (Ceylan et al., 2007). Another similar study by Ataman and Tabban (1977) examining the flood events as natural hazards considers the number of damaged buildings and affected provinces in the period from 1960 to 1975. Although the total number of events is not mentioned, it is reported that 945 provinces and 24,582 buildings were damaged between 1960 and 1975 (Ataman and Tabban, 1977). Each study reflects the flood damage data differently based on their supporting institutions, each employing different indicators according to their specific requirements. Therefore, all available and related literature, case studies, technical reports and old newspaper reports were reviewed to provide an overview of flood hazards in Turkey, while reflecting on the suitability of different disaster databases to fulfil this task and crosschecking the TABB database information. Economic and human losses data were also included in the most severe flood events list (Appendix A, Table A.2) which was retrieved from the literature and news archive sources.

2.2.2.4 Pre-processing of TABB

As outlined in Sect. 2.2.2.1, TABB is the only regional and publicly accessible disaster database for Turkey. Nevertheless, all disasters are listed without generic disaster group types. To make the TABB database more orderly and comparable with other data sources (EM-DAT, Dartmouth), all events were reclassified according to their generic disaster groups. For natural disasters, the IRDR Peril Classification System (IRDR, 2014) was implemented. For anthropogenic disasters, a combined classification system was created by adapting both EM-DAT technological disaster classification and literature sources, in particular Jha (2010). All disasters in TABB were assigned to a generic disaster group, a disaster subgroup, a main disaster type, a sub-disaster type and a sub-sub-disaster type using the disaster classification system shown in Figure 2.3. After reclassification, the TABB database was comparable to other data sources in terms of common terminologies for hazards. The spatial distribution of natural hazards is also important for identifying disaster-prone regions that are in need of support through disaster management and risk mitigation. While the TABB platform allows users to display the location of each event on the map, it is unfortunately not possible to download geo-referenced data. Therefore, all dis-

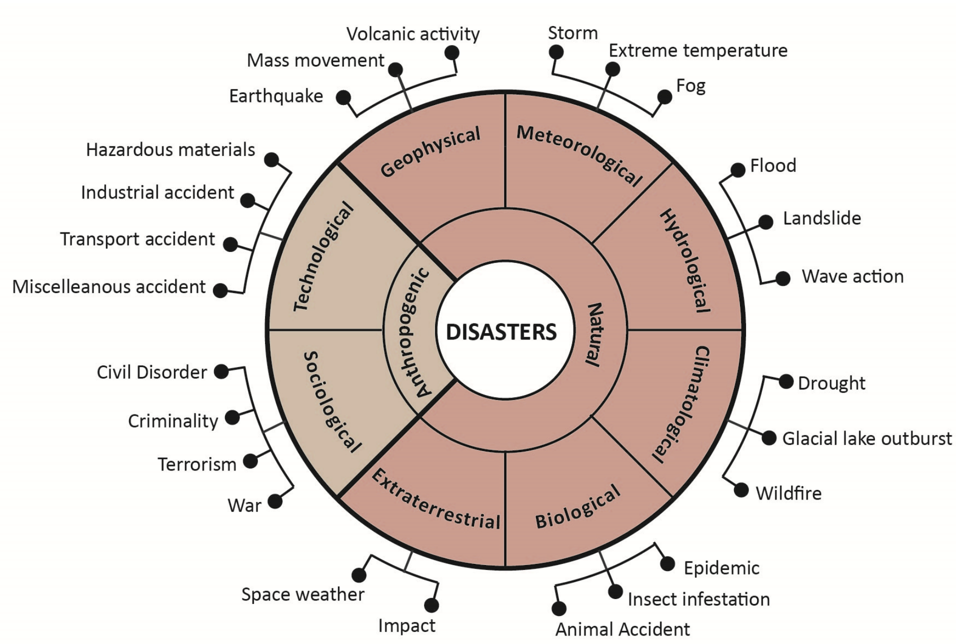


Figure 2.3: Disaster classification system (adapted from IRDR (2014)).

asters in TABB were digitized, geo-referenced, mapped and linked with the TABB loss data as an attribute table to enable event impacts to be displayed and to analyse the loss data as well.

For a better review of the TABB database in terms of economic impacts, economic losses were inflation-adjusted in US$ by using the event days' exchange rates as given by the Central Bank of the Republic of Turkey (CBRT) (TCMB, 2016; EVDS, 2016). For this calculation, explanatory notes in TABB and in the literature, which were used to complement the list of most severe flood events (Appendix A, Table A.2), and information obtained from AFAD representatives during an interview were all considered. In 2005, a new regulation went into effect for the Turkish Lira monetary unit and six zeroes were deleted from the currency (e.g.

10,000,000 TL before 2005 = 10 TL after 2005). This fact has caused discrepancies in the TABB database during economic loss calculations. Therefore, all flood events in TABB were filtered and classified according to their event dates, and economic losses were corrected by taking into account the 2005 changes to the monetary value.

For the purposes of this analysis, the period from 1960 to 2014 was selected to consider a minimum time frame of 50 years and also to consider the hydro-meteorological data availability for further steps regarding the flood events.

2.2.3 Results and Discussion

2.2.3.1 Hazard profile of Turkey

In the last 50 years, Turkey has experienced numerous natural hazards. Between 1960 and 2014, EM-DAT (as of June 2015) reports 269 hazards—136 anthropogenic hazards and 133 natural hazards—in total. According to EM-DAT, geophysical hazards are the principle type of hazard in the list with 42.1% of all natural hazards and then hydrological hazards as the second most frequent with 35.3%. For the same time period, TABB (as of June 2015) lists 18,208[1] hazards, consisting of 5219 anthropogenic hazards and 12,988 natural hazards. In contradiction to EM-DAT, meteorological hazards are the most frequent hazards in this database (31.8% of all hazards) and hydrological hazards are the third frequent hazard type in the list (21.4%) based on the number of events (Figure 2.4). In the TABB database, 181 erosion and two geo-medical events are also listed. Since these subsub-disaster types do not exist in the IRDR peril classification system, they are listed under the category "Other" in Figure 2.4.

When analysing the frequencies of damaging events based on the main disaster types, wildfire is the most frequent hazard (19.9%, n = 2586) in Turkey according to TABB (Figure 2.5). Flood hazards (8.3%, n = 1076) take the sixth place in

[1] In the TABB database, one famine event is also listed. But, since there is no detailed information in the explanations as to the reason (anthropogenic, e.g., war, or natural, e.g. extreme temperature, drought) of the famine, this event was not included in the classification.

the list after storms (18.2%, n = 2364), earthquakes (15.4%, n = 2004), landslides (13.1%, n = 1702) and extreme temperature (12.7%, n = 1647). When fatalities are considered, earthquakes are the most destructive hazards in Turkey, causing 75,904 fatalities between the years 1960 and 2014 according to the TABB database, followed by extreme temperature hazards (with 60,222 fatalities). Flood hazards are the third most destructive hazard type, in which 795 people died.

As the EM-DAT database applies thresholds (Table 2.2), the number of events

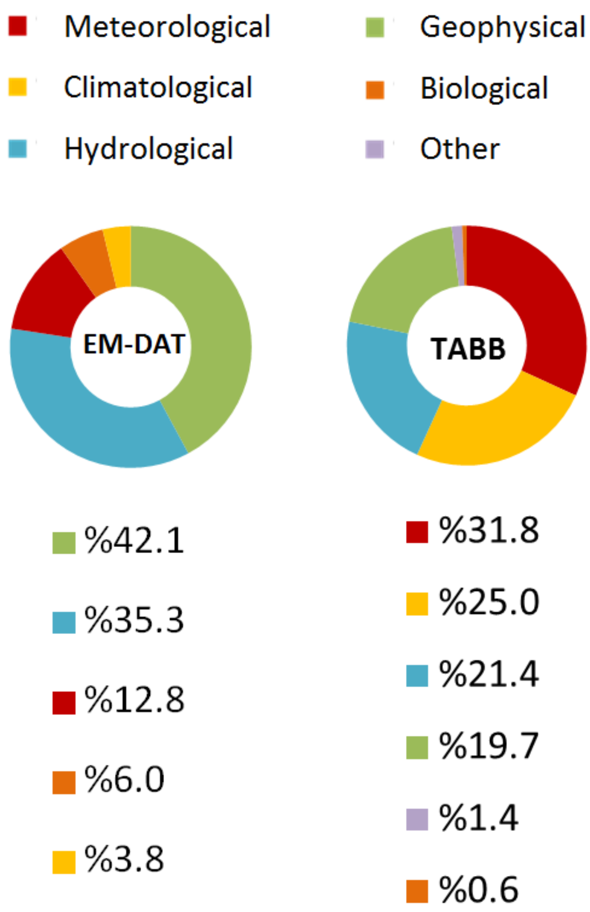


Figure 2.4: Frequencies of natural disaster subgroups in Turkey (1960–2014).

differ greatly from the data given by TABB. EM-DAT also contains substantially fewer records for Turkey. For the period from 1960 to 2014, EM-DAT reports 55 earthquake events which are the most frequent hazard type in Turkey (41.4% of all

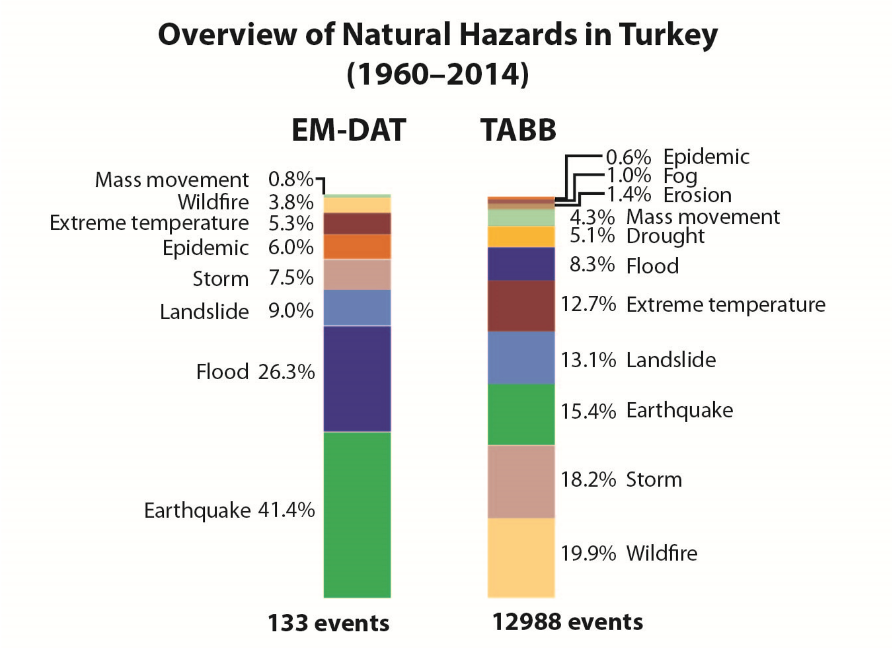


Figure 2.5: Overview of natural hazards in Turkey based on disaster main types (1960–2014).

natural hazards, see Figure 2.5), while flood events are second place in the list, with 35 events (26.3% of all natural hazards). In line with the number of events, earthquakes were reported as the most destructive hazard type in Turkey, causing 32,256 fatalities, and followed by floods with a death toll of 773.

Figure 2.6 shows the cumulative distribution of natural hazard occurrences by year for the TABB from 1960 to 2014. It is possible to see the rising trend of the temporal distribution—especially after the 1980s—of number of natural hazards. The evolution of information systems in the early 1980s (Guha-Sapir and Below, 2002) and, in parallel, the development of loss data collection and storage technologies are regarded as major reasons for this effect. In Turkey, even by the 1950s, the Disaster Inventory Information Project (ABEP) was in place, developed by AFAD in order to prepare the baseline and a database for natural disaster risk management studies. Furthermore, policy changes with regard to disaster loss data collection and storage in Turkey in the early 1980s caused a steep increase in events recorded in the TABB database (Gökçe et al., 2008). In 1993, efforts were made to begin digitizing the written records, using only one host computer due to technical and economic limitations. Data input ended in 1999, with the large Marmara earthquake. In 2003, disaster data input again became the main topic for the AFAD Research and Loss Adjustment Department, and disaster data input had fully resumed by 2005 (Gökçe et al., 2008). This development is reflected in the temporal distribution of disaster data shown in Figure 2.6. Maps in Figure 2.7 provide a general overview of the spa-

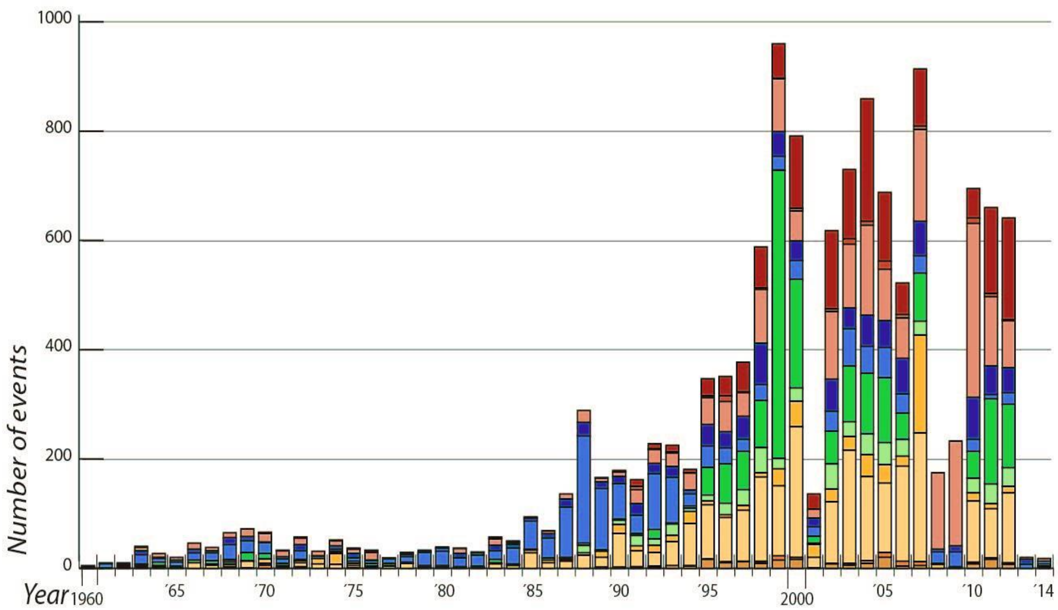


Figure 2.6: Cumulative distribution of natural hazard occurrences by year (TABB, 1960–2014).

tial distribution of natural hazards in Turkey based on the number of events. With these maps, it is possible to illustrate the frequency of the natural hazards and thus roughly identify disaster-prone areas. For instance, when spatial distribution maps (Figure 2.7) are analysed, it is possible to see that landslides occur more often in the Eastern Anatolia and Black Sea regions of Turkey. Similarly, it is also possible to see that earthquakes take place more often in the Aegean and Marmara regions and following the line of the North Anatolian Fault and East Anatolian Fault (see also Figure 2.2), where seismic activity is higher (Erdik et al., 1999). In the spatial dis-

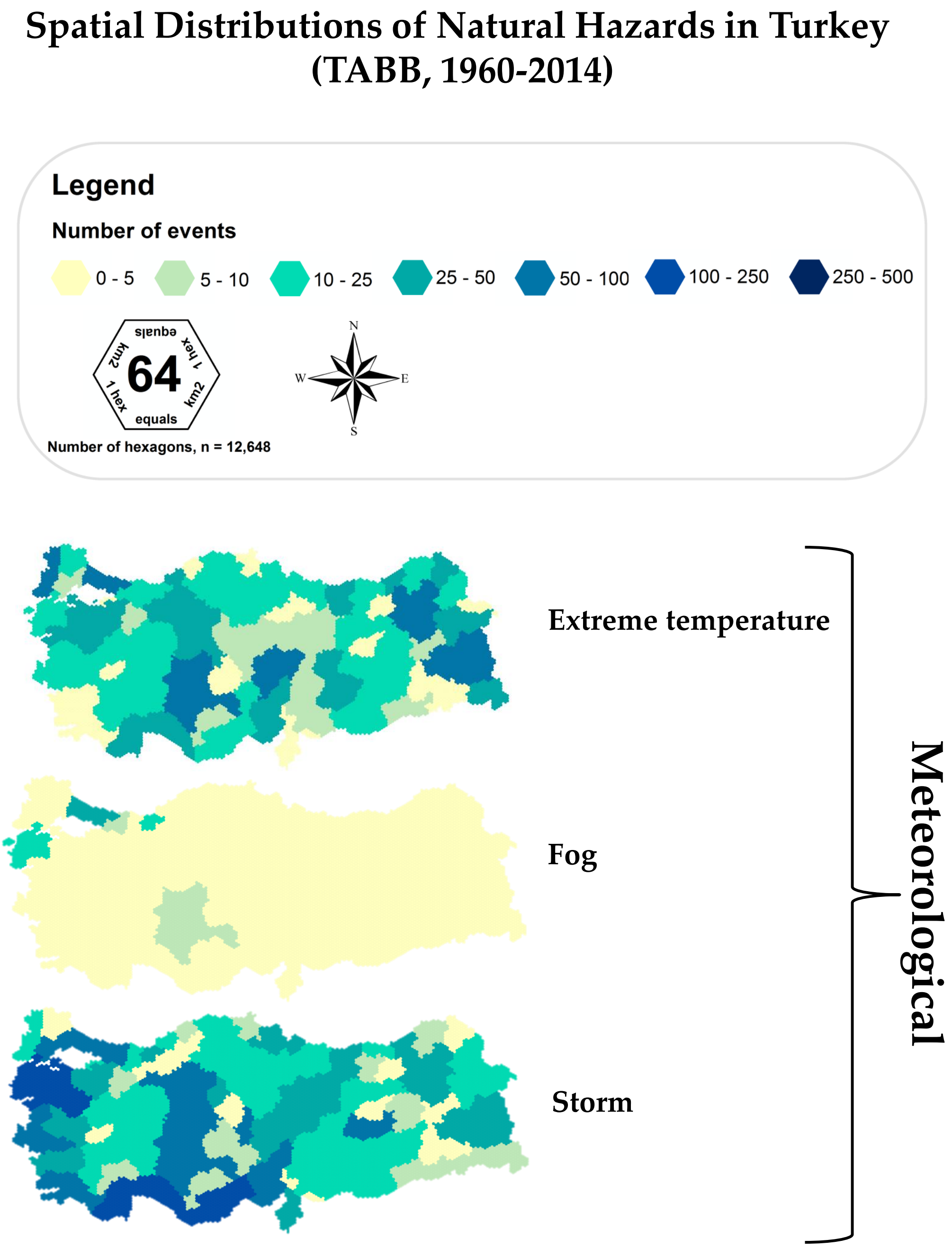


Figure 2.7: Spatial distribution of natural hazards in Turkey (TABB, 1960–2014).

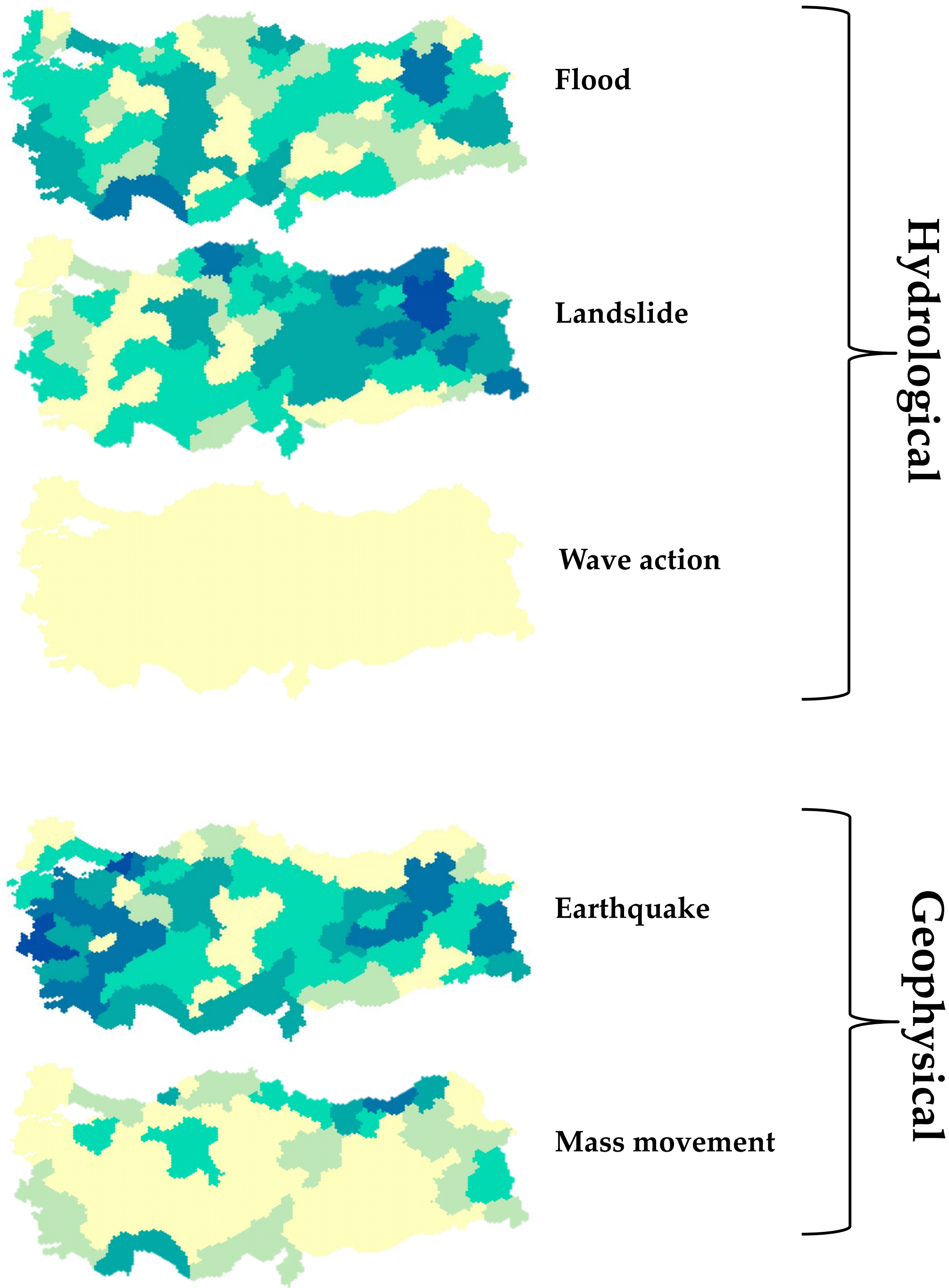


Figure 2.7 (Continued): Spatial distribution of natural hazards in Turkey (TABB, 1960–2014).

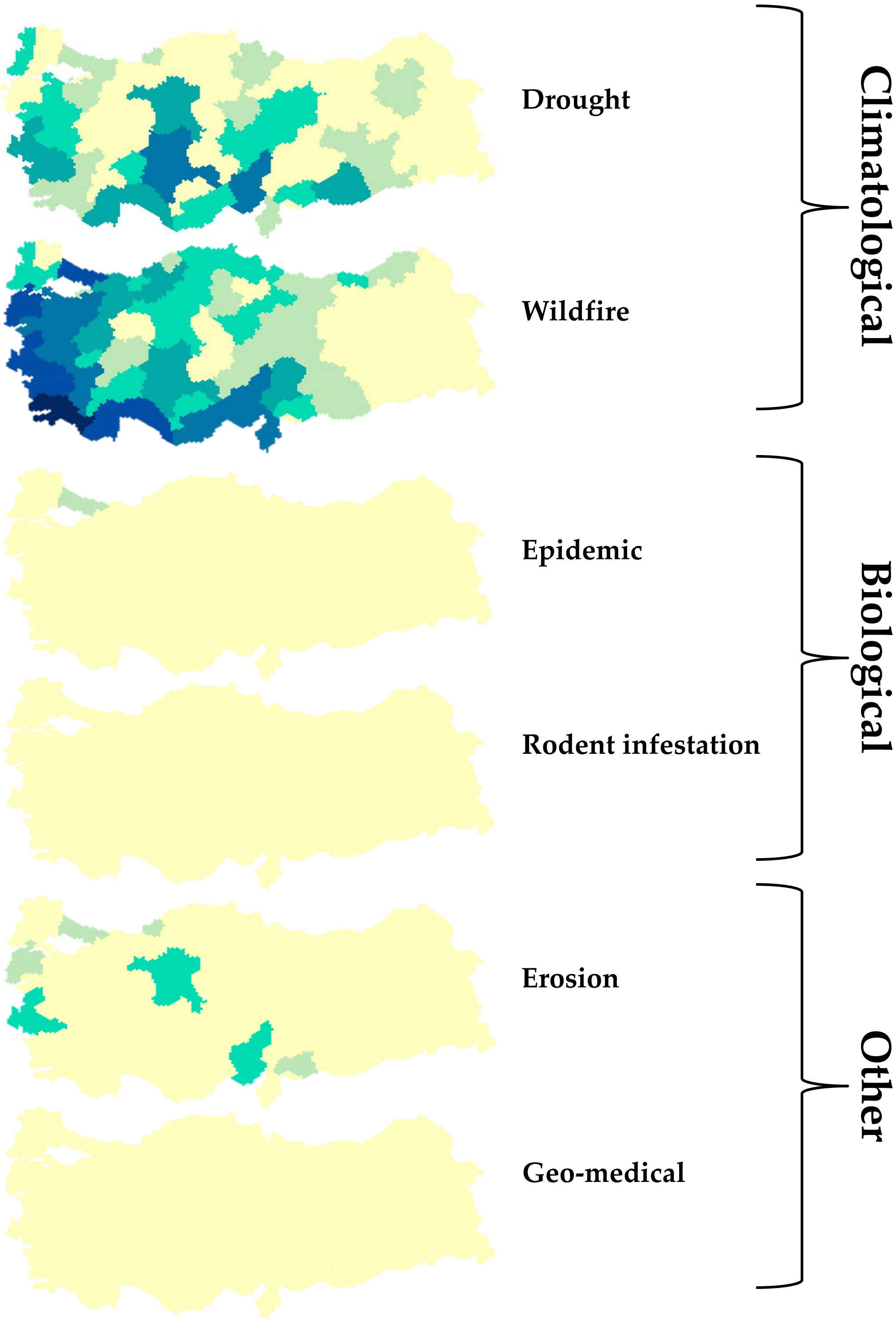


Figure 2.7 (Continued): Spatial distribution of natural hazards in Turkey (TABB, 1960–2014).

tribution maps, wildfire events can also provide information about the pattern of this hazard type. In contrast to landslides, earthquakes and wildfires, it is not possible to identify a particular pattern for other hazard types (e.g. extreme temperature, flood) (Figure 2.7). In order to examine the question of how important flood events are in Turkey, in comparison with other natural hazards as revealed in Turkey Disaster Database (TABB) in more detail, it is necessary to analyse the floods in the context of other factors (e.g. human losses, affected people, economic losses) for seeing the sociological and economic impacts.

2.2.3.2 Flood hazards in Turkey

As outlined above, flood hazards are one of the most frequent hazard types in Turkey, and according to TABB data analyses floods are the third highest in terms of human losses in the natural disasters list. In Turkey, flood hazards can be stimulated by heavy rainfall, topography, geological properties and/or human-induced factors (e.g. improper land use, constructions in stream beds—notably in the Black Sea region) (Kadıoğlu, 2012). Floods are often due to heavy rainfall on the coastal areas of the western and southern parts of Turkey or to a sudden increase in air temperature, resulting in snowmelt in the eastern, mountainous part of southeast Turkey, especially the Eastern Black Sea region (Arman et al., 2010). According to the analysis of the TABB database between the years 1960 and 2014, most flood events happen in the Erzurum Province (64 flood events), which is located in the Eastern Anatolia region of Turkey (see also Figure 2.7). Antalya Province, which is located in the Mediterranean region, also suffers from frequent flooding, as the second on the list with 55 flood events. In this, hazard and risk terms are different, as occasionally hazard frequencies are defined as hazard risk. Risk is sometimes taken as synonymous with hazard, but risk has the additional implication of the statistical chance of a particular hazard actually occurring. Therefore, hazard may be defined as "*a potential threat to humans and their welfare*", while risk (likely consequence) may be defined as "*the probability of a hazard occurring and creating loss*" (Smith and Petley, 2009). To analyse the severity of hazards, it is important to understand interactions between hazards and elements at risk. These interactions could be summarized as follows: (1) hazards to people—death, injury, disease, mental stress; (2) hazards to goods—property damage, economic loss; and (3) hazards to environment—loss of flora and fauna, pollution, loss of amenity (Smith and Petley, 2009). Using human loss, the number of affected people and economic loss information in the TABB database were analysed by societal and economic impact. These results could give important information for flood risk mitigation studies, with regard to societal and economic impacts.

2.2.3.2.1 Societal and economic impacts of flood hazards (1960–2014) Turkey has suffered from several flood events in the last 50 years. The TABB database reported 1076 flood events which caused 795 fatalities and around US$ 800 million in economic loss (on the basis of inflation-adjusted losses) between 1960 and 2014. In the TABB database, however, the number of flood events shown does not reflect the human or economic impacts. Therefore, the TABB database was analysed in terms of economic and human losses to review the impacts. TABB analyses in regard to human losses show that flood hazards are more destructive in the Eastern Black Sea region (Figure 2.8). Trabzon Province, which is located in Eastern Black Sea region, has the most fatalities (145 deaths) between 1960 and 2014. Similarly, when TABB is analysed in regard to economic losses, Mediterranean and the Black Sea regions suffer from the highest economic losses. The greatest economic loss due to flood hazard in the period from 1960 to 2014 occurred in Antalya Province, which belongs to the Mediterranean region, at US$ 340 million (Figure 2.9) when losses are inflation-adjusted. In view of the TABB analysis results, it is possible to conclude that the Black Sea and Mediterranean regions are comparatively more prone to flood hazards and risks than other regions in Turkey.

When the spatial distribution of economic losses caused by flood events is analysed, the pattern of economic loss mostly shows parallels with the continuity of the Pontides in the northern part of Turkey, with the continuity of the Taurides in the southern part, and also with the coastal zones in both the northern and southern parts (Figure 2.9). The frequency of the flood events can be interpreted while taking into

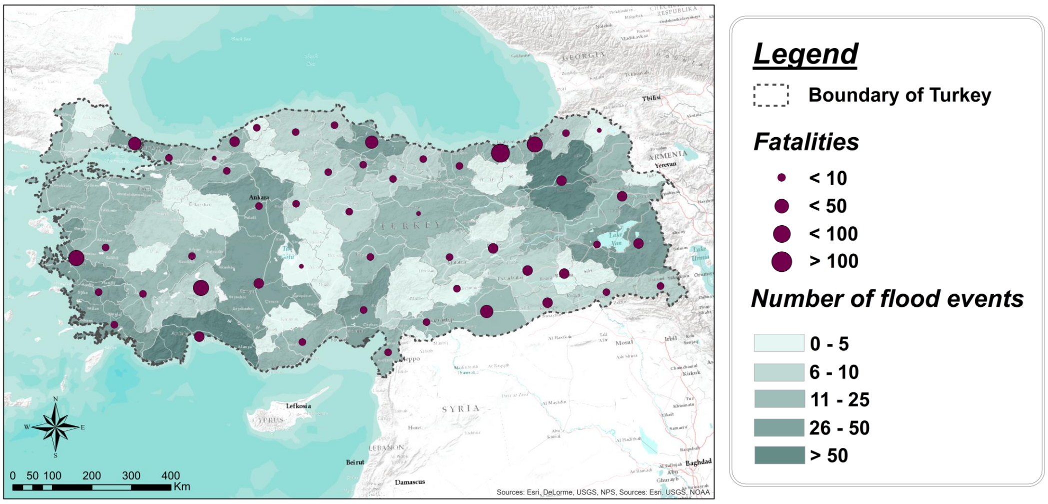


Figure 2.8: Fatalities due to flood hazards in Turkey (TABB, 1960–2014).

account heavy rainfall effects due to the orographic barrier position of the Pontides and Taurides. Here, the influence of geological structures on economic loss patterns can be explained in terms of the frequency of events occurring, which might have higher destructive effects on (vulnerable) assets that is located in hazard-prone areas.

Beside geological factors, man-made factors (e.g. land use type, urbanization, density of industrial areas) are also important to consider when interpreting economic loss patterns due to floods. For example, the Marmara region is known as a large industrial area in Turkey (Doğruel (2013), see Figure 2.9), and when the TABB results were examined in terms of economic losses, it is possible to see the higher losses in Marmara region and this could be interpreted as a result of higher number of vulnerable assets in hazard-prone area. Similarly, high economic losses due to flood events in the Mediterranean region could be linked with the density of greenhouses. In Turkey, 89.6% of agricultural greenhouses are located in the Mediterranean region (Sevgican et al., 2000), which are heavily damaged in times of flooding. When economic losses are analysed by considering industrial regions, it is possible to see that although the Eastern Black Sea region and the eastern part of Turkey have poorly or only moderately industrialized areas, economic losses are high. This case indicates the other triggering factors (e.g. geologic–topographic factors, inadvisable urban land use) which can cause high economic losses as a result of floods.

When the results of the flood data analyses are examined, the Black Sea region has the highest number of events (22.2%). Eastern Anatolia follows the Black Sea region with 21.2%, and the Mediterranean region is third with 6.6% in regard to the frequency (Table 2.3). Özcan (2006) indicates that 52% of flood hazards in Turkey occur in the Marmara, Black Sea and Mediterranean regions. Somewhat different from this statement, TABB analyses show that 60% of all flood events in Turkey occur in the Black Sea, Eastern Anatolia and Mediterranean regions. Similarly, when TABB is analysed in regard to human losses, the Black Sea region takes first place in the list with 33.2%. Eastern Anatolia takes second place with 17.3%, and the Mediterranean region follows Eastern Anatolia with 14.7% (Table 2.3). These results are consistent with the literature (e.g. Beyhun et al. (2005)), which indicates that most human deaths occurred in the Black Sea region, especially in the Eastern Black Sea region for the time period 1970–1996.

When the TABB results are analysed with regard to economic losses, the greatest losses caused by floods are seen to occur in the Mediterranean region (42.1%). The Black Sea region is also affected and is second highest at the list at 28.2%. While the Aegean region is not at the top either in frequency or human losses, it is third on the economic losses list at 12.1%. When this result is compared with industrial regions in Turkey (Figure 2.9), it can be seen that the Aegean region contains industrial zones, hinterland and emerging regions. Furthermore, the percentiles of economic losses in this area can be interpreted as a result of this industrial activity.

All in all, the TABB database was mainly analysed in terms of human loss and economic loss in order to identify the indications of TABB database in terms of societal and economic impacts of floods. The TABB results show that floods have more destructive effects in the Black Sea, Mediterranean and Eastern Anatolian regions in terms of fatalities and frequency in particular. Considering economic losses as well, the Aegean region could be added to the list of flood-prone regions. These

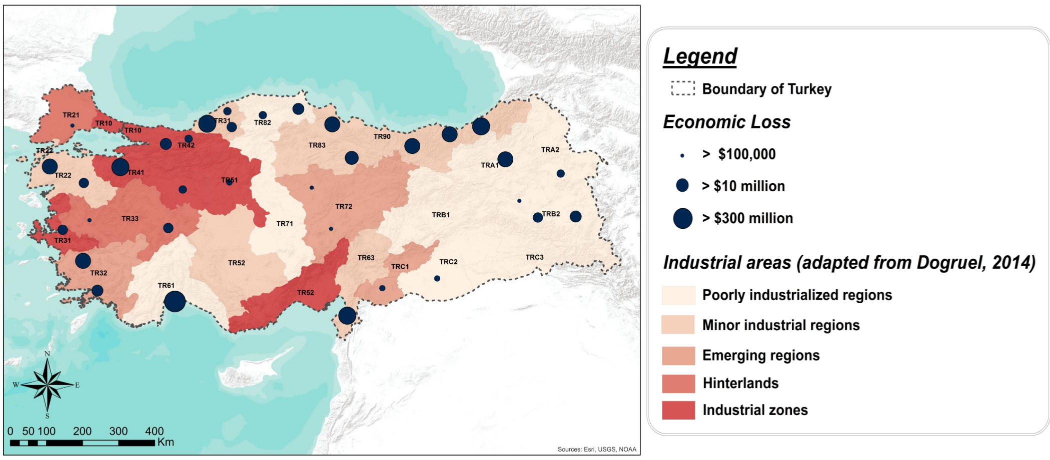


Figure 2.9: Economic losses caused by floods in Turkey (TABB, 1960–2014)

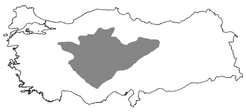
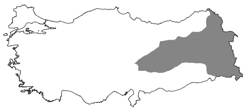
results mainly provide the information about flood hazards and impacts in terms of human and economical losses, which could be baseline for flood mitigation and risk assessment studies.

2.2.3.2.2 The 25 most severe flood events The comparative review of the TABB database shows that global or regional databases do not always include the same severe events. To better understand the flood pattern, an analysis of the catastrophic flood events is a useful next step. Therefore, a list of the most severe flood events was compiled, which served as a basis for a detailed analysis of flood hazards in Turkey. Catastrophic flood hazards between 1960 and 2014 were identified using all the data and information that was available mainly in TABB and EM-DAT. In addition, the scientific literature, news archives and the Global Active Archive of Large Flood Events—Dartmouth Flood Observatory (Dartmouth, 2016) were used to complement the databases. With this part of the study, the aim was to identify further mismatches in the different data sources and to analyse the TABB database's sufficiency in terms of data quality and accuracy. For more detailed event analyses, the 25 most catastrophic flood events were listed between the time period 1960 and 2014 (Appendix A, Table A.2). Additionally, to see the spatial distribution of the most severe flood hazards in Turkey, all events were digitized, geo-referenced and mapped (Figure 2.10). In order to relate the list of most severe flood events (Appendix A, Table A.2, Ref. Nr.) with the map, reference numbers were assigned to each event and displayed in the map (Figure 2.10). The province boundaries that were mainly affected by the flood events were also illustrated. According to Figure 2.10, it is possible to see that most of the catastrophic flood events took place in the Eastern Black Sea, Eastern and Southeastern Anatolia and Mediterranean regions.

To retrieve this list and gain an overview of the societal and economic impacts of these 25 most catastrophic flood events, human loss, economic loss and the number of affected people were considered as basic indicators.

Considering and comparing all sources of information, it becomes apparent that the fatalities, number of affected people and economic losses differ dramatically. For example, although the Mersin–Adana flood event of December 1968 was the most destructive event in Turkey with 147 fatalities as reported in EM-DAT, there is no information in either the TABB, Dartmouth archives or in the scientific literature of the same event. Similarly, the Isparta (Senirkent) flood event of July 1995 was reported as one of the most destructive flood events in terms of fatalities (74 fatalities) in TABB, as well as in case studies in the literature. Surprisingly, however, this event exists neither in EM-DAT nor in the Dartmouth archives. On the other hand, information for some of the flood events is sometimes very similar with regard to the number of reported fatalities, the number of affected people or the economic losses—even in different data sources. One flood that hit the Western Black Sea region (Zonguldak, Karabuk, Bartin, Sakarya) in May 1998 was identified as the most devastating event in terms of economic losses. EM-DAT reported 10 fatalities, 1,240,047 affected people and US$ 1.0 billion in economic loss. Dartmouth reported 19 fatalities and US$2.0 billion economic losses, and TABB reported 5 fatalities and 43,547 affected people for the same flood event. Case studies on the same flood event mention differing numbers for human and economic losses. Human losses vary from 10 to 27 fatalities and affected people vary from 1.2 million to 2.2 million. Finally, the maximum economic loss is given as US$ 2.0 billion for this flood event. Since each database benefits from different sources (Table 2.1), in-

Table 2.3: Percentage of frequencies and impacts of floods in geographic regions of Turkey (TABB 1960–2014).

	Geographic region	% Economic loss	% Fatalities	% Number of events
	Aegean	12.1	8.3	10.7
	Black Sea	18.2	**33.2**	**22.2**
	Central Anatolia	1.8	11.6	11.5
	Eastern Anatolia	5.4	17.3	21.2
	Marmara	9.7	4.9	11.0
	Mediterranean	**42.1**	14.7	16.6
	Southeastern Anatolia	0.7	10.0	6.8

Bold indicates the maximum values

formation for each flood event reveals some differences. These differences between the data taken from different databases reflect a good example of the systematic bias prevalent in loss databases.

2.3 Discussion

The comparison of the different loss databases shows that large mismatches between global and national databases can occur. Current global and national databases for monitoring losses from national hazards suffer from a number of limitations, which, in turn, can lead to misinterpretations of the loss data. These biases include a hazard bias, a temporal bias, a threshold bias, an accounting bias, a geographic bias and a systematic bias (Gall et al., 2009). According to the comparison of EM-DAT and TABB, it is possible to see these major biases in loss information. This comparative review of the TABB database provides a good example of temporal bias, threshold bias and accounting bias in particular. Temporal bias infers that losses are comparable over time (Gall et al., 2009). Changes in monetary value over time directly affect the economic losses. In TABB, all economic losses are given in Turkish Lira (TL), and since the changes to the monetary value in TL and US$ are different, it would be a mistake to compare losses over time. Especially as the 2005 currency unit changes can cause confusion when comparing economic loss data.

Another issue regarding the economic losses given in TABB involves missing or inconsequential data. When the list of the most severe flood events was interpreted, it seemed that some non-realistic loss data were included in TABB (Appendix A, Table A.2, e.g., US$ 0.084, US$ 20.74, etc.). These numbers could be described as faulty data input or mistakes. These mistakes were detected and corrected; considering the monetary unit changes from 2005 the economic losses were also adjusted. This case shows the importance of data quality and accuracy control in loss data. Similarly, when fatalities were analysed for all natural hazards, extreme temperature hazards were seen to have caused 60,222 fatalities according to TABB and 60,000 fatalities had occurred in one event (08.10.1996, extreme temperature (cold wave), Kars-Sarikamis province, Glide Nr: S-24505f5e-1985, TABB June, 2015). The number of fatalities might be interpreted as unrealistic when the population of the Sarikamis region at time was analysed (TÜİK, 2014). In the current version of TABB (February, 2016), it was possible to see that this extreme temperature event was removed from the database. The TABB database contains eleven damage indicators (Appendix A, Table A.1). However, most of the data for these indicators (e.g., number of damaged buildings, total missing, displaced, etc.) are incomplete. When the fill rate of each indicator in the TABB was analysed (Table 2.1), it is possible to see that approximately 98.35% of the damage indicator information is incomplete/missing in total. The analyses of these examples also reflect the im-

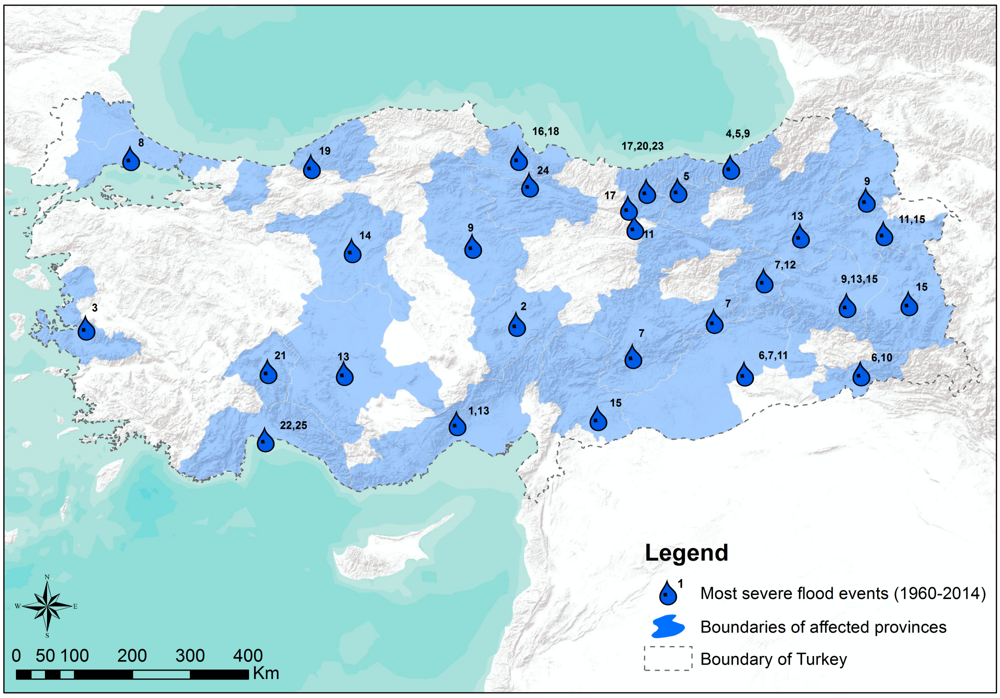


Figure 2.10: Most severe flood hazards in Turkey (1960–2014).

portance of standardization, accuracy and quality control studies in loss databases. Another bias in these databases is the threshold bias. Threshold bias infers that all losses, regardless of size, are counted (Gall et al., 2009). An event is only included in EM-DAT if one of the entry criteria is fulfilled. In contrast to EM-DAT, TABB contains all hazard events without any thresholds (Table 2.2). Threshold bias caused mistakes when comparing the two differently-scaled databases. Another conspicuous bias in this study is the systematic bias. Systematic bias infers that losses are the same regardless of the database used. Systematic bias impacts data from the initial data collection methods right through to the computation of the data (Gall et al., 2009). EM-DAT and the TABB obtain the data from various sources (Table 2.2), and the lack of standardization during data collection and computing processes leads to mistakes during the database comparison. With this implication, our aim was to show the current situation of loss data in TABB with a comparative overview, so this study could help later studies overcome these problems and biases and support the development of high quality, reliable and standardized databases for natural hazards.

Accurate accounting of disaster impacts is an important element of improving disaster risk management (Guha-Sapir and Below, 2002). In disaster management studies, damage assessment from natural hazards plays an important role. The estimation of the economic damage from flood hazards in particular is gaining more attention in Europe (Merz et al., 2010). Furthermore, historical data allows analysts to search for disaster trends and causal factors across time and regions (Guha-Sapir and Below, 2002). Flood hazards are important in Turkey and, to estimate the damage from flood hazards, it is important to understand which database should be used and further improved. A TABB database analysis, linking fatalities and economic losses, shows that such over-simplified relationships are insufficient to explain the impact of floods. Therefore, further analyses are needed to go into more detail. As a starting point, a list of the most severe events was created and mapped (Figure 2.10) to supply a useful dataset for historically severe flood events in Turkey (Appendix A, Table A.2). Furthermore, to reveal the biases in the flood database, a comparative data list was presented and data gaps were filled by drawing from other data sources (e.g., Dartmouth, literature, etc.). These events will be used for further studies covering flood-triggering processes and drivers of risk.

2.4 Conclusion

In this study, an overview of the spatial and temporal distribution of natural hazards, particularly flooding, was presented for Turkey to understand how important flood events are in Turkey, in comparison with other natural hazards as revealed in Turkish Disaster Database. The TABB database was reclassified and then compared with other data sources (e.g., Dartmouth, EM-DAT, literature, etc.) in regards to the number of events as well as economic and human losses. Also, the most severe flood events in Turkey were retrieved and interpreted for the years 1960-2014 for more detailed event analyses to check the quality and the accuracy of the TABB database.

In conclusion, suggestions and implications could be summarised as follows:

- As revealed by TABB database, flood events have high destructive effects in terms of economic and the societal impacts after earthquakes.
- In the last fifty years, 1,076 flood events occurred which caused 795 fatalities and the US$ 800 million economic loss in Turkey.
- Black Sea and Mediterranean regions have the highest event frequency, highest economic and human losses due to flood hazards.
- Most of the loss parameters in TABB (e.g., number of damaged buildings, total missing or displaced, total damage, etc.) are incomplete. During the process of computing disaster data, attention should be paid to the accuracy of data and data quality controls.
- As a government office and as the only publicly accessible disaster data source for Turkey, AFAD should collect high-quality data and produce related publications regularly.
- TABB database should be classified according to a globally accepted disaster classification system for providing a unified terminology for operating loss databases. In terms of standardization, methodology and definitions should be explained clearly.

- Local databases could provide more detailed information and could be useful for regional studies on damage assessment and risk mitigation studies. Therefore, importance should be attached to national-scale loss databases.

Chapter 3

Analysis of the Most Severe Flood Events in Turkey (1960–2014): Which Triggering Mechanisms and Aggravating Pathways Can Be Identified?

Published as: Koç, G., Petrow, T. and Thieken, A.H. (2020). 'Analysis of the Most Severe Flood Events in Turkey (1960–2014): Which Triggering Mechanisms and Aggravating Pathways Can Be Identified?' *Water* (12), 1562-1594. doi: 10.3390/w12061562.

3.1 Introduction

Turkey has been seriously affected by flood events, especially in the last fifty years. Floods have been recorded as the second most destructive natural hazard in Turkey according to the Emergency Events Database (EM-DAT); the Turkish Disaster Database (TABB) reported 1076 flood events causing 795 fatalities and US$800 million in economic losses in the period 1960–2014 (Koç and Thieken, 2018). The severity of floods can be influenced by climatic factors (e.g., weather types and associated rainfall, sudden increase in air temperature, and consecutive sudden snowmelt), topographic factors (catchment properties; e.g., shape, size, slope, and elevation), soil properties, land use properties, and human-induced factors (e.g., urbanization, hydraulic engineering practices, and unplanned infrastructure practices) (Kadıoğlu, 2012). There are numerous methods for studying a flood triggering conditions and flood classification based on different variables. For example, Nied et al. (2014) classified the floods in the Elbe River basin between 1957 and 2002 based on soil moisture, weather patterns, and flood types to understand the relationship between hydro-meteorological patterns and flood types. Similarly, Turkington et al. (2016) classified the floods in two different Alpine catchments, Ubaye (France) and Salzach (Austria), based on temperature, precipitation indicators, and day of the year to identify changes in the distribution of flood types and characteristics of the flood types for future climate scenarios. Prudhomme et al. (2013) also classified the flood sensitivity of the catchments in Great Britain for future climate scenarios in a condition of changing precipitation, temperature, and potential evapotranspiration. Schröter et al. (2014) evaluated the hydro-meteorological factors (i.e., precipitation, antecedent conditions, initial river flow, and peak flood discharge) using extreme value statistics in order to assess the causal mechanism of the June 2013 flood in Germany. Merz and Blöschl (2003) also proposed a framework for flood-causing mechanism identification using diagnostic maps based on flood-process types (i.e., long-rain floods, short-rain floods, flash floods, rain-on-snow floods, and snowmelt floods) at the regional scale. Seasonal patterns of floods are also important for understanding the dominant flood-process types and a good indicator to investigate the flood-causing processes (Beurton and Thieken, 2009). For example, Beurton and Thieken (2009) used the cluster analysis to classify the seasonality of the floods in Germany, which provides important information for understanding the flood-producing mechanisms, such as atmospheric circulation and specific hydrological response.

In Turkey, most flood events were also analyzed as case studies with regard to their meteorological characteristics, including atmospheric conditions and their influence on precipitation patterns or spatial variability of rainfall regimes (e.g., Baltacı et al. (2015); Baltacı (2017); Kömüşçü and Çelik (2013); Türkeş and Tatlı (2011); Lolis and Türkeş (2016); Sariş et al. (2010)). Up to now, there has been no study reflecting upon the main causal factors and aggravating pathways of severe flood events in the aggregate of atmospheric circulation patterns, topography, soil properties, and land use type influences at the national scale. However, for a better flood risk assessment and management, quantification of all processes along the flood risk chain, from the flood-triggering precipitation to the hydrological processes in the catchment, the hydraulic processes in the river system, and the response of the catchment, is required (Merz et al., 2016; Thieken et al., 2015), since the response of a catchment to a rainfall event differs also depending on topography, drainage characteristics, soil properties, and land use (Sivapalan, 2003). Merz et al. (2014) indicated that statistical approaches are necessary to understand the climatic context of floods and they have to be complemented by the search for the causal mechanisms and dominant processes in the atmosphere, catchment, and river system that have influence on flood characteristics. Therefore, unlike the previous studies, our aim was to develop an approach for evaluating the triggering mechanisms together with the aggravating pathways that led to catastrophic flood events in Turkey between 1960 and 2014.

In all previous studies, hydro-meteorological variables play an important role for the flood classification, while other potentially influencing factors such as catchment properties were neglected. To limit modeling efforts and to better understand the causal mechanisms, a bottom-up approach suggested by Zscheischler et al. (2018) was followed. In line with this approach, the events with severe impacts were chosen as a starting point, and drivers and pathways along the whole risk chain were analyzed. From the set of events documented in the TABB and EM-DAT databases, the 25 most severe floods in Turkey were identified, taking into account the number of fatalities and affected individuals as well as economic losses as the main indicators. To conduct a detailed analysis of the triggering mechanisms and aggravating pathways, an important first step is to determine the parameters to be analyzed and accordingly obtain meaningful data; however, there are challenges in obtaining suitable data for large-scale areas. For instance, Hammer et al. (2017) indicated that access to large-scale data might be challenging due to their costs or privacy policies. Accessing data for the entirety of Turkey is also challenging due to the costs or privacy policies of different data-providing government institutions. Therefore, our study focused on using accessible datasets for Turkey to answer the main research questions in a way that can be readily transferable to other researchers and countries with similar data policies.

The identification of potentially aggravating mechanisms helps provide an understanding of the floods from occurrence to consequence (Kandilioti and Makropoulos, 2012). Sayers et al. (2002) conceptualized the link between occurrence and consequence with the Source–Pathway–Receptor–Consequence (SPRC) model. In this flood risk assessment process, the source of the hazard (e.g., rainfall, waves, or storm surges), pathways (e.g., overflow and floodplain inundation), and receptors (e.g., people or properties) must be identified to understand a flood system (Sayers et al., 2002). Sayers et al. (2002) implemented this approach in the United Kingdom and also indicated that it is possible to have multiple sources, pathways, and receptors (Kandilioti and Makropoulos, 2012). Therefore, by identifying the main triggering and aggravating mechanisms, we enable a better understanding of the different pathways and provide information for further flood risk studies by conceptualizing the SPRC model using Turkey as an example (Figure 3.1).

Floods are complex processes which occur due to a combination of natural and human-induced factors. However, in each flood event, one of these factors plays a relatively more important role than the others. The classification of these factors contributes to a better understanding of flood-generating processes and their pathways and therefore provides an entry point for better management (Tarasova et al., 2019). For the systematic evaluation of these factors and to understand the dominant causal parameters of the events within a comparative assessment, the classification of similar features is a required next step. Therefore, hierarchical cluster analysis

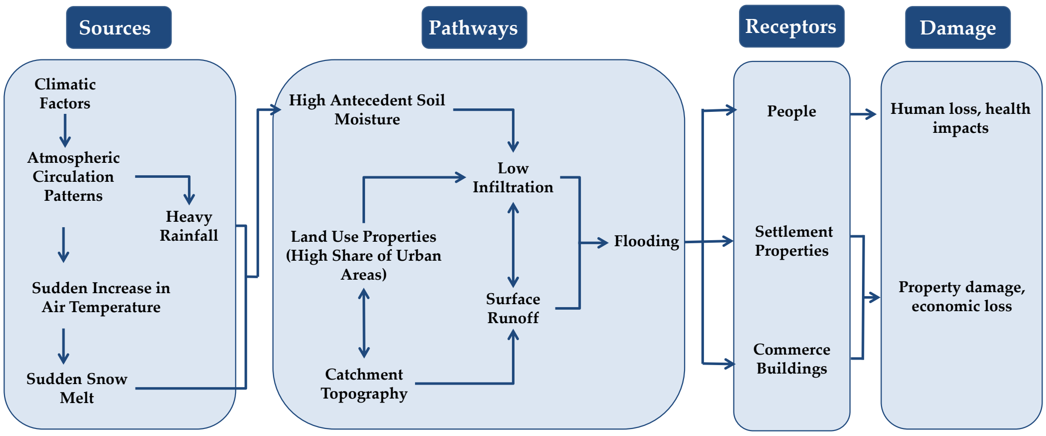


Figure 3.1: Conceptualized Source–Pathway–Receptor–Consequence (SPRC) model diagram for analyzed flood events (adapted from Sayers et al. (2002)).

was used to group the determined numerical parameters according to their similarity.

With this approach, major aggravating mechanisms and associated pathways for each of the 25 most severe flood events were identified for Turkey during the period 1960–2014.

3.2 Study Area, Datasets, and Methods

3.2.1 Study Area

Turkey is a transcontinental country located mainly on the Anatolian peninsula and acts as a bridge between Europe and Asia. The total surface area of Turkey amounts to 783,562 km^2 and the mean elevation is 1132 m (maximum 5137 m—Mount Ararat). Turkey comprises seven geographic regions (Figure 3.2) and each region differs with respect to its climatic conditions.

The total annual precipitation ranges from 580 to 1300 mm in the Aegean and Mediterranean regions, which have a Mediterranean climate with hot, dry summers and mild to cool, wet winters (MGM, 2020). The Black Sea region has the highest annual precipitation amounts, which reach up to 2500 mm due to its temperate oceanic climate with warm, wet summers and cold, wet winters (MGM, 2020). The Marmara region has a transitional climate between a Mediterranean climate and an oceanic climate with warm to hot, moderately dry summers and cool to cold, wet winters with a mean annual precipitation of 662.3 mm (MGM, 2020). The Central and Eastern Anatolia regions have a continental climate with hot summers and cold winters and 481.4 mm mean annual precipitation. Southeastern Anatolia has a transitional climate between a Mediterranean climate and a continental climate from west to east. Here, the mean annual precipitation amounts to 532.2 mm (MGM, 2020).

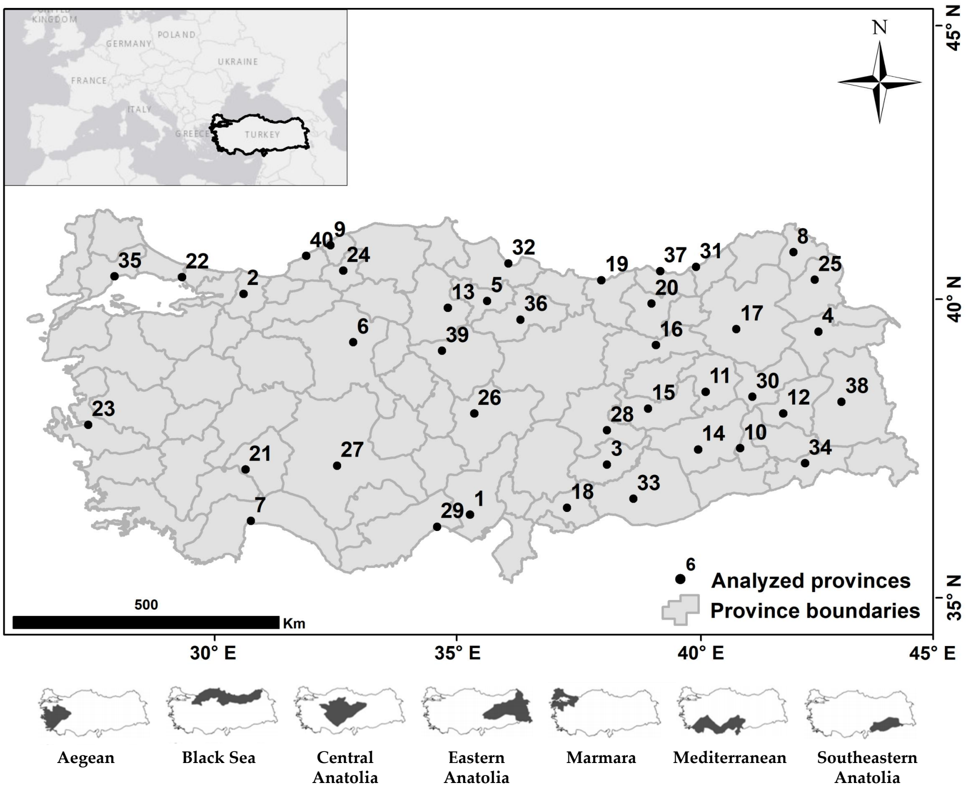


Figure 3.2: Site location map of the study area, analyzed provinces (numerated, please see the Appendix B, Figure B.1 for province names), and geographic regions of Turkey (at the bottom).

The Anatolian peninsula has experienced many floods over the last 50 years, which have caused great societal and economic impacts (Koç and Thieken, 2018). The most severe of these events were analyzed in this study with regard to their potential triggering mechanisms (i.e., atmospheric circulations and precipitation amounts) and aggravating pathways (i.e., topography, catchment size, land use types, and soil properties).

3.2.2 Datasets

3.2.2.1 The 25 Most Severe Flood Events

Koç and Thieken (2018) compiled a list of the most catastrophic flood hazards between 1960 and 2014 using the information that was available in the Turkey Disaster Database (TABB) and the Emergency Events Database (EM-DAT) (Figure 3.3). The Global Active Archive of Large Flood Events—Dartmouth Flood Observatory (Dartmouth), related scientific literature, and news archives were additionally used to fill in the gaps in the retrieved event list (Koç and Thieken, 2018). These events were ordered by their societal and economic impacts (i.e., the number of fatalities, the amount of economic losses, and the number of affected people) as key indicators for this ranking, which means that the events were selected purely based on their reported impacts. This event dataset was used to analyze the main

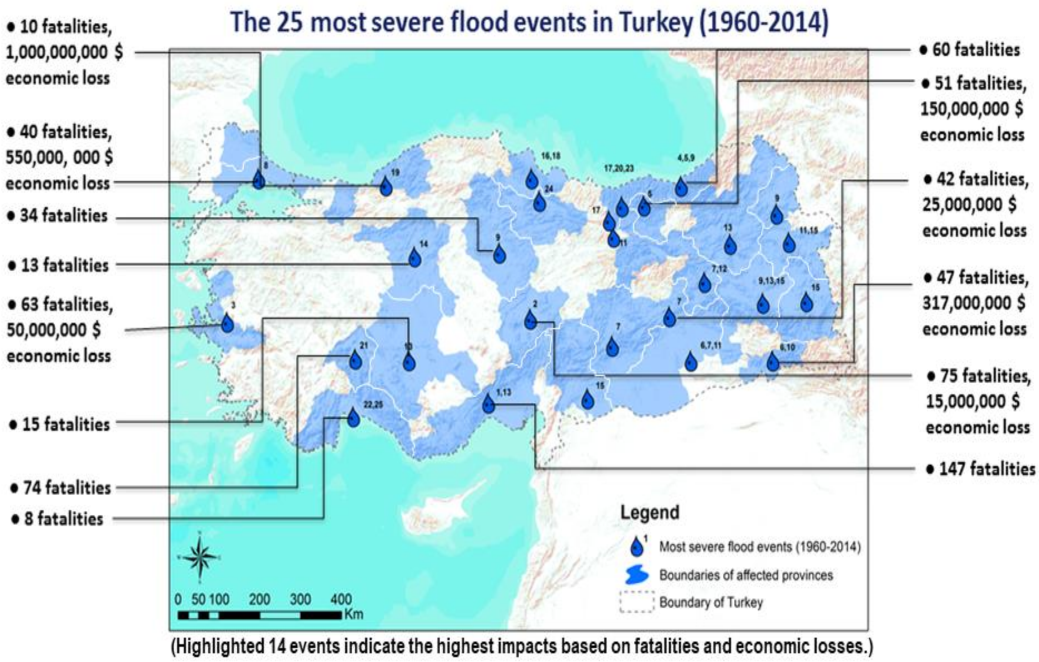


Figure 3.3: The 25 most severe flood events in Turkey (adapted from Koç and Thieken (2018)).

triggering and aggravating mechanism for each flood event. Since some flood events on the list were large-scale and affected more than one sub-basin, each sub-basin was analyzed as a separate case study resulting in 78 case studies in total. Atmospheric circulation patterns (ACP), precipitation, digital elevation models (DEMs), soil data, and land use were selected for a more detailed analysis and clustering of the main causal mechanisms of the floods on the regional scale. Additional information was acquired from related publications to fill in the gaps in the analyzed dataset.

3.2.2.2 Daily Precipitation Data (Turkish State Meteorological Service Dataset, 1960–2014)

The Turkish State Meteorological Service (TSMS) was founded in 1925 in Ankara to record meteorological data (MGM, 2019c) and is the only legal organization that supplies meteorological information in Turkey (MGM, 2019a). The TSMS data are publicly available and it is possible to request all the available data via the Meteorological Data Information Sales and Presentation System (MEVBIS) (MGM, 2019b). The TSMS data can be used for free by Turkish government organizations and Turkish universities with an official request letter. Other users can obtain the data for a certain fee.

The TSMS operates 403 rainfall stations throughout Turkey (Figure 3.4). Each station has a different starting date of operation and hence each station has a unique record period. TSMS, which started collecting rainfall data manually, introduced Automatic Meteorological Monitoring Stations (OMGI) in 2007 (MGM, 2019d). In this study, we used daily precipitation data (mm/day) from 282 stations for the time period 1960–2014, which had no long interruptions in the recording period (Figure 3.4). To eliminate the data gaps, we used the ERA5 data to create consistent time series.

TSMS daily precipitation data were related to the relevant Atmospheric Circulation Patterns (ACP) and the Antecedent Soil Moisture (ASM). Precipitation data (mm/day) were also included in the cluster analysis (PREC). Section 3.2.3.1 and 3.2.3.3 explain the determination of ACP, ASM, and PREC parameters in more detail.

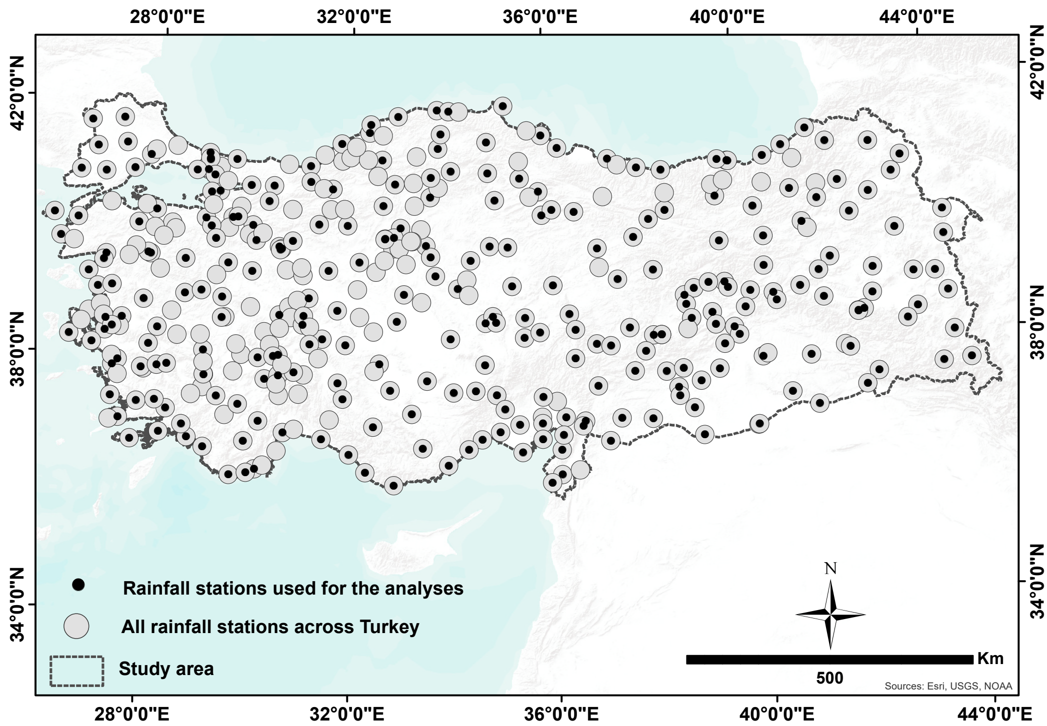


Figure 3.4: Spatial distribution of rainfall stations in Turkey.

3.2.2.3 ERA5—Climate Reanalysis Data

ERA5 (ECMWF Re-Analysis) is the fifth-generation European Centre for Medium-Range Weather Forecasts (ECMWF) involved in atmospheric reanalysis, which combines modeled data from past observations to generate consistent time series of multiple climate variables from 1979 to the present (ECMWF, 2019). ERA5 data are freely available in GRIB format, which have an hourly temporal resolution and are mosaicked in 0.25° × 0.25° (atmosphere) tiles (ECMWF, 2019).

For the study, the ERA5 reanalysis (total precipitation parameter) was used to fill the gaps in the TSMS precipitation data to generate a consistent time series for cross-checking the reported event date of the 25 analyzed severe events, the event day precipitation amount (PREC), and related ACPs.

3.2.2.4 Hess and Brezowsky Großwetterlagen Catalog (HB-GWL, 1881–2016)

Atmospheric circulation patterns occur in different local and seasonal settings and vary in their duration. Owing to their potential to absorb moisture, some circulation patterns are more capable of causing flood events than others. To reveal the relevant ACP for Turkey, we analyzed different ACPs.

There are various approaches to classifying ACPs (e.g., Bárdossy and Filiz (2005); Huth et al. (2008)). Each methodology comprises two main steps: (i) the definition of circulation types; and (ii) the assignment of individual cases to circulation types (Bárdossy and Filiz, 2005). ACPs can be defined subjectively and manually using expert knowledge and experience or can be defined using objective numerical methods to generate a set of patterns (Bárdossy and Filiz, 2005; Bárdossy, 2010). For instance, Türkeş and Tatlı (2011) used a spectral clustering method and defined eight clusters for precipitation regimes during 1929–2007 in Turkey. However, this classification was not usable for this study, since it was based on annual precipitation amounts. Lolis and Türkeş (2016) analyzed and classified the precipitation regimes in Turkey during 1979–2011 to disclose the sub-regions that were mostly affected by specific evolution types of ACPs from atmospheric reanalysis data. Baltacı et al. (2015) subjectively determined three main circulation pattern (CP) types in the Marmara region by applying the Lamb Weather Type methodology to a reanalysis of sea-level pressure data for the period 1971–2010. Similarly, Littmann (2000) presented twenty weather types in the Mediterranean basin, which also includes western and southwestern Turkey, based on subjective identification between 1992 and 1996. However, these classifications were only used as supportive information in this study and not as the main ACP classification system due to non-overlapping study periods.

The Hess and Brezowsky Großwetterlagen catalog (HB-GWL) is a subjectively-identified circulation pattern classification system. The Großwetterlagen (GWL) catalog is the only classification system which includes large-scale weather characteristics across Europe and is widely used (James, 2007; Schwander et al., 2017;

Kučerová et al., 2017). This catalog was initially designed by Baur et al. (1944) and was revised and improved by Hess and Brezowsky (Hess and Brezowsky, 1952, 1969, 1977). HB-GWL was updated by Werner and Gerstengarbe (2010) until 2009 and has been continuously updated at the Potsdam Institute for Climate Impact Research (PIK), Germany, since then. There are 30 different CPs defined in the HB-GWL catalog (Table 3.1) and each CP type was defined based on the spatial distribution of pressure systems and frontal zone locations across Europe (Petrow et al., 2009). The HB-GWL catalog contains the dominant CP types on a daily basis between 1881 and 2016 and was provided by PIK Potsdam. Although focusing on Central Europe, the HB-GWL was also found to be suitable for Turkey (personal communication with PIK representatives on 7 February 2019). Since it is the only daily weather classification system that covers the entire study period 1960–2014, we used the HB-GWL catalog for our study.

3.2.2.5 Digital Elevation Model (CGIAR-CSI SRTM, 90 m v.4)

The Consortium for Spatial Information (CGIAR-CSI) provides high-resolution remote sensing imagery and spatially-explicit multidisciplinary datasets (CGIAR-CSI, 2019). The Shuttle Radar Topographic Mission (SRTM) Digital Elevation Models (DEMs) were originally produced by the National Aeronautics and Space Administration (NASA) and are freely available for all over the world at a 90 m resolution at the equator, and mosaicked in $5° \times 5°$ tiles (SRTM, 2019).

For this study, the SRTM 90 m DEM version 4.0 data were used to calculate the Infiltration Number (IN) and the catchment boundaries (TCA) (see Section 3.2.3.4 for details).

3.2.2.6 Soil Map of Turkey (BTG, 1987)

In Turkey, soil mapping studies began in the early 1930s and were improved at certain intervals in 1938, 1940, 1958, 1960, and 1975 (Tanrıkulu, 2017). The current soil map of Turkey was updated in 1987 by the Ministry of Forestry and Water Affairs based on FAO-UNESCO and Soil Taxonomy, considering topography (slope),

Table 3.1: Classification, definition, and associated circulation patterns (CPs) of Hess and Brezowsky Großwetterlagen (HB-GWL) catalog (adapted from Hess and Brezowsky (1977)).

No.	GWL	Form of Circulation	Circulation Type	Original Definition in German	Translated Definition in English
1	WA	Zonal	Westerly	Westlage, antizyklonal	West wind, anti-cyclonic
2	WZ			Westlage, zyklonal	West wind, cyclonic
3	WS			Südliche Westlage	Southern West wind
4	WW			Winkelförmige Westlage	Angular West wind
5	SWA	Mixed	Anticyclonic	Südwestlage, antizyklonal	Southwest wind, anti-cyclonic
6	SWZ		Cyclonic	Südwestlage, zyklonal	Southwest wind, cyclonic
7	NWA		Anticyclonic	Nordwestlage, antizyklonal	Northwest wind, anti-cyclonic
8	NWZ		Cyclonic	Nordwestlage, zyklonal	Northwest wind, cyclonic
9	HM		Anticyclonic	Hoch Mitteleuropa	High pressure system, Central Europe
10	BM		Anticyclonic	Hochdruckbrücke (Rücken) Mitteleuropa	High pressure bridge over Central Europe
11	TM		Cyclonic	Tief Mitteleuropa	Low pressure system, Central Europe
12	NA	Meridional	Northerly	Nordlage, antizyklonal	North wind, anti-cyclonic
13	NZ			Nordlage, zyklonal	North wind, cyclonic
14	HNA			Hoch Nordmeer-Island, antizyklonal	High pressure Iceland-Norwegian Sea, anti-cyclonic
15	HNZ			Hoch Nordmeer-Island, zyklonal	High pressure Iceland-Norwegian Sea, cyclonic
16	HB			Hoch Britische Inseln	High pressure, British Isles
17	TRM			Trog Mitteleuropa	Trough Middle Europe
18	NEA		Anticyclonic	Nordostlage, antizyklonal	Northeast wind, anti-cyclonic
19	NEZ		Cyclonic	Nordostlage, zyklonal	Northeast wind, cyclonic
20	HFA		Easterly	Hoch Fennoskandien, antizyklonal	High pressure Fennoscandia, anti-cyclonic
21	HFZ			Hoch Fennoskandien, zyklonal	High pressure Fennoscandia, cyclonic
22	HNFA			Hoch Nordmeer-Fennoskandien, antizyklonal	High pressure Norwegian Sea-Fennoscandia, anti-cyclonic
23	HNFZ			Hoch Nordmeer-Fennoskandien, zyklonal	High pressure Norwegian Sea-Fennoscandia, cyclonic
24	SEA		Anticyclonic	Südostlage, antizyklonal	Southeast wind, anti-cyclonic
25	SEZ		Cyclonic	Südostlage, zyklonal	Southeast wind, cyclonic
26	SA		Southerly	Südlage, antizyklonal	South wind, anti-cyclonic
27	SZ			Südlage, zyklonal	South wind, cyclonic
28	TB			Tief Britische Inseln	Low pressure, British Isles
29	TRW			Trog Westeuropa	Trough, Western Europe
30	U		—	Übergang/unbestimmt	Transition, no classification

soil depth, drainage properties, salinity and alkalinity of the soil, land use, vegetation and stand properties, and land use capability properties. These maps were digitized by the Ministry of Forestry and Water Affairs, Information Technology Department in 2013 (Tanrıkulu, 2017). The Soil Map of Turkey (BTG, Major Soil Groups, Büyük Toprak Grupları in Turkish) was used to determine the Infiltration Rate (IR) in the study areas (see Section 3.2.3.5).

3.2.2.7 Corine Land Cover Data (CLC 2012)

CORINE Land Cover (CLC) is a European project that was initiated by the European Environment Agency (EEA) and aims to regularly produce a consistent national land cover database including land cover changes for 39 countries in the European Economic Area by visual interpretation of high-resolution satellite imagery (EEA, 1995). The CLC dataset includes 44 classes with a Minimum Mapping Unit (MMU) of 25 ha and is freely available in both raster (100 m resolution) and vector (ESRI and SQLite geodatabase) formats (Copernicus, 2019).

In the present study, the CLC 2012 dataset was used to calculate the proportion of the area with water bodies (WB) and artificial areas (industrial areas, urban areas, etc.), hereafter referred to as urbanized areas (UA).

3.2.3 Methods

In this study, we developed a new approach that allows us to evaluate the dominant factor of flood-aggravating mechanisms on a regional basis in Turkey using publicly accessible and free data sources. This approach was designed as a structured process, which uses the parameters selected based on the main causes and pathways of flooding and data availability.

Following the SPRC model in Figure 3.1, eight parameters were chosen to evaluate the dominant parameter of aggravating mechanisms for severe flood events: (1) PREC (Event Day Total Precipitation); (2) ACP (Atmospheric Circulation Pattern); (3) ASM (Antecedent Soil Moisture); (4) IN (Infiltration Number); (5) IR (Infiltration Rate); (6) UA (Share of Urbanized Areas); (7) WB (Share of Water

Bodies; and (8) TCA (Total Catchment Area). These parameters were determined for the 25 events shown in Figure 3.3 and the 78 case studies (Appendix B, Table B.1) mentioned above.

The determination of the parameters is presented in the following sections.

3.2.3.1 Event Day Precipitation (PREC)

Daily precipitation data were obtained from the TSMS, and 30-day time series were created by considering the reported day as the midpoint (i.e., the 15 days before the event, the reported event day, and the 14 days after the event) for 78 cases. With this approach, we aimed to see the antecedent conditions and the after the event day conditions, whether there were multiple peaks. The TSMS station data were taken as representative for each catchment. In the case that there were multiple stations in the catchments, the maximum precipitation amount was considered as representative. ERA5 daily precipitation data were also intersected with the time series to fill the data gaps. Daily precipitation amounts were derived from hourly data for the ERA5 data. Peak rainfall day was compared with the reported event day in TABB and EM-DAT databases using the consistent time series and cross-checked with related literature. Both datasets show consistency, especially in terms of peak rainfall days on time series. However, precipitation amounts are slightly different since ERA5 is modeled data. Therefore, the TSMS station data records were prioritized during the analysis. The reported event day was corrected if necessary based on rainfall peaks and literature information. The total precipitation amount of the corrected event day at the representative station was used as a PREC parameter for the cluster analysis.

3.2.3.2 Determination of the Atmospheric Circulation Pattern Types (ACPs)

Flood occurrence in large-scale areas is linked with atmospheric phenomena in general Bárdossy and Filiz (2005). Therefore, it is important to determine the atmospheric circulation pattern types (ACPs) associated with the severe flood events in Turkey as a triggering factor. To achieve this objective, the Hess and Brezowsky

Großwetterlagen catalog (HB-GWL, see Section 3.2.2.4) was used.

A 30-day period time series for each flood event was analyzed to specify the effective ACPs. The corrected event day (see Section 3.2.3.1) was considered as a reference to determine the decisive ACPs. Effective ACPs before the event and on the event day were compared with rainfall amounts at rainfall stations in the affected catchments and neighboring ones. The triggering ACP of the rainfall peaks (not the flood itself per se) was recorded for each event. However, ACP values were not included in the hierarchical clustering since they were non-numerical values, but these values were used to interpret the cluster results in terms of the main flood-generating circulation types in Turkey.

3.2.3.3 Determination of the Antecedent Soil Moisture (ASM) Parameter

Soil moisture is an important factor concerning the antecedent conditions of a flood event (Nied et al., 2013). For large-scale catchments, remote sensing methods combined with simulation models are frequently used to determine the soil moisture, and a wide variety of studies using these methods are available. Nied et al. (2013) implemented a spatiotemporal analysis of hydro-meteorological and remotely sensed radar data to understand the soil moisture pattern–flood occurrence relationship. Similarly, Brocca et al. (2009) used scatterometer data to estimate antecedent wetness conditions. Most of the studies were carried out in small catchments. Furthermore, for improved models of antecedent soil moisture conditions, better data are essential (e.g., remote sensing data, discharge data, relative humidity, duration of sunshine, etc.). However, neither the time scale of the study (1960–2014) nor the size of the study area (entire Turkey, 783,562 km^2) is suitable for these methods. Hence, another approach to estimate the antecedent soil moisture conditions was considered.

Özer (1990) suggested a method to estimate the general antecedent soil moisture conditions using daily precipitation data. He classified the five-day cumulative daily total precipitation before the event day into three classes and assigned the pre-event soil conditions: (I) dry; (II) moderately saturated; and (III) saturated (Table 3.2). The ASMs of the severe flood events were thus determined using

Table 3.2: Precipitation limits for antecedent soil moisture estimation in Turkey (Özer, 1990).

		Five-Day (Before the Event) Cumulative Daily Total Precipitation (mm)	
Antecedent Soil Moisture Class	**Antecedent Soil Moisture Conditions**	**November–March**	**April–October**
I	Dry	<12	<36
II	Moderately Saturated	12–28	36–53
III	Saturated	>28	>53

Özer (1990)'s approach. Daily precipitation data from the 282 rainfall stations (Figure 3.4) were used to create areal precipitation maps by kriging. Five-day rainfall data before the event of each case were summed via overlapping areal daily precipitation data. For the areal rainfall data, the number of stations in and around the affected area was quite important for interpolation. However, the TSMS stations data contain too many data gaps (N/A value) for a good interpolation. Therefore, the ERA5 GRIB precipitation raster data were also used to fill the data gaps. Five-day cumulative daily total precipitation maps were reclassified according to Table 3.2. For each catchment, the percentage of areas with saturated soil conditions (Class III, Table 3.2) was calculated and used as an ASM parameter for the cluster analysis.

3.2.3.4 Calculation of the Infiltration Number (IN) and the Total Catchment Area (TCA)

Topography is one of the most important flood-generating factors (Masoudian et al., 2011). Land use properties, drainage networks, and, accordingly, runoff characteristics of a catchment are influenced by topography (Rama, 2014). Therefore, the analysis of morphometric parameters of a catchment for flood events plays an important role in understanding runoff dynamics.

Topography with its complex geomorphology heavily influences flood dynamics in Turkey. The orographic barrier effects of the Pontide Mountain Ranges in the north and the Tauride Mountain Ranges in the south, sudden height changes over short distances, and sudden snowmelt during the spring season in the southeastern part of Turkey (Figure 3.5) can all be identified as flood-influencing mechanisms based on morphometric properties. Therefore, a numerical metric for the cluster analysis to show the comparative drainage properties of the catchment only based on topography was calculated for each event and used to reveal the geomorphological influence on flooding.

The drainage characteristics play an important role in the time of concentra-

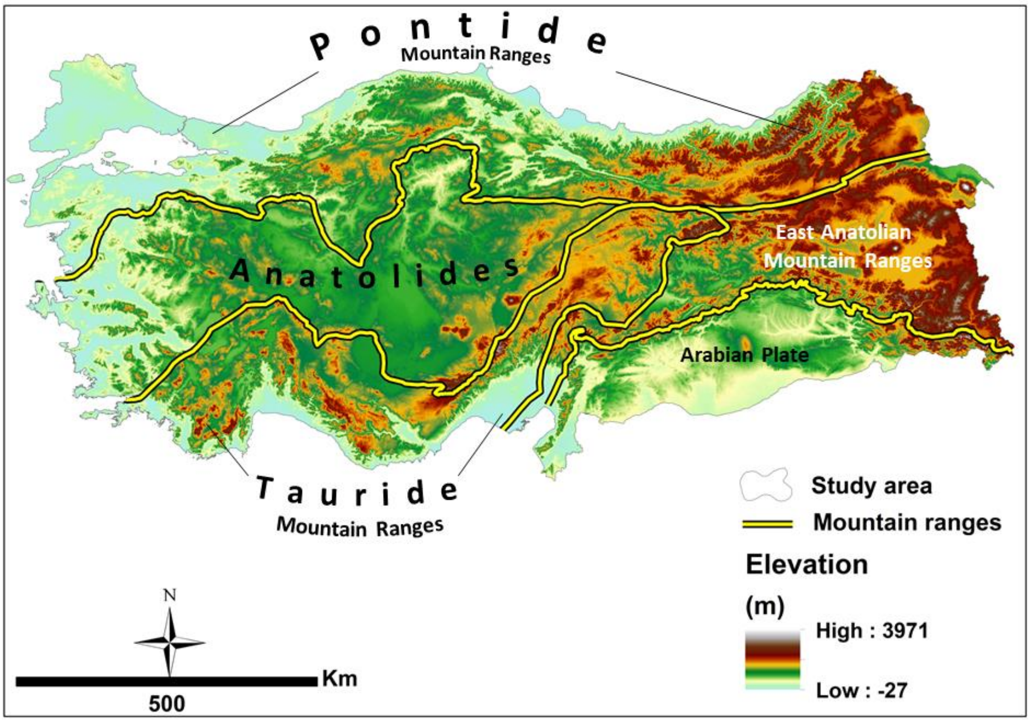


Figure 3.5: Elevation map and mountain ranges of Turkey (based on Shuttle Radar Topographic Mission, Digital Elevation Model; mountain range boundaries based on Candan et al. (2016)).

tion, and consequently runoff velocity, especially for flash floods, which are defined here following the TABB and EM-DAT as "rapid inland floods due to intense rainfall with short duration, which is typically associated with thunderstorms". The Infiltration Number (IN) captures such drainage characteristics and was therefore chosen as a parameter in this study.

The IN was developed by Faniran (1968) and is defined by $IN = F_s \times D_d$, where F_s is the stream frequency (no unit) and D_d is the drainage density (km/km^2), which gives information about the drainage texture of a watershed (Rama, 2014). Drainage density (D_d) and stream frequency parameters were calculated based on Horton (1945)'s approach. D_d is defined as "the total streams of all orders to total drainage area" and formulated as $D_d = \sum L_u / A$, where L_u is the stream length (km) and A is the total catchment area (km^2). F_s is defined as the "number of stream segments per unit area" and formulated as $F_s = \sum N_u / A$, where N_u is the number of stream segments (no unit) and A is the total catchment area (km^2) (Rama, 2014). The term "stream segment" is defined as each segment of the stream, which is classified based on Strahler stream order, from the first order to maximum order (Rama, 2014), and calculated by the GIS Stream Order Tool (Strahler order method) in this study (Figure 3.6). Based on the IN, comparative infiltration characteristics of the flood events

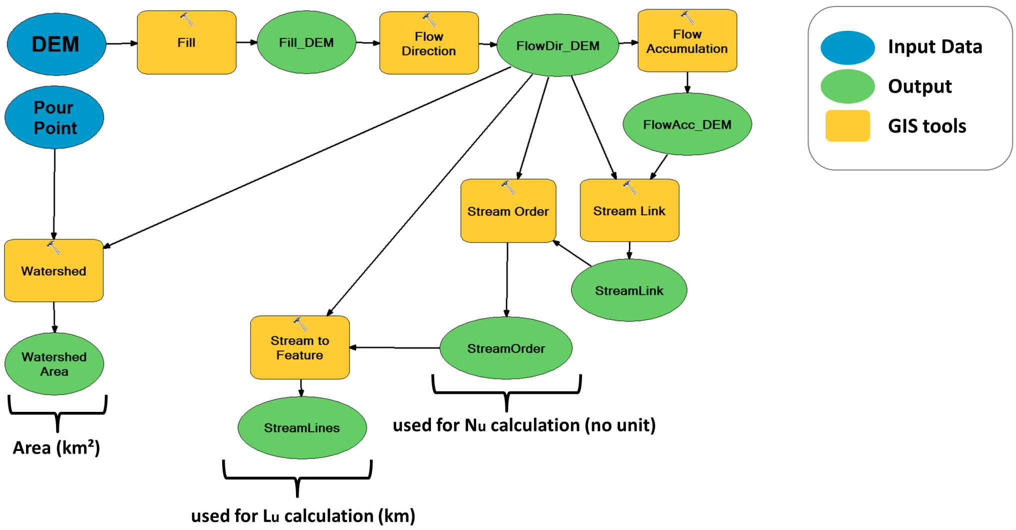


Figure 3.6: Conceptualized model of Infiltration Number (IN) and Total Catchment Area (TCA) calculation.

can be assessed, whereby a higher IN means higher runoff and, accordingly, higher flood potential.

The IN calculation was implemented using Geographic Information Systems (GIS) tools (ArcGIS Software, Hydrology tool). An automatized calculation model was created by ArcGIS Model Builder (Figure 3.6) and each parameter of the IN factor was calculated for 78 cases (Appendix B, Table B.1).

Additionally, the total catchment areas (TCAs) were also automatically derived from the SRTM DEM. The related publications and the news archives for the analyzed 25 events were used to cross-check and fill the data gaps in the TABB and EM-DAT datasets in terms of the affected districts. The affected districts of each province (Appendix B, Table B.1) were used as pour points and catchments were automatically created using the GIS Watershed tool (Figure 3.6).

3.2.3.5 Calculation of the Infiltration Rate (IR)

The infiltration capacity of the soil affects the runoff volume in upstream catchment areas and, consequently, flood magnitudes of the catchment downstream in combination with its topographic factors (Prachansri, 2007). Therefore, an analysis of soil properties is important for understanding runoff characteristics and the related pathways of flood hazards. For this purpose, the soil map of Turkey was used to derive a possible flood aggravating factor to be included in the cluster analysis. Özer (1990) classified the Major Soil Groups of Turkey (BTG) in terms of their minimum infiltration rates by considering land use properties. He classified 23 major soil groups into four classes depending on their runoff potentials (Table 3.3 and Appendix B, Table B.2, B.3).

Table 3.3: Infiltration rate classification of hydrologic soil groups (Özer, 1990).

Hydrologic Soil Group *	Runoff Potential	Minimum Infiltration Rate (mm/h)
A	Low	7.5–10.0
B	Medium	3.0–7.5
C	High	0.8–3.0
D	Very high	0.0–0.8

* Please see the Appendix B, Table B.2 and B.3 for the detailed soil map unit symbols.

According to Özer (1990)'s classification, hydrologic soil groups provide information about the minimum infiltration rate of the soils. Therefore, Özer (1990)'s classification system was applied to the Turkish Soil Maps to calculate the IR factor of each event. For each catchment area, the percentage of the area with comparatively high infiltration rates (Hydrologic Soil Groups A and B, see Table 3.3) was calculated and used as the IR parameter for the cluster analysis.

As mentioned in Section 3.2.2.6, the soil map of Turkey was last updated in 1987. However, land use change is a dynamic process and land coverage might differ immensely at short time scales. Therefore, to eliminate the miscalculation of the area with high infiltration rate soils, the soil map was intersected with the CLC 2012 land use map, and urbanized areas were assigned as Hydrologic Soil Group D (Table 3.3). In so doing, the IR parameter was updated.

3.2.3.6 Determination of Urbanized Areas (UA) and Water Bodies (WB) Parameters

Land use is also important as a potential flood-influencing factor. With the land use changes (e.g., deforestation, drainage, urbanization, agricultural practices, etc.), soil moisture, infiltration properties, runoff characteristics, and water storage capability of the land can change significantly (Rogger et al., 2017) and land use properties have a strong impact on flood events, as mainly controlled by human activities. Therefore, land use parameters were also included in the cluster analysis.

The artificial areas represented with CLC codes 1** (111, 112, 121, 122, 123, 124, 131, 132, 133, 141, and 142) provide information about the urban areas (CLC codes 111 and 112); industrial, commercial, and transport units (CLC codes 121,122, 123, and 124); mine, dump, and construction sites (CLC codes 131, 132 and 133); and artificial areas (i.e., recreational and leisure urban parks, and sport and leisure facilities) (CLC codes 141 and 142) (Copernicus, 2019). The share of artificial areas in the CLC 2012 dataset was calculated for the 78 case studies and used for cluster analysis as the UA factor.

The water bodies represented with CLC codes 4** and 5** (411, 412, 421, 422, 423, 511, 512, 521, 522, and 523) provide information about the wetlands (CLC codes 411 and 412), water-courses serving as water drainage channels with minimum width of 100 m (i.e., natural water streams, rivers that are canalized, artificial canals, branching glacial rivers with dynamically changing courses, and interspersed gravel islands, where water surface in yearly average occupies >50% of the area) (CLC codes 511 and 512), and marine waters (i.e., coastal lagoons, estuaries, sea, and oceans) (CLC codes 521, 522, and 523) (Copernicus, 2019). The share of water bodies in the CLC 2012 dataset was also calculated and used for cluster analysis in order to capture the retention capacities of the catchments.

3.2.3.7 Cluster Analysis

Cluster analysis is a widely used, prevalent statistical tool for the natural sciences, such as biology, ecology, or atmospheric research fields (Yim and Ramdeen, 2015; Behrens et al., 2018; Unal et al., 2003). Similarities or dissimilarities between the data points are measured and presented as distance in cluster analysis (Qian et al., 2004). Cluster analysis is an unsupervised method, which means the input–output relation of the dataset is not given as a function. Unsupervised methods are used to cluster the dataset in cases where there is no knowledge of the relation between variables. Therefore, it is also important to select the proper cluster analysis type (e.g., connectivity-based, centroid-based, distribution-based, or density-based clustering) based on input–output dataset properties (Mimmack et al., 2001). It is possible to summarize the input–output relation of the dataset we used as follows:

- There are no functional relations between the input parameters.
- There is no pre-cluster information.
- There is no areal cluster information.

Given the reasons listed above, the dataset is most suitable for the connectivity-based (hierarchical) clustering method. For the calculations, we used "R" software, "agnes {cluster}" algorithm, and Euclidian distance, which is the most frequently used distance metric, especially in climatology (Milligan and Cooper, 1987). The Euclidean distance (d_E) between two observations x and y, each with n variables, is determined by: $d_E\ (x,\ y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$. Euclidean distance does not take into account the correlation between the variables and assigns equal weight to each variable (Milligan and Cooper, 1987). Since there is no pre-information over the variables that are used for cluster analysis, Euclidean distance was selected to assign equal weight to each input variable.

To analyze the main aggravating mechanisms of severe flood events in Turkey, all parameters were clustered using hierarchical clustering and the complete-linkage method, which is known to create homogeneous clusters. The aim was to group similar parameters into the same cluster and to assess the dominant causal factor for each flood event. Before the implementation of the cluster analysis, all numeric parameters were standardized with the "scale" function. With this scaling, based on the standard score (also called as z-values or z-scores) method, we aimed to eliminate miscalculations due to unit differences.

3.3 Results

3.3.1 Flood Types and Atmospheric Circulation Patterns (ACP)

The 25 most severe flood events in Turkey between 1960 and 2014 were used as a starting point to analyze the main triggering factors for flood hazards. In this dataset, 40% (n = 10) of the events occurred in summer. Flash floods were most frequent, at 64% (n = 16) (Figure 3.7).

When the 25 events were analyzed with regard to the associated ACPs, 14

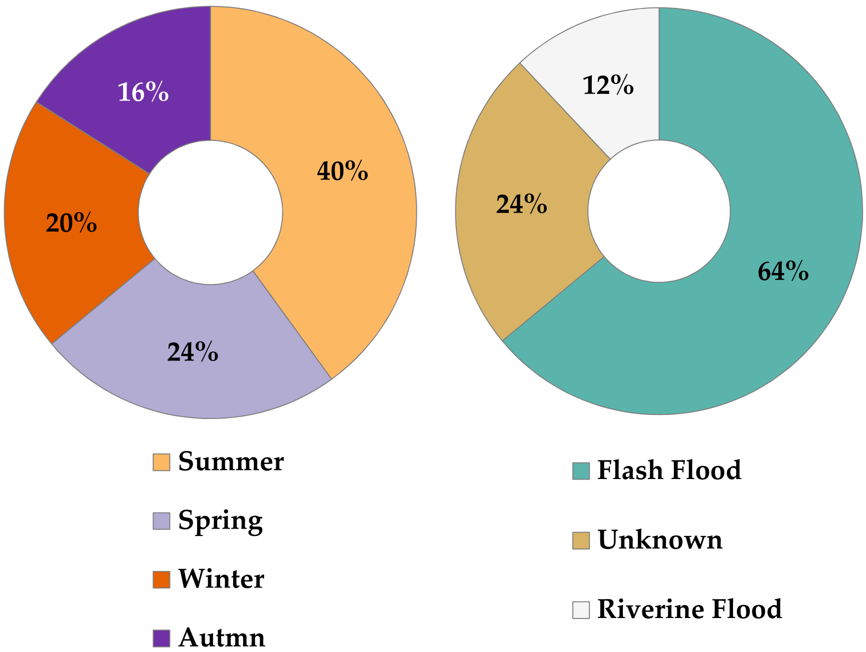


Figure 3.7: Type and seasonal frequency of the 25 most severe flood events (1960–2014).

out of the 30 ACPs were detected as triggers of at least one flood event. The BM (high pressure bridge over Central Europe, anticyclonic, see Table 3.1) circulation pattern takes first place with 16% (n = 4) as a flood-triggering ACP, followed by the SWZ (Southwest wind, cyclonic) pattern with 12% (n = 3). All other ACPs only triggered one or two events from our dataset.

To analyze the influence of the ACPs per season, we looked at the overarching form of circulations (see Table 3.1). Table 3.4 indicates that zonal, i.e., westerly, circulations do not play an important role in comparison to mixed or meridional circulations, with BM and SWZ being the important mixed circulations. It should be noted that half of the flood events studied that occurred in spring or summer were triggered by meridional circulations, whereas three out of four floods in autumn were triggered by mixed circulations (Table 3.4).

Table 3.4: Frequency of the most severe flood events' form of circulation in Turkey (1960–2014).

	Number of Floods				
Form of Circulation *	**Winter**	**Spring**	**Summer**	**Autumn**	**Sum**
Zonal	1	1	2	0	4 (16%)
Mixed	2	2	3	3	10 (40%)
Meridional	2	3	5	1	11 (44%)
Sum	5 (20%)	6 (24%)	10 (40%)	4 (16%)	25 (100%)

* Please see Table 3.1 for circulation form of ACPs.

Since only 25 events were analyzed, the question arises as to how representative these findings are. Therefore, daily ACP data were used as supportive information for a better interpretation based on rainfall-producing frequencies to cross-check and determine the heavy precipitation as the dominant triggering factor.

According to the ACPs' long-term frequency analysis during 1960–2014 (data not shown), BM (high pressure bridge over Central Europe) and WZ (West wind, cyclonic) are the most frequent circulation pattern types that play a significant role as rainfall producing ACPs. They were also dominant for the analyzed 25 severe flood events. Furthermore, this analysis shows that the BM (high pressure bridge over Central Europe) circulation pattern is mostly responsible for the very high rainfall events, which is partly represented in terms of the ACP frequencies. According to the results, it might be interpreted that the BM (high pressure bridge over Central Europe) circulation pattern plays the significant role for autumn flash floods, while the SWZ-WZ (Southwest/West wind, cyclonic) mostly triggers summer flash floods in the 25 events we analyzed.

3.3.2 Antecedent Soil Moisture (ASM) of the Most Severe Flood Events

According to Özer (1990)'s approach, the antecedent soil moisture was calculated for each case (n = 78, Appendix B, Table B.1), based on the five-day cumulative daily total precipitation before the event day. The share of the area with saturated soil conditions (Class III, Table 3.2), which provides information about the pre-event conditions of the flood events, was used as an ASM parameter for the cluster analysis. Accordingly, just 7.7% of all cases (n = 6) had completely saturated soil conditions in the entire catchment (saturated area rate in the catchment = 100%) before the actual flood event occurred. Nevertheless, 82.1% (n = 64) of all cases showed completely dry conditions before the flood events (saturated area rate in the catchment = 0%) (Appendix B, Table B.1, ASM).

3.3.3 Infiltration Number (IN)

The Infiltration Number (IN) of the 78 case studies was calculated based on Faniran (1968)'s method (see Section 3.2.3.4, Figure 3.6). IN is a unitless parameter that shows the comparative infiltration ability of the catchments only based on topography. According to the calculations, Erzurum province, part of Eastern Anatolia (see Figure 3.2 and 3.5, and FH11_06 in Appendix B, Table B.1), has the maximum IN value with 9.33 and Isparta (Sütçüler) province, part of the Mediterranean region, has the minimum IN value with 1.03 (see Figure 3.2 and 3.5, and FH03_04 in Appendix B, Table B.1). The average IN value for all catchments is 5.15. The IN parameter is directly proportionate to runoff, which means the higher is the IN, the higher is the runoff and thus the resulting flood potential.

3.3.4 Infiltration Rate (IR)

Based on Özer (1990)'s classification, hydrologic soil groups that provide information about the minimum infiltration rates of soils were integrated with the Turkey Soil Map. For each catchment, the share of area with comparatively high infiltration rates (Hydrologic Soil Groups A and B, Table 3.3), which indicates a low surface runoff potential of the catchment, was determined (see Section 3.2.3.5).

According to the calculations, only one catchment (1.3%, n = 1) had the highest percentage (80–100%) of areas with high infiltration capacity soils. Overall, 8.9% of the catchments (n = 7) had a high percentage (40–80%) and another 8.9% of the catchments (n = 7) had a moderate percentage (20–40%) of areas with high infiltration capacity. The majority of the catchments (60.3%, n = 47) had low percentages (0–20%) and 20.5% of the catchments (n = 16) did not contain any soil type with high infiltration capacity (IR = 0%, Appendix B, Table B.1, IR).

3.3.5 Cluster Results

Hierarchical clustering (complete-linkage with Euclidean distance) was applied to assess the main aggravating mechanisms of the analyzed flood events (see Section 3.2.3.7). During the selection of the appropriate clustering method, input–output relations of the variables and their correlation coefficients (Figure 3.8) were considered: Since there is no significance correlation between the input variables or any functional relation, connectivity-based clustering was chosen.

According to the dendrogram (Appendix B, Figure B.2), six clusters were defined; the sizes of the clusters were quite heterogeneous. Table 3.5 summarizes the characteristics of each cluster as mean values of the input variables. The results were mapped using ArcGIS (Figure 3.9), and thus the visual presentation allows us to analyze the spatial pattern of each cluster and helps us understand the flood-producing mechanism.

Cluster 1 contains only two cases, and they are clustered mainly based on their very high TCA and high WB values. The mean catchment area in Cluster 1 amounts to 46,854.60 km^2 and the mean share of WB is 4.08% (Table 3.5). In addition to the

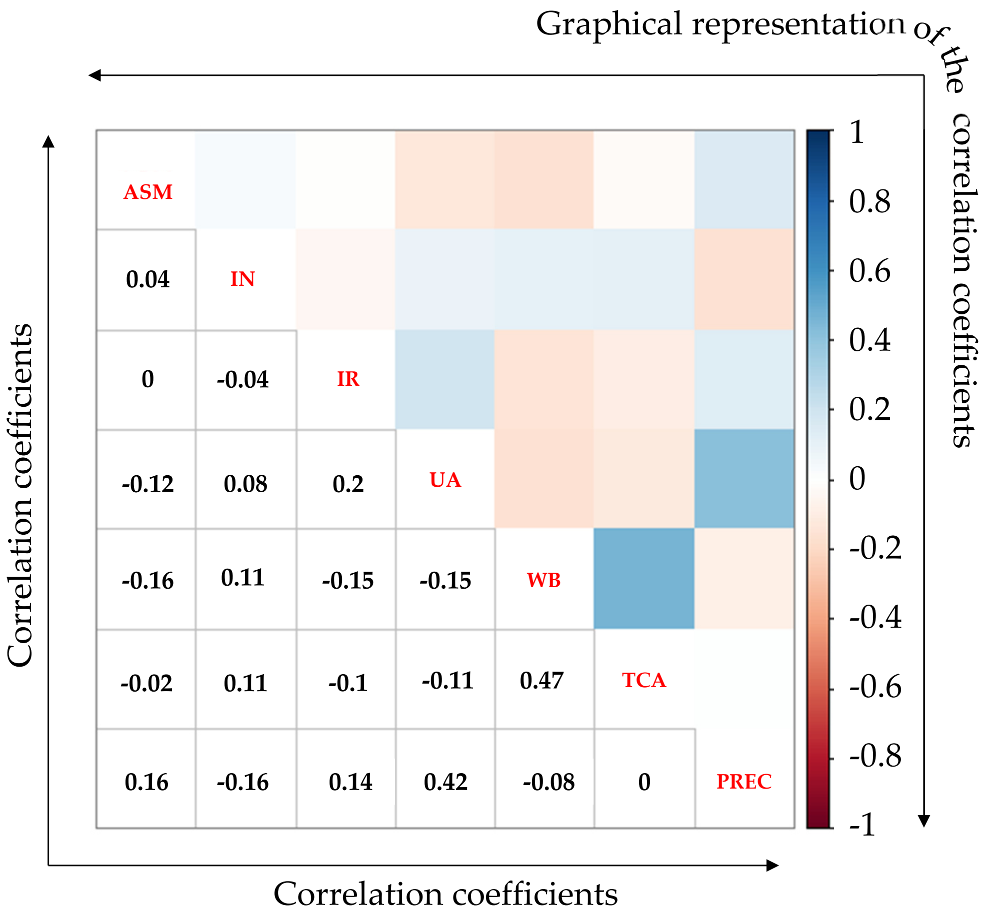


Figure 3.8: Correlation matrix of the input parameters.

large catchment size and shape factors, rapid change in the elevation over short distances (see Figure 3.5) probably also plays an important role for runoff characteristics in this cluster. Şırnak province in southeastern Anatolia (see Figure 3.2 and 3.5, and FH10_01 in Appendix B,Table B.1) and Samsun (Çarsamba) province in the Black Sea region (see Figure 3.2 and 3.5, and FH24_01 in Appendix B, Table B.1) have high IN values due to their drainage properties; furthermore, rapid elevation changes (slope gradient changes) in these regions (see also Figure 3.5) along with the size and shape factors of the catchments aggravate the flood events (Table 3.5 and Figure 3.9). When the ACPs were analyzed for this cluster, it was revealed that both events were triggered by SWZ-WZ (Southwest/West wind, cyclonic) circulation pattern types.

Table 3.5: Mean values of each cluster.

Cluster No.	Number of Cases	Mean ASM (%)	Mean IN (km/km^2)	Mean IR (%)	Mean UA (%)	Mean WB (%)	Mean TCA (km^2)	Mean PREC (mm/day)
1	2	0.10	5.78	1.61	0.95	4.08	46,854.60	59.85
2	2	0.00	5.16	11.24	86.82	0.00	6.95	210.00
3	5	0.00	8.00	5.76	11.54	0.09	559.90	37.34
4	5	4.90	4.43	64.62	20.42	0.61	56.50	133.36
5	9	92.23	5.30	11.89	1.39	0.25	2062.18	86.47
6	55	1.36	4.91	9.70	25.93	0.89	1338.28	44.90
Overall Mean	78 cases	11.92	5.15	13.05	6.64	0.80	2422.70	59.50

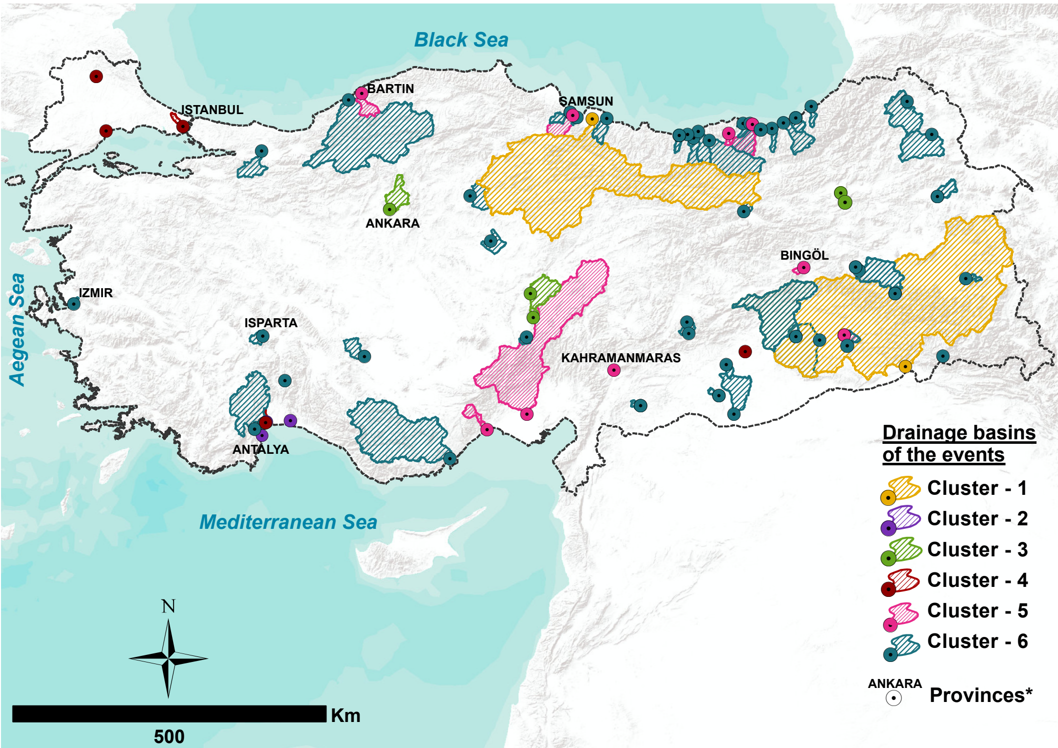


Figure 3.9: Spatial distribution of clusters (see Figure 3.2 for all the analysed provinces' locations and Appendix B, Figure B.1 for the provinces' names).

Cluster 2 also contains two cases with very high UA (mean UA = 86.82%), very high precipitation (mean PREC = 210 mm/day) values, and small catchment areas (mean TCA = 6.95 km^2). Since both catchments were affected by the same flood event (November 1995 flood event, Appendix B, Table B.1), ACPs for both cases are NZ (North wind, cyclonic). High urbanization rates in small catchments change the land use properties and, accordingly, decrease the infiltration rate substantially in Cluster 2. Both cases in this cluster are located in the Mediterranean region (Figure 3.9) and urbanization was determined to be the main aggravating factor.

Cluster 3 contains five cases, where a high infiltration number (IN), i.e., high topographic factor, is the striking feature (mean IN = 8.00 km/km^2, Table 3.5). All cases are located in central and eastern Anatolia, where the steep topography is dominant (Figure 3.9). Nevertheless, no dominating ACP type was identified for this cluster (Appendix B, Table B.1), but all events occurred in spring or summer.

In Cluster 4, extreme rainfall events were determined as the main triggering mechanism (mean PREC = 133.36 mm/day). Although the catchments in Cluster 4 show a high infiltration rate (mean IR = 64.62%, n = 9), heavy precipitation totals and high rainfall intensity (14.6 mm/h) (Şahinalp, 2007; Kömüşçü, 2011) are considered the main factors in the severity of these events. BM (high pressure bridge over Central Europe) is the dominant ACP for this cluster, which was one of the most frequent rainfall-producing circulation pattern types in Turkey between 1960 and 2014 (see Section 3.3.1).

Cluster 5 contains nine cases that have very high ASM values (mean ASM = 92.23%). In Cluster 5, basically pre-event conditions are the main influencing factor. Very high antecedent soil moisture (mean ASM = 92.23%, Table 3.5) and, accordingly, low infiltration capacity is the pathway of the flood hazards in this cluster. No dominant ACP type or season was identified for this cluster (Appendix B, Table B.1).

Cluster 6 comprises the highest number of events (n = 55, Table 3.5); consequently, no specific dominant influencing factor could be identified. However, the spatial distribution of the events in Cluster 6 indicates a direct relation to the mountain ranges of Turkey (compare Figure 3.5 and 3.9); the Tauride Mountain Ranges in the south, Pontide Mountain Ranges in the north, East Anatolian Mountain Ranges in the east, and Anatolides in central Anatolia (Figure 3.5). This situation illustrates the orographic barrier effect in these areas. Thus, the aggravating factor for these events can be regarded as a combination of orographic rainfall and topographic factors.

In summary, each cluster is characterized as follows:

Cluster 1: Main aggravating factor: Drainage Properties (i.e., size, shape and soil type)

- Dry pre-conditions, very low antecedent soil moisture (mean ASM = 0.10%)
- Very low infiltration capacity, very low infiltration rate (IR) (mean IR = 1.61%)
- Very large catchment size (mean TCA = 46,854.60 km^2)
- Comparatively high percentage of area with water bodies (mean WB = 4.08%)

Cluster 2: Main aggravating factor: Urbanization

- Dry pre-conditions, very low antecedent soil moisture (mean ASM = 0.00%)
- Very high percentage of urbanized area (UA) (mean UA= 86.82%)
- Very small catchment area (TCA) (mean TCA = 6.95 km^2)
- Extreme rainfall (mean PREC = 210 mm/day)

Cluster 3: Main aggravating factor: Topography

- Dry pre-conditions, very low antecedent soil moisture (mean ASM = 0.00%)
- Very high topographic factor, infiltration number (IN) (mean IN = 8.00 km/km^2)
- High rainfall intensity (this information was obtained from the related literature (Cluster 3 (Özdemir and Bozyurt, 2003))).

Cluster 4: Main aggravating factor: Extreme rainfall

- Dry pre-conditions, low antecedent soil moisture (mean ASM = 4.90%)
- Low topographic factor, infiltration number (IN) (mean IN = 4.43 km/km^2)

- Very high infiltration capacity, very high infiltration rate (IR) (mean IR = 64.62%)

- Extreme rainfall (mean PREC = 133.36 mm/day)

Cluster 5: Main aggravating factor: Saturated soil conditions

- Very high antecedent soil moisture (mean ASM = 92.23%)

- Comparatively low infiltration rate (IR), high runoff (mean IR = 11.89%)

- High rainfall (mean PREC = 86.47 mm/day)

Cluster 6: Main aggravating factor: Orographic effect of mountain ranges

- Spatial distribution over the mountain ranges

- Sudden snowmelt through Eastern Anatolian Mountain Ranges (this information was obtained from the related literature (Cluster 6 (Ceylan et al., 2007; NOAA, 2004; Buldur et al., 2007; Istanbul Metropolitan Municipality, 2007; Avcı and Sunkar, 2015))).

3.4 Discussion

The study aimed to understand the main aggravating mechanisms of the severe flood events in Turkey between 1960 and 2014. Event Day Precipitation (PREC), Atmospheric Circulation Patterns (ACP), Antecedent Soil Moisture (ASM), Infiltration Number (IN), Infiltration Rate (IR), Urbanized Areas (UA), Water Bodies (WB), and the Total Catchment Area (TCA) were considered to reflect important flood-causing factors. We were able to create one representative parameter for each causal factor using freely accessible datasets. The direct or indirect relevance of atmospheric circulation, precipitation patterns, and catchment properties (topography, soil, and land use) on the severe flood events in Turkey between 1960 and 2014 were investigated and used to cluster the events. As a result, six different clusters were retrieved and their properties were defined. To check the validity of this methodology, a few case studies were selected to cross-check the cluster results with the literature.

Cluster 1's definition indicates that drainage properties of the catchment are the main influencing factor for the flood events in this cluster. The cases in Cluster 1 have very large catchment sizes and very low infiltration capacities (Table 3.5). To verify this statement, the flood event in May 2000 in Samsun province (Figure 3.2, FH24_01, Appendix B, Table B.1) was selected as being representative because its parameter values were similar to the mean values of Cluster 1. Based on the related literature, this event was triggered mainly by heavy rainfall and saturated soil conditions. The clustering results show that low infiltration capacity might explain the saturated soil conditions. However, ASM values do not reflect the saturated soil conditions for Cluster 1. When we analyzed the related literature further, it indicated that the underground water table in the catchment was high (Şahin, 2002). Since ASM parameters were calculated only based on five-day cumulative precipitation amounts before the event day, the influence of high water table conditions on saturation could not be reflected. Nevertheless, low infiltration capacities are reflected in IR values of the catchment for Cluster 1 (Table 3.5 and Appendix B, Table B.1). Taking all this information into account, it is possible to state that drainage properties (i.e., catchment size and shape, and soil type) are the most important aggravating factor for Cluster 1.

For the Antalya flood event in November 1995 (Figure 3.2, FH03_02 and FH03_03 in Appendix B, Table B.1, and Cluster 2), Kömüşçü et al. (1998) indicated that Antalya province was affected due to cyclonic weather conditions, which influenced a larger region called the Mediterranean catchment. However, cluster analysis results show that the FH03_02 and FH03_03 catchment areas are quite small (mean catchment area = 6.95 km^2) and the mean urban area (M-UA) percentage is high (M-UA = 86.82%). In these two small catchments, it might be interpreted that unplanned urbanization occurred in parallel with low infiltration/high runoff. Furthermore, heavy precipitation is the triggering factor for these cases; exposed assets in the affected areas might drive the damage to a bigger extent in small catchments. The flooded regions that belong to Cluster 2 (FH03_02 and FH03_03, Appendix B, Table B.1) have a high share of urbanized areas in very small catchments. Yılmaz (2008) reported that livestock industry facilities and greenhouses comprise the main share of the urban areas in these catchments and were heavily affected by the November 1995 flood event in economic terms. This clustering information could be very useful for land use planning (such as planned urbanization, infrastructure improvement, and determination of cattle-shed/greenhouse area/type) and flood prevention studies (such as flood-zoning) (Hudson and Botzen, 2019), in terms of defining the hazard pathway (Figure 3.9 and Table 3.5) to reduce the flood risk. İzmir and Isparta provinces (Figure 3.2) were also affected by the same flood event (FH03_01 and FH03_04, Appendix B, Table B.1); however, due to their lower share of urban area (UA-FH03_01 = 25.93% and UA-FH03_04 = 14.35%, Appendix B, Table B.1), UA factors were not defined as the main aggravating mechanisms for these cases and they were grouped into Cluster 6.

Very high infiltration numbers (mean IN = 8.00 km/km^2) and thus the topography was determined as the main aggravating factor for Cluster 3. The June 1988 flood event (FH14_01, Appendix B, Table B.1) was selected as representative for this cluster due to its parameter values, which are close to the sample average values of Cluster 3. Although the catchments in Cluster 3 have dry pre-conditions (mean ASM = 0%), a high topographic factor (IN) in combination with high rainfall intensity (Özdemir and Bozyurt, 2003; Akyar, 2018) caused the flood event in Ankara (Figure 3.2). All cases in Cluster 3 are located in Central and Eastern Anatolia (Figure 3.2 and 3.9, and Appendix B, Table B.1), where flash floods in spring and summer are dominant due to sudden elevation changes over short distances.

Cluster 4's definition indicates that these events were triggered mainly by heavy rainfall (mean PREC = 133.36 mm/day) despite good infiltration rates of the soils (mean IR = 64.62%). When the related literature was analyzed for Cluster 4, heavy rainfall which was much higher than the seasonal averages was identified as the main triggering factor for FH06_03 (Appendix B, Table B.1) (Şahinalp, 2007). Similarly, Kömüşçü (2011) and NOAA (2009) indicated that FH08_01 and FH08_02 events (Appendix B, Table B.1) were triggered by two full days of torrential rainfall, which was the highest amount in 80 years. Another case in Cluster 4, FH17_03 (Appendix B, Table B.1), was also triggered by large-scale heavy rainfall which affected all of Turkey and the Balkans according to a NOAA report (NOAA, 2006) and newspaper archives (Anonymous, 2006a,c,e,b,d). Yılmaz (2008) reported that the December 1997 Antalya flood event (Figure 3.2 and FH22_01 in Appendix B, Table B.1) was triggered by orographic heavy rainfall as well, which is also grouped into Cluster 4. Event definitions in the related literature verify and show obvious consistency with cluster results, therefore the main triggering mechanism for Cluster 4 was determined to be heavy rainfall. When the cases in this cluster were analyzed in terms of ACP types, BM (high pressure bridge over Central Europe) dominates the ACPs for Cluster 4. As also presented in Section 3.3.1, it is possible to interpret the BM (high pressure bridge over Central Europe) as playing an important role as a rainfall-producing circulation pattern type in Turkey.

According to the cluster analysis, saturated soil conditions were identified as the main aggravating factor for Cluster 5. To cross-check the consistency of the results, the related literature was analyzed. Artan (1997) indicated that the December 1968 flood event (FH01_01 and FH01_02, Cluster 5, Appendix B, Table B.1) was triggered by a month of precipitation, which caused saturated soil conditions before the event. Similarly, when the literature on the FH05_01 and FH05_04 cases (Appendix B, Table B.1, Cluster 5) are analyzed, it is possible to see that these events also comprised three days of orographic rainfall mainly caused by a frontal system that was brought about by northerner cold and southerner hot weather conditions (Yüksek et al., 2013). Due to the saturated conditions, debris flow was also caused in these regions (Yüksek et al., 2013). FH06_10, FH12_01, FH12_02, FH16_01, and FH19_03 (Appendix B, Table B.1, Cluster 5) cases were also aggravated by saturated soil conditions due to prolonged rainfall. Batman province (Figure 3.2, FH06_10) was heavily affected by heavy rainfall, which continued for six days (Şahinalp, 2007). Kahramanmaras and Bingöl provinces (Figure 3.2, FH12_01 and

FH12_02) were flooded due to the three-day prolonged torrential rainfall (Sunkar and Denizdurduran, 2015). Similarly, Samsun province (Figure 3.2, FH16_01) was affected by heavy rainfall, which continued for three days as well (Bahadır, 2014). Ceylan et al. (2007) and Cellek (2020) indicated that prolonged rainfall occurred before the May 1998 Bartin flood event (Figure 3.2, FH19_01), which caused saturated soil conditions and an increase of Bartin Creek water levels. ASM values in each case (Table B.1, ASM) and also the mean ASM value (mean ASM = 92.26%) of Cluster 5 are consistent with the literature: high antecedent soil moisture based on prolonged rainfall can be determined as a pathway, and a new rainfall event over highly saturated soil conditions can be determined as the source and main triggering factor behind the flood events.

Cluster 6 contains many cases (n = 55) and each of them has different characteristics. Summer flash floods dominate Cluster 6 (n = 28, Appendix B, Table B.1). No dominant aggravating factor could be identified for this cluster. However, when the cases were mapped, it was revealed that Cluster 6 comprises mainly large-scale events in terms of affected areas. Each event in Cluster 6 caused floods in more than one sub-basin in different geographic regions in Turkey (see Figure 3.2 and 3.9). Different characteristics (e.g., region, flood type, and clustered parameters) and a wide range of spatial distributions based on geographic region can be interpreted to conclude that Cluster 6 events were triggered by comparatively larger-scale atmospheric circulations that affect larger areas regardless of region, topography, or land use properties. Nevertheless, the spatial distribution of the events in Cluster 6 shows consistency with the mountain ranges of Turkey (Figure 3.5 and 3.9). The orographic barrier effects in the northern, southern, and eastern parts of Turkey due to the Pontides, Taurides, and East Anatolian Mountain Ranges are the main influencing factor for severe flood events in these regions (Yılmaz, 2008; Yüksek et al., 2013; Turgut, 2007). Another interesting outcome for the Cluster 6 event analysis is that sudden snowmelt is the main influencing mechanism for all the cases located throughout the Eastern Anatolian Mountain Ranges (Eastern and Southeastern Anatolia and Eastern Black Sea regions, Figure 3.2 and 3.5) (n = 11), and these cases occurred in spring/summer. Since both TSMS and ERA5 rainfall data include the snowfall amounts in water equivalents (MGM, 2019d; ECMWF, 2019), the cluster results do not reflect the direct impact of sudden snowmelt. Therefore, this information was obtained from the related literature (Ceylan et al., 2007; NOAA, 2004; Buldur et al., 2007; Istanbul Metropolitan Municipality, 2007; Avcı and Sunkar, 2015).

When the clustering results were compared with the previous studies based on atmospheric circulation and precipitation pattern classifications in Turkey (e.g., Türkeş and Tatlı (2011); Sariş et al. (2010)), Cluster 2 is in accordance with the Southern Aegean and Western Mediterranean (SAEG-WMED) precipitation region based on Türkeş and Tatlı (2011)'s classification, which affects particularly the coastal regions in the western Mediterranean. Cluster 3 shows consistency with the East Continental Central Anatolia (ECCAN) precipitation region, which influences continental central Anatolia with convective events. Based on Türkeş and Tatlı (2011)'s classification, Cluster 6 comprises the Black Sea (BLS), Continental Eastern and Southeastern Anatolia (CEAN-CSEAN), and Mediterranean (MED) precipitation regions, which were triggered by orographic lifting over the Taurus, East Anatolian and North Anatolian Mountain Ranges (see Figure 3.5 and 3.9). Clusters 1, 4, and 5 do not show direct consistency with Türkeş and Tatlı (2011)'s classification results. When the results were compared with the classification proposed by Sariş et al. (2010), Cluster 3 was in accordance with the Inland Regimes class, which was defined as a rainy spring period and characteristic convective rains (Sariş et al., 2010). Cluster 6 shows consistency with the Coastal Regimes class, which was defined as being consistently controlled by cyclogenesis and orographic rains (Sariş et al., 2010). The other clusters cannot be directly linked with the classification by Sariş et al. (2010). Since these classifications are only based on precipitation data, aggravating factors such as topography, urbanization, or drainage properties cannot be reflected.

The cluster results also give important information about the Source–Pathway–Receptor– Consequence (SPRC) model elements of the flood hazards in Turkey, which are summarized in Table 3.6.

While the results of Clusters 1, 2, 3, and 5 give information about the pathways of the flood events that aggravate the consequences, the results of Clusters 4 and 6 reflect the sources of the events and do not provide clear information about the pathways. Consequently, the main triggering mechanisms for Clusters 1, 2, 3, and 5 can be characterized by their different aggravating pathways.

Table 3.6: Source–Pathway–Receptor–Consequence (SPRC) model elements of the clusters.

Cluster	Source	Pathway	Receptor	Damage
1	ACP (SWZ/WZ) Frontal (Cyclonic) rainfall	**Catchment properties**		
2	Frontal (Cyclonic) rainfall	**Land use properties (high share of urbanized area)**		
3	Convective rainfall	**Topography**	People Settlement properties Business organizations	Human loss, health impacts Economic loss, property damage
4	**ACP (BM)** **Frontal (Cyclonic) rainfall**	-		
5	Frontal (Cyclonic) rainfall	**High antecedent soil moisture**		
6	**ACP** **Orographic rainfall** **Sudden snowmelt**	-		

Bold indicates the SPRC model elements identified via cluster analysis.

3.5 Conclusions

In this study, the triggering mechanisms and aggravating pathways of the 25 most severe flood events in Turkey were analyzed in terms of the atmospheric circulation pattern types, precipitation patterns, and catchment properties (topography, catchment size, land use types, and soil properties). A new approach was developed to investigate which of these parameters were possibly the main influencing factors leading to the high flood impacts. For this methodology, eight parameters were determined and calculated. Then, these 25 events with 78 cases (i.e., affected areas) were classified via hierarchical cluster analysis using seven of these parameters. The ACP parameter was used as supportive information to the cluster results. As a result, six different clusters were identified and interpreted with regard to the dominant influencing factors of the floods within that cluster. The resulting implications and limitations can be summed up as follows:

- A structured approach to classify floods was designed, using parameters chosen based on their potential triggering and aggravation factors.

- All input variables were obtained and calculated from freely accessible data.

- According to the cluster analysis, six clusters were found based on their dominant flood-producing factors.

- Mapping the clusters also provided the opportunity to interpret the results better in terms of the spatial distribution of the triggering mechanisms and aggravating pathways based on region.

- Orographic rainfall and sudden snowmelt were important influencing factors for spring/summer floods in the regions that extend along the Eastern Anatolian Mountain Ranges.

- In central and eastern Anatolia, rapid elevation changes (slope gradient changes) over short distances aggravated the flood events. Geomorphological properties were the relevant factor for floods in these regions.

- The BM (high pressure bridge over Central Europe) circulation pattern type played an important role as a rainfall-producing mechanism, especially for autumn flash floods in Turkey.

- In small catchments, the share of urbanized areas seemed to be an important factor for the flood impacts, with its infiltration attenuation impact. Therefore, planned urbanization in the small catchment is of great importance for flood risk mitigation studies.

- Cluster results can be used as base information; clustering of the dominant flood-producing mechanisms can help hazard classification (source and pathway identification, in particular) in the preliminary risk assessment process.

- However, 25 events are only a small number of case studies and do not represent the entire variety of flood events and their triggering mechanisms. More detailed analyses with more case studies would be a useful next step in understanding the atmospheric circulation pattern impacts on flood events in Turkey. Furthermore, ASM parameter calculations are only based on precipitation and do not reflect the antecedent soil moisture due to underground water table levels or irrigation.

- UA and WB parameters should be calculated based on event day land-use data.

- Additional datasets (such as runoff volume, flood extent, and depth) can be integrated into the cluster analysis. This methodology can be improved with a detailed dataset on event-based calculations and can provide basic information for understanding the triggering mechanisms and aggravating pathways of the flood events.

This study investigated and clustered the direct or indirect relevance of atmospheric circulation, precipitation patterns, and catchment properties for the severe flood events and SPRC model elements of these events in Turkey, between 1960 and 2014. The spatial distribution of clusters gives important information about the dominant triggering mechanisms on the regional scale. The classification of the floods can be useful for selecting mitigation types. For example, structural mitigation studies on, e.g., floodplain and river restoration might be conducted in the catchments where drainage characteristics (e.g., Cluster 1) and topography (e.g., Cluster 3) are the main aggravating pathways. Existing infrastructure can be maintained (e.g., creek clearing, storm-water drainage systems, etc.) in the catchments where the share of urban area is high. Furthermore, the roads can be improved to provide better access to hospitals or evacuation areas in the case of a severe flood event, especially in urbanized areas (e.g., Cluster 2). In addition to structural mitigation studies, non-structural mitigation practices can be implemented: early warning systems or household emergency plans might be developed in the catchments where the events can be predicted periodically (e.g., sudden snowmelt during spring/summer in Eastern and Southeastern Anatolia, Cluster 6).

This study can be useful for event definition and classification in flood risk management studies in order to understand the main causal factors and aggravating pathways affecting the selection of suitable mitigation practices.

Chapter 4

Estimating Direct Economic Impacts of Severe Flood Events in Turkey (2015-2020)

Published as: Koç, G., Natho, S. and Thieken, A.H. (2021). 'Estimating Direct Economic Impacts of Severe Flood Events in Turkey (2015-2020)'. *International Journal of Disaster Risk Reduction* (58), 102222. doi: 10.1016/j.ijdrr.2021.102222.

4.1 Introduction

Flooding is one of the most destructive natural hazards in the world, causing US$ 651 billion in economic losses and over 100,000 fatalities, and affecting 1.6 billion people worldwide from 2000 to 2019 (CRED and UNDRR, 2020). In terms of event frequency, floods are only listed in sixth place in the Turkish Disaster Database (TABB) after wildfires, storms, earthquakes, landslides and extreme temperature (Koç and Thieken, 2018), yet have caused significant societal and economic impacts (e.g. Gürer and Uçar (2009); Öcal (2019); Kocaman et al. (2020)). Floods are the second most destructive natural hazard in Turkey after earthquakes in terms of human and economic losses (Özşahin, 2013; Koç and Thieken, 2018), which caused 795 fatalities and US$ 800 million in economic losses (based on inflation-adjusted losses) between 1960 and 2014 (Koç and Thieken, 2018). In order to prevent these huge flood losses, disaster risk management requires reliable estimates in advance, in terms of frequency and magnitude of potential flood events, as well as their economic damage (Nafari et al., 2017).

Estimating such economic flood impacts is important, since it provides crucial information for decision-making processes within flood risk management. Applications include an assessment and mapping of vulnerabilities and risks, decisions on cost-effective risk reduction measures, appraisals of the likely required compensation payments by the re-/insurance sector, coordination of (governmental) financial aid during and immediately after the floods, or prioritizing infrastructure restoration (Thieken, Ackermann, Elmer, Kreibich, Kuhlmann, Kunert, Maiwald, Merz, Müller, Piroth, Schwarz, Schwarze, Seifert and Seifert, 2008; Merz et al., 2010; Lindell, 2013; Yang et al., 2016). However, it is still difficult to accurately estimate the tangible damage of floods due to the complexity of the components, such as damage or complete destruction of buildings in various sectors, including housing contents, equipment, etc., which should also be considered within an accurate loss assessment model (Van der Veen, 2004; Merz et al., 2010; Prihantini, 2020). There are several studies in the literature for industrialized countries (i.e. Germany, France, Italy) (e.g. Thieken, Ackermann, Elmer, Kreibich, Kuhlmann, Kunert, Maiwald, Merz, Müller, Piroth, Schwarz, Schwarze, Seifert and Seifert (2008); Apel et al. (2009); Seifert et al. (2010); André et al. (2013); Naulin et al. (2016); Sieg et al. (2017); Natho and Thieken (2018); Sieg et al. (2019); Molinari et al. (2020)) that present detailed loss modelling of direct losses for different hazards (i.e. storm, flood, hail) and different sectors. However, the scale of losses still cannot be understood well in its full extent due to incomplete, inconsistent or unreported information (Van der Veen, 2004; Gall et al., 2009; Meyer et al., 2013; Gall and Kreft, 2013), or significant levels of uncertainty (Merz et al., 2010; Sieg et al., 2019; Molinari et al., 2020). Therefore, most of the studies focused on direct tangible losses (Merz et al., 2004; Natho and Thieken, 2018; Yang et al., 2018), which are possible to estimate using replacement costs of damaged assets that can be monetized.

With the signing of the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), United Nations (UN) member countries agreed to reduce direct economic disaster losses in relation to the global gross domestic product (GDP) by 2030 as one of the seven global SFDRR targets (Target C) (UNISDR, 2015c). To facilitate the monitoring of this target, UNDRR (formerly UNISDR - United Nations International Strategy for Disaster Reduction) proposed a methodology to estimate the direct economic losses from natural hazards (UNISDR, 2015a,b). This loss estimation method was adapted from the United Nations Economic Commission for Latin America and Caribbean – ECLAC model, and was tested with datasets from 82 developing countries (EC, 2014; UNISDR, 2015a). The main point of the UNDRR method is to provide a simple approach that allows administrations to consistently estimate direct economic losses for a wide range of disasters, after preliminary assessment of hazardous events based on documented physical damage (i.e. number of affected buildings, amount of destroyed agricultural area, number of livestock lost, etc.). Natho and Thieken (2018) implemented, adapted and calibrated this methodology for Germany (as model M-DELENAH), which was the first implementation of the method for an industrialized country, and extended a country-specific methodology to new sectors (i.e forestry, private transport, urban infrastructure). Although detailed survey data were used to adapt and extend the method, it was concluded that: i) the UNDRR method underestimates the losses in general, ii) loss documentation even in industrialized countries needs to be improved to fill the data gaps and iii) more case studies are necessary to test the method including adaptations and extensions (Natho and Thieken, 2018). Recently, Molinari et al. (2020) compared the model performance of nine different micro-scale damage models for direct flood damage estimation of the residential sector in an Italian case study, and the results revealed great differences between these nine micro-scale models. In the study, it was also indicated that the estimation error by the lump-sum model, M-DELENAH, (see Natho and Thieken (2018)) is comparable to or lower than that of the micro-scale models (Molinari et al., 2020). Thus, macro-scale damage models can provide reasonable estimations in the right order of magnitude, which makes them particularly valuable for estimating losses from recent damaging events. However, this requires validity of the model, although validating loss models is rarely undertaken (e.g. Gerl et al. (2016)).

Due to the data gaps present in loss documentation, it is quite challenging to find well-documented events in national databases that allow researchers to apply a good loss estimation approach. Even though Turkey has made good progress in terms of improving its national loss database (TABB - Turkish Disaster Database) between 2013 and 2015 (UNISDR, 2015b), considerable parts of the TABB dataset are still incomplete or missing. With regard to physical loss indicators, which are needed for the UNDRR model, for instance, 84.6% of the "number of damaged buildings" indicator is incomplete in the TABB database. Similarly, the share of missing values for the "number of destroyed buildings", "total damage (Turkish Lira – TL)", "destroyed agricultural area (ha)" and "cattle loss" indicators are 99.2%, 98.1%, 98.9% and 99.7%, respectively (Koç and Thieken, 2018).

To analyse the flood event documentation in Turkey, Koç and Thieken (2018) presented a comparative study on different loss databases (i.e. TABB, EM-DAT, Dartmouth) and compiled a list of the 25 most severe flood events for Turkey. However, the study showed that there are significant mismatches between different loss databases in terms of economic losses. Reasons for this incompleteness are manifold, such as the different entry criteria of various loss databases.

Koç et al. (2020) focused on the triggering mechanisms (i.e. atmospheric circulations, event-day precipitation, etc.) of those 25 severe floods compiled by Koç and Thieken (2018). Among other things, it was revealed that the list is biased since it was retrieved only based on recorded impacts, and there are severe floods missing that were not documented by loss databases but were mentioned in news archives and reported by the Turkish State Meteorological Service (MGM, 2020). Within the frequency analysis of the flood-triggering circulation pattern types, daily total precipitations of the severe floods were classified (Figure 4.1). It was discovered that the five heaviest precipitation events were not listed in the 25 severe floods list due to missing information on the impacts (Figure 4.1). This finding challenges bottom-up modelling approaches and underlines the need for a consistent event and loss documentation. Incompatibilities between documented loss databases, hydrometeorological datasets (i.e. precipitation) and grey literature, such as reports by the Turkish State Meteorological Service or newspaper archives, reveal the urgent need for a consistent event and loss documentation.

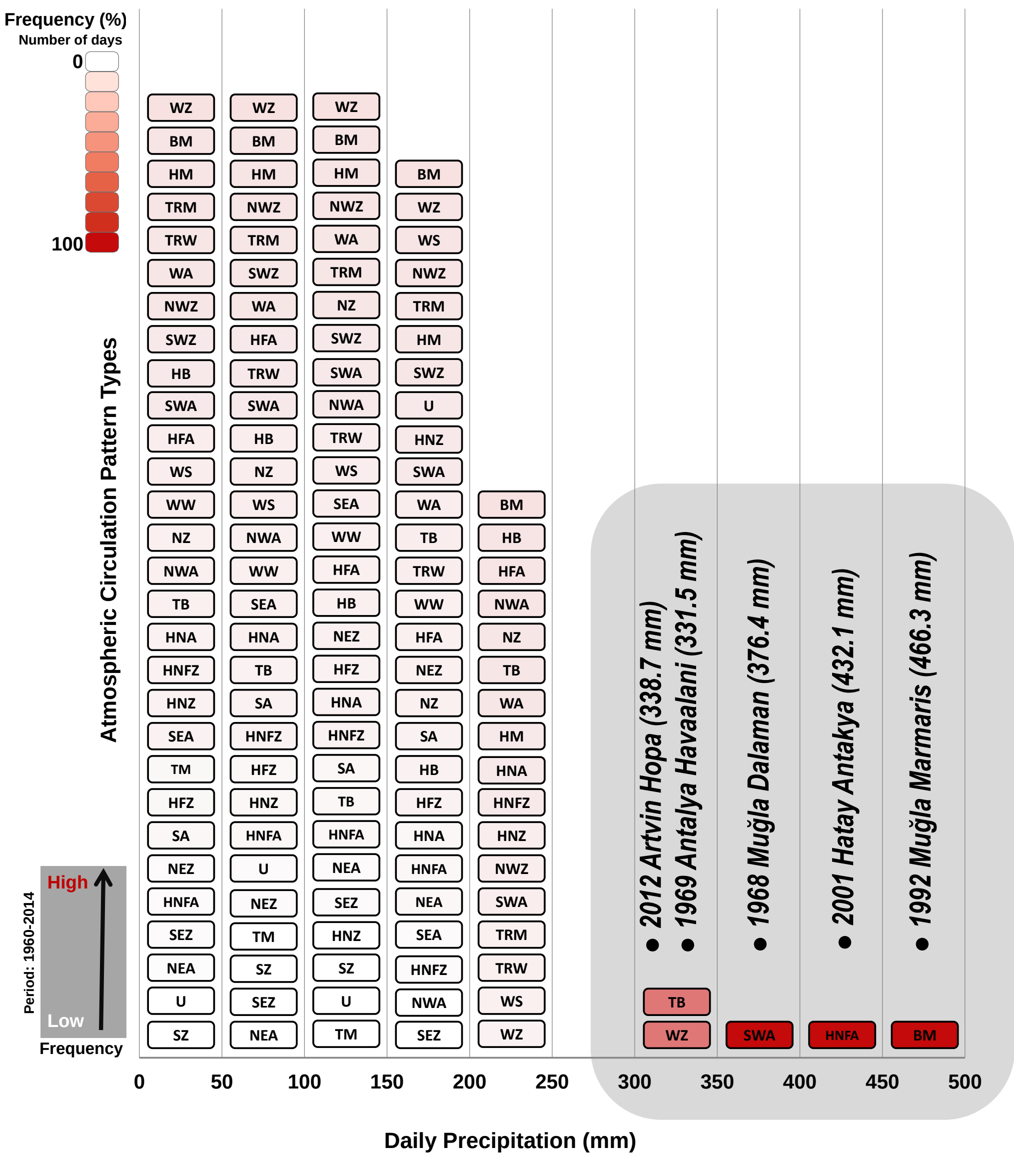


Figure 4.1: Missing documented severe floods in Turkey (highlighted in grey) in circulation pattern frequency analyses between 1960 and 2014 (created based on Koç et al. (2020)). Abbreviations represent the circulation pattern types based on Hess and Brezowsky's circulation pattern catalogue (Hess and Brezowsky, 1977); full names are given in Appendix C, Table C.1.

As one of the 187 United Nations (UN) members, Turkey signed the SFDRR and aimed to improve the national loss databases and reduce the direct economic losses due to natural hazards in Turkey by 2030. Therefore, our motivation is to propose recommendations to enhance the flood loss documentation by calibrating, validating and applying the UNDRR loss estimation method for the first time in Turkey. This includes the provision of loss estimates for recent (2018–2020) damaging events. Hence, we aim to provide a consistent flood loss estimation model for Turkey to fill data gaps in the loss documentation and to estimate losses as quickly as possible after events for a better coordination of financial aid. Ultimately, this also contributes to an improvement of recovery decisions in Turkey.

4.2 Method: Implementation of the loss estimation model

The macro-scale loss model used in this study was proposed by UNISDR (2015a, 2017b); it is structured based on the collection and use of simple and uniform physical damage indicators (e.g. number of damaged assets) as a starting point. The physically damaged or destroyed units are transformed into economic losses by considering the average unit size of the assets, unit replacement costs and typical damage ratios. Damage ratios (d) are defined as the financial loss in relation to the total asset value of the damaged premise before the damage occurred (with d = 100% or 1, being totally damaged or destroyed) (UNISDR, 2015a). The UNISDR (2015a) approach estimates the total economic loss as the sum of direct economic losses in the sectors of agriculture (as the sum of crop loss (C2-1) and livestock loss (C2-2)), industry (C3), commerce (C4), housing (damaged (C5) and destroyed (C6)) and critical/public infrastructure (C7 – as the sum of health (D2), educational facilities (D3) and roads (D4), see Figure 4.2).

In the simplest version of the model, where the average size of the facilities is assumed to be the same for all sectors, the loss of each sector C3, C4, C5, C6, D2 and D3 is formulated as:

$$\text{Direct loss} = N \times S \times C \times d \tag{4.1}$$

where S is the average size of the premises (m^2), C is the (re)construction cost per unit area (m^2), d is the average damage ratio (d = 1 for C6) and N is the event-specific variable number of damaged or destroyed premises (or units), which is the only model parameter derived from the event documentation.

The total direct economic loss (C1) is defined by the equation:

$$C1 = C2 + C3 + C4 + C5 + C6 + C7 \tag{4.2}$$

where

$$\begin{aligned} C2 &= C2\text{-}1 + C2\text{-}2 \text{ and} \\ C7 &= D2 + D3 + D4 \end{aligned} \tag{4.3}$$

For the industry (C3), commerce (C4) and housing (C5, C6) sectors, as well as health (D2) and educational facilities (D3), the parameter N refers to the number of damaged buildings (or destroyed residential buildings in C6). For the housing sector (C5, C6), the parameter N could refer to the number of individual apartments or entire buildings depending on the loss documentation. Event documentation should be carefully analysed, and when the damaged unit is reported as entire building, the average size of the total floor space should be considered. For transportation infrastructures (roads, D4), N refers to the length of damaged or destroyed units in kilometres (km). For the agriculture sector (C2-1), the event-specific variables of damaged or destroyed units are defined as the area in hectares (ha), and the cost parameter C is calculated by considering the average yield per ha (ton/ha) and the price per ton yield (monetary unit/ton). For livestock losses (C2-2), the number of livestock is considered by their average weight and average price per weight unit. The UNDRR method regards only four-legged animals such as cows, sheep, goats, etc. when calculating livestock loss. However, the poultry and apiculture sectors also play an important role in Turkey in terms of agricultural production (TEPGE, 2009; Burucu and Gülse Bal, 2017; GEKA, 2020; Kutlu and Kılıç, 2020; AgriculturalStat, 2020). Turkey takes sixth place for poultry exports and meets 2% of overall demand in the world (AgriculturalStat, 2020) for the poultry sector. Similarly, Turkey takes second place in the world for honey production at 17%, and the apiculture sector plays a considerable role in the local economy and rural development in Turkey (GEKA, 2020; Kutlu and Kılıç, 2020). Therefore, in this study two new modules for poultry (i.e. fowl) and apiculture (i.e. loss of bee hives) were implemented (Figure 4.2).

Poultry loss (C2-2-1) was calculated using an approach analogue to that used for cattle loss as suggested by UNISDR (2015b) and given in Equation 4.4, where N represents the number of poultry (i.e. turkey, duck, chicken, goose) lost, C is the average poultry price per kg (costs), and W is the average weight of the poultry (kg).

$$C2-2-1 = N \times C \times W \tag{4.4}$$

For apiculture loss (C2-2-2), the following formula was used:

$$C2-2-2 = N \times C \times Y \tag{4.5}$$

where N is the number of bee hives damaged, C is the average price of honey per kg (costs) and Y is the average yield per bee hive. Since honey prices per kg are calculated including the cost of bee hives (Özsayın and Karaman, 2018; TÜİK, 2020), only the yield value per bee-hive was considered for direct apicultural loss calculations.

In the study, we were able to calculate the direct losses for educational facilities (D3) and the transportation infrastructures (roads, D4) from the critical-public infrastructure module (C7) (Figure 4.2). Direct losses for educational facilities (D3) were calculated by an approach analogue to that for the commercial (C4) and residential (C5 and C6) sectors (see Equation 4.1). Loss of roads (D4) was calculated

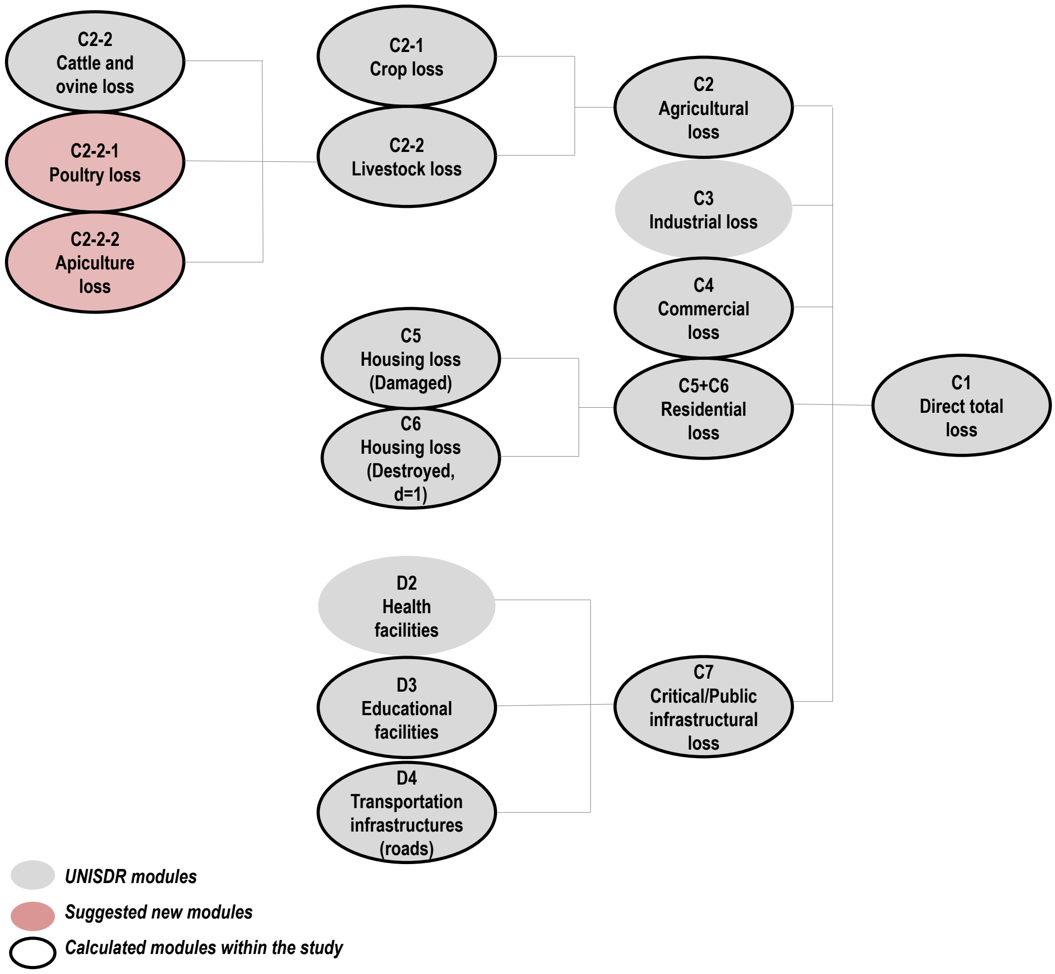


Figure 4.2: Conceptualized UNDRR loss model diagram and suggested/calculated new modules.

via the following equation:

$$D4 = N \times C \tag{4.6}$$

where N is the number of kilometres affected and C is the average reconstruction cost per kilometre.

For model applications, UNISDR (2015a) proposed the following procedure:

- Collect good-quality data, ideally disaggregated, on physical damage per hazardous event.
- Apply replacement cost per unit to estimate economic value
- Convert the economic value from the one expressed in national currency into

the one expressed in US dollars

Following these recommendations, all calculations were carried out in the national currency (Turkish Lira – TL) and at the end of the calculations the results were converted to US$ for facilitating the comparison at the international level.

In order to provide a consistent direct loss estimation, either crop output, average livestock prices or (re)construction costs have to be scaled to a common reference year or the event date (depending on the use context of the loss estimates), since costs change in time due to inflation. In this study, we used event date process and exchange rates.

To estimate the direct economic losses due to floods in Turkey, we implemented the UNDRR model in a three-step process:

i. **Calibration** of damage ratios per sector based on country-specific values with a well-documented flood event

ii. **Validation** of the calibrated model and comparison with other model variants

iii. **Application** of the best model variant to recent floods events

4.2.1 Calibration

Damage ratios are important input parameters that might change with different sectors, different natural hazards or the severity of the events (Thieken, Ackermann, Elmer, Kreibich, Kuhlmann, Kunert, Maiwald, Merz, Müller, Piroth, Schwarz, Schwarze, Seifert and Seifert, 2008) and influence the model performance directly (Natho and Thieken, 2018). Therefore, we first started setting up the model with country-specific values for all model parameters, including a calibration of the damage ratios (calibrated model). Within the study, we used a well-documented flood event (the 2016 Mersin flood event, explained in more detail in Section 3) to individually calibrate the damage ratios for the agricultural (C2), commercial (C4) and residential sectors (C5), as well as educational facilities (D3). In order to calibrate the damage ratios, we were able to use country-specific event day or reference season information for the affected locations provided by the governmental institutions in Turkey (i.e. Official Gazzette (2001); TİGEM (2017); Deryol (2019); TÜİK (2020); Tarım Kütüphanesi (2020); Çiftçi (2020)).

By using Equation 4.1, the damage ratios were calibrated for crop losses (C2-1) and for greenhouses. For these calculations, documented destroyed agricultural areas (ha) or greenhouses (ha) were used as N, average yield per unit area (ton/ha) information was used as S, and average crop output per unit area (TL/ha) information was used as C parameters. Finally, the documented economic losses (TL) were used as direct losses and the damage ratios (d) were calibrated for agricultural areas and greenhouses.

In order to calibrate the damage ratios for commercial (C4), residential (C5) and educational (D3) sectors, a similar approach was used. The documented numbers of damaged buildings were used as N for each sector, the average size of the buildings (m^2) for each sector were used as S, and the average construction cost of the buildings (TL/m^2) for each sector were used as C parameters in Equation 4.1. The documented economic losses (TL) were used as direct losses and the damage ratios (d) were calibrated for commercial (C4), residential (C5) and educational (D3) sectors.

4.2.2 Validation

In the second step, we validated the calibrated model for the events for which total monetary losses and physical losses were documented. In order to find the best model, we compared three different model variants:

a. The UNDRR reference values with a uniform damage ratio (d = 0.25)

b. Country-specific values and a uniform damage ratio (d = 0.25) suggested by UNISDR (2015a), and

c. Country-specific values and calibrated damage ratios from Step 1 (Section 4.2.1)

4.2.2.1 Validation with the UNDRR reference values

The basic version of the UNDRR method (UNISDR, 2015a) was implemented for the three events (2015 Artvin, 2019 Düzce (only for crop loss (C2-1) module), and 2020 Rize events, explained in more detailed in Section 3). For the reference damage ratio (d = 0.25) and the unit replacements costs (i.e. crop output, reconstruction costs of the buildings (for commercial, residential sectors and educational facilities, rehabilitation cost of the roads)), the values suggested by the UNISDR (2015a) were considered.

All parameters suggested by UNISDR (2015a) were converted from US$ to Turkish Lira (TL) using event day exchange rates in order to eliminate confusion between UNDRR references and documented losses during the calculations.

4.2.2.2 Validation with the country-specific values and a uniform damage ratio

The second variant of the validation was carried out by following the same steps in Section 4.2.2.1 for each sector. Instead of UNDRR reference parameters, country-specific parameters were used for calculations, but still the uniform damage ratio (d = 0.25) was used for all sectors. With this approach, the aim was to compare the fixed and calibrated damage ratios in order to find the best model variant.

4.2.2.3 Validation with country-specific values and calibrated damage ratios

Finally, the calibrated model was verified with country-specific parameters and the calibrated damage ratios from Step 1 (hereafter called the ‘adapted model’) for the three validation events.

In order to identify the best model option for the application, the root mean square error (RMSE) of each variant was calculated.

4.2.3 Application

The model that performed best in the validation was used to estimate direct economic losses (C1) for flood events that recently occurred in Turkey that have documented physical losses for different sectors, but no economic loss information has been provided so far.

4.3 Data

4.3.1 Severe flood events in Turkey (2015–2020)

Eight severe flood events between January 2015 and August 2020 were used to test the UNDRR economic loss estimation method (Figure 4.3). Between 2015 and 2019, the most severe event for each year was selected based on national and international reports (i.e. AFAD, Munich Re) considering the availability of physical damage documentation and cross-checked with international databases (i.e. EM-DAT, Dartmouth) or news archives. Very recently, in the summer of 2020, three severe flood events occurred one month apart and were given wide national and international media coverage (see Appendix C, Table C.3 for sources); they were used to either validate the model or apply the adapted model. In the study, we only considered the single-hazard flood events. Multi-hazard events (also known as cascade events, compound events, coupled events or domino effects (Kappes et al., 2012; Gill and Malamud, 2014); that were triggered by a flood event and eventuated in landslides or rock falls were not considered due to biased event documentation per single-hazard type.

The 2016 Mersin case study was used to calibrate the model, particularly the damage ratios for the agricultural (C2-1), commercial (C3) and residential (C5) sectors, as well as the educational facilities (D3), since both physical damage and economic losses were documented separately for each sector in a report from a state media source (Turkish Radio and Television Corporation – TRT).

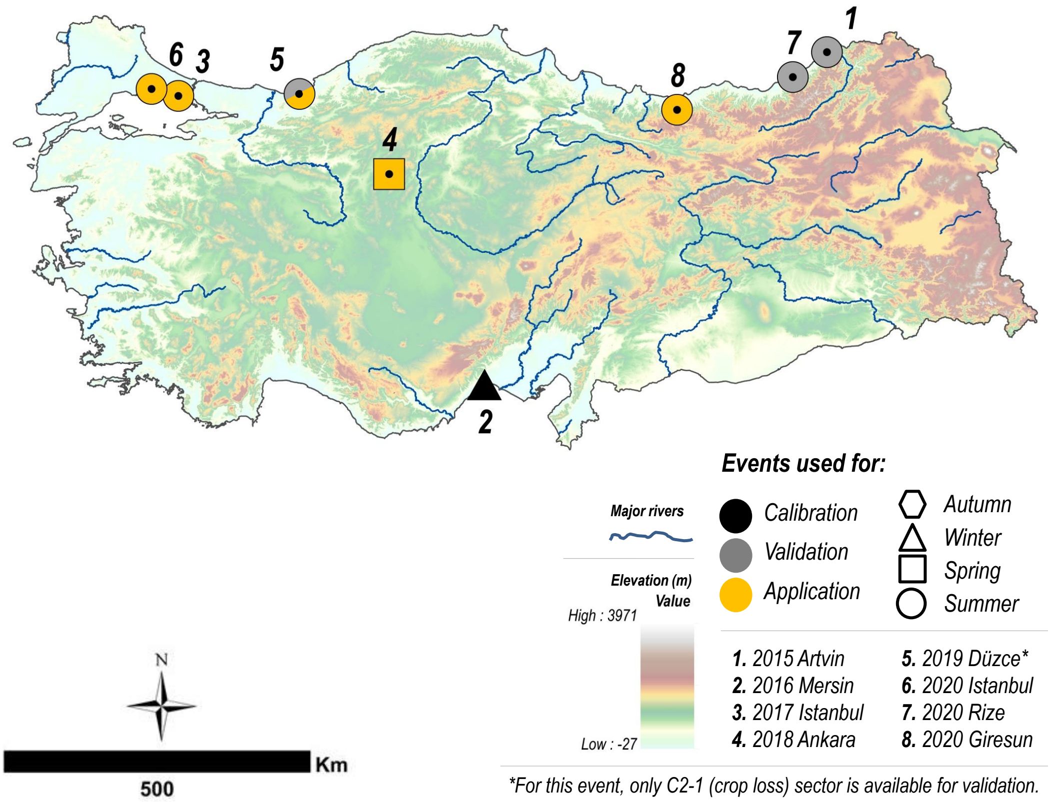


Figure 4.3: Site location map of considered case studies.

The 2015 Artvin and 2020 Rize events were used to validate the model, since overall losses were documented for these events. In the case of the 2019 Düzce event, only crop losses (C2-1) could be verified, since the financial loss was only reported for this sector (Figure 4.3, Figure 4.4 and Appendix C, Table C.2).

All other cases (i.e. 2017 Istanbul, 2018 Ankara, 2019 Düzce (for livestock loss (C2-2), residential sector (C5 and C6) and transportation infrastructure (D4)), 2020 Istanbul and 2020 Giresun) were used for the model application (Step 3, Section 4.2.3) to provide initial direct economic loss estimates (Figure 4.4).

For all selected case studies, we were able to apply the UNDRR method for the residential sector (Figure 4.4). In six cases, information about damage to commercial facilities was available, and in three cases agricultural losses were reported (Appendix C, Table C.2). Occasionally, data on damage to educational facilities and transportation infrastructure (roads) were available, too (Appendix C, Table C.2).

Events	Sectors							
	C2 Agriculture				C4 Commercial	C5/C6 Residential	C7 Critical/Public Infrastructure	
	C2-1 Crop loss	C2-2 Livestock loss					D3 Educational facilities	D4 Transportation Infrastructures (roads)
		Cattle & Ovine	C2-2-1 Poultry	C2-2-2 Apiculture				
2015 Artvin					Validation	Validation	Validation	
2016 Mersin	Calibration	Calibration	Calibration	Calibration	Calibration	Calibration	Calibration	
2017 Istanbul						Application		
2018 Ankara					Application	Application		
2019 Düzce	Validation	Application	Application	Application		Application		Application
2020 Istanbul					Application	Application		
2020 Rize					Validation	Validation		
2020 Giresun		Application			Application	Application		Application

Case studies/sectors used for: ● Calibration ● Validation ● Application

Figure 4.4: General view of available data for each sector and the considered case studies.

4.3.2 Model parameters and input data

In the study, direct economic losses were estimated using the replacement costs of damaged assets that can be monetized. Accordingly, both the UNDRR reference parameters and newly derived country-specific parameters were used and compared.

4.3.2.1 The UNDRR reference parameters

The UNDRR proposes the collection and use of simple and uniform physical indicators of damage (counts of assets affected) in the beginning, instead of requesting countries to directly evaluate the economic values of direct losses. For the countries for which these economic values of assets are not available, the UNDRR suggests reference parameters that are extrapolated prices using a set of regressions of known processes against GDP per capita (UNISDR, 2015a).

Agricultural sector: For the agricultural sector, the FAO (2020) nation-wide dataset – suggested by the UNISDR (2015a) – was used to obtain crop output information. IMF (2020) and World Bank (2020a) statistics were used for average yield information (Appendix C, Table C.4). For livestock loss calculation, average livestock prices between 2015 and 2019 were obtained from the FAO (2020) dataset and 2020 prices were obtained from the European Commission Food, Farming and Fisheries dataset (EC, 2020). The UNISDR (2015a) reference value (75 kg) was used for the average livestock weight (Appendix C, Table C.4). Since UNISDR (2015a) references neglect poultry and apicultural losses, only cattle and ovine losses were included in the calculations.

Commercial sector: For the commercial sector, the average size of facilities (S) was considered to be 25 m^2 as suggested by the UNISDR (2015a) and the average construction cost (C) per unit area was calculated using the following equation:

$$C = 304 + 0.0118 \times \text{Gross Domestic Product (GDP) per capita} \tag{4.7}$$

Equation 4.7 was derived from the statistical regression produced using the correlation between construction cost per unit area (US$/$m^2$) and GDP per capita (US$). This equation was calculated using data from 85 countries and is suggested to be applied to all types of facilities (nation-wide) (i.e. commercial, residential, educational and health facilities) in case construction costs cannot be obtained for each sector (UNISDR, 2015a).

Since the GDP changes over time, construction costs were calculated by considering the event year GDP for all case studies (Appendix C, Table C.5) within the study.

Residential sector: The average size of the residential facilities (S) was considered to be 45 m^2 and the average construction cost (C) per unit area was calculated by Equation 4.7 as suggested by UNISDR (2015a) (Appendix C, Table C.6). The damage ratio was considered to be 0.25 for damaged facilities (C5) and 1 for destroyed facilities (C6) (UNISDR, 2015a).

Since some of the physical damage to residential facilities was documented as buildings (entire building, not single flats), the average number of flats on each floor from Çiftçi (2020) was also considered (Appendix C, Table C.6).

Critical/Public infrastructure sector: The average size of educational facilities was considered to be 60 m^2 and the average construction cost (C) per unit area was calculated by Equation 4.7 (Appendix C, Table C.7).

Average reconstruction costs for roads were derived from the ROCKS (2018) dataset as suggested by UNISDR (2015a). For the events considered, there was no information on the share of paved/unpaved roads. Therefore, average costs were considered.

4.3.2.2 Country-specific parameters

The governmental institutions in Turkey (i.e. Turkish Statistical Institute - TÜIK, Republic of Turkey Presidency of Revenue Administration – GIB) offer a wide range of publicly accessible statistics for many subjects (e.g. agriculture, industry, inflation and prices, population and demography, construction and housing, etc.) on different scales, such as by province or district. Therefore, for this study we were able to access the event day information (i.e. crop output, yield prices, livestock prices, construction costs, average size of the facilities) for affected locations on the premises.

Agricultural sector: For the agricultural sector, we were able to access and use the TÜIK dataset for event day information in terms of crop output, yield prices and livestock prices for the affected regions (Appendix C, Table C.4).

For the average weight of each livestock type (i.e. cattle, ovine, poultry), we considered the Ministry of Agriculture reports on livestock in Turkey (TİGEM, 2017; Tarım Kütüphanesi, 2020) (Appendix C, Table C.4).

Commercial sector: For the commercial sector, we considered a recent study on the financial conditions of commercial properties by Deryol (2019) to determine the average size of commercial facilities in Turkey from 2015 to 2020 (Appendix C, Table C.5).

Residential sector: In the study, the average size of houses was considered to be 141.9 m^2 and the average number of flats on each floor was considered as 4.2 based on a very recent study on long-term projections (1964–2019) by Çiftçi (2020) (Appendix C, Table C.6).

Critical/Public infrastructure sector: The average size of educational facilities was assumed to be 12,571.4 m^2 based on regulations on the principles of construction planning in Turkey (Official Gazzette, 2001) (Appendix C, Table C.7).

Average reconstruction costs for roads were derived from the General Directorate for Highways (KGM, 2020) dataset (Appendix C, Table C.7). The average costs were also considered for the country-specific values, since there was no information on the share of paved/unpaved roads.

For the average construction costs of the premises, annual price reports for each sector (commercial, residential and educational facilities) provided by the Republic of Turkey Presidency of Revenue Administration (GİB, 2020) were used. Since these reports were quite detailed for each sector and year, we were able to use the reference year construction cost per unit area for each sector (Appendix C, Tables C.5-C.7).

4.4 Results

Results of the calibration, validation and application are presented in the following sections.

4.4.1 Damage ratio calibration

A calibration of damage ratios for agricultural (C2), commercial (C4) and residential sectors (C5) and educational facilities (D3) was carried out with the 2016 Mersin flood event data. Damage ratios were calculated as 0.34 for crop loss and 0.09 for greenhouses. For commercial, residential and educational facilities, damage ratios were derived as 0.32, 0.04 and 0.01, respectively (Table 4.1).

Based on the calibration results, Table 4.1 shows that damage ratios for crop loss and commercial sectors are higher than the average damage ratios of 0.25 suggested by UNISDR (2015a). In contrast, calibrated damage ratios for greenhouses, the residential sector and educational facilities are considerably lower illustrating the huge range and diversity of this model parameter.

Table 4.1: Calibrated damage ratios based on the 2016 Mersin flood event and country-specific model parameters.

	Agriculture (C2-1)		**Commercial**	**Residential**	**Educational**
	Crop loss	Greenhouse	**(C4)**	**(C5)**	**facilities (D3)**
Damage ratio (d)	0.34	0.09	0.32	0.04	0.01

4.4.2 Model validation

To investigate the model performance, three model variants were applied to three events: Artvin (2015), Düzce (2019) and Rize (2020) (see Section 4.3.1, Figure 4.4). The results are depicted in Figure 4.5.

When documented and calculated losses are compared, the model with the UNISDR (2015a) reference values mostly underestimates the losses, due to the lower average size of the facilities as well as the lower average size of the live-stock. However, for the 2019 Düzce event, the model with country-specific values and the uniform damage ratio (d = 0.25) underestimates the losses more (Figure 4.5), due to lower average yield per ha and lower average crop output (Appendix C, Table C.4).

According to the adapted model, direct economic losses for the 2015 Artvin, 2019 Düzce (only for sector C2-1) and 2020 Rize events were calculated as 13.05 million TL, 5.12 million TL and 11.68 million TL, respectively, whereas their documented losses were reported as 15 million TL, 5 million TL and 12 million TL (Figure 4.5).

In comparison to the 2019 Düzce and 2020 Rize flood events, the 2015 Artvin flood loss result has a higher error. Among the three model variants, the adapted model delivered the best results with the lowest error (RMSE = 1.14, Figure 4.5). Hence, this model variant was used for further applications.

4.4.3 Model application and comparison

The direct economic losses were estimated for five events (i.e. Istanbul (2017, 2020), Ankara (2018), Düzce (2019) and Giresun (2020); see Figure 4.3, Figure 4.4)

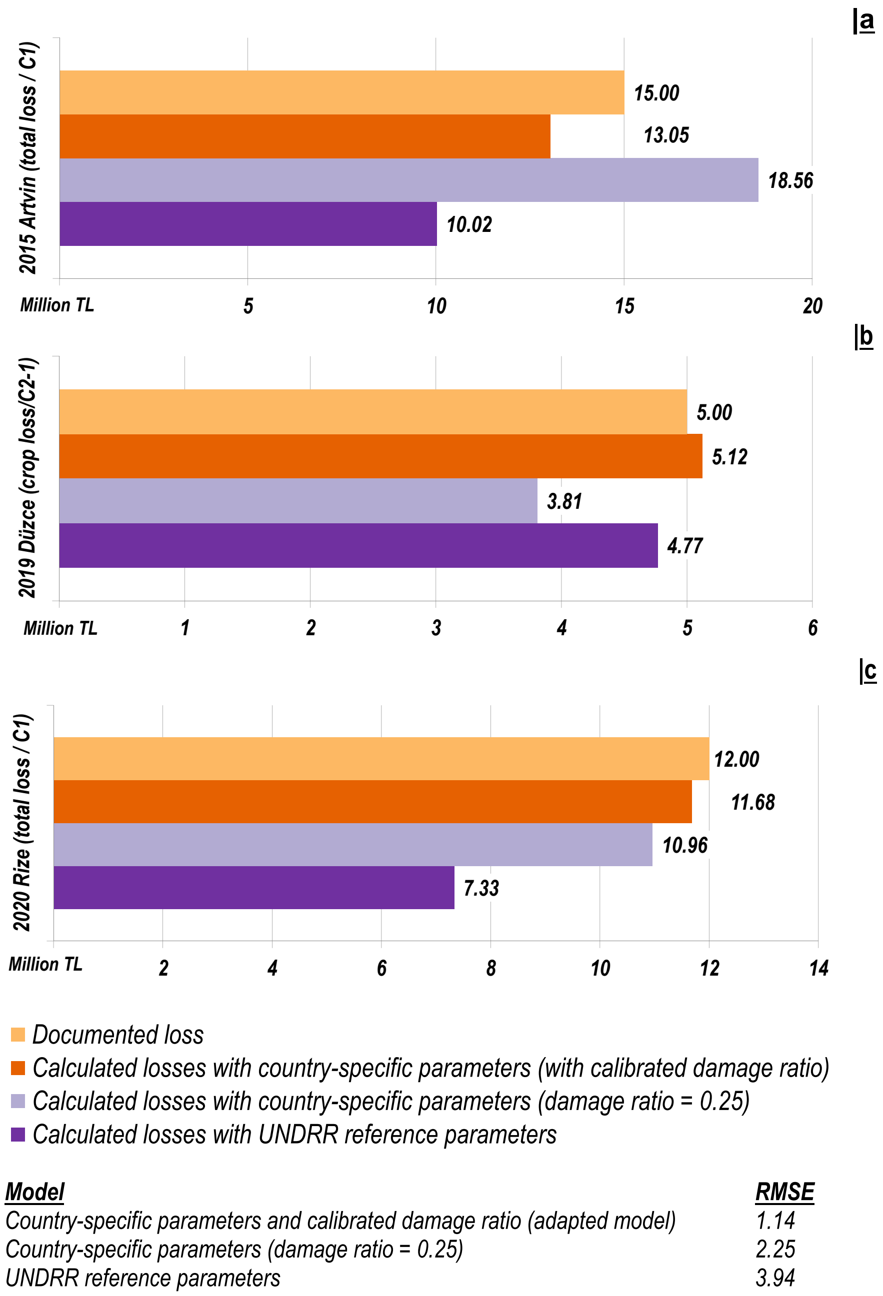


Figure 4.5: Case studies used for validation and comparison of documented and calculated losses: a) for the 2015 Artvin flood, b) for the 2019 Düzce flood (only for crop losses) and c) for the 2020 Rize flood.

based on the documented number of damaged facilities with the calibrated model using country-specific parameters (adapted model). Hence, the highest losses were obtained for the 2020 Giresun flood event at 94.19 million TL, followed by the 2019 Düzce event at 91.47 million TL. Total losses of 8.96 million TL, 4.99 million TL and 2.55 million TL were estimated for the 2017 and 2020 Istanbul and 2018 Ankara flood events, respectively (Figure 4.6a).

To better compare all events, all estimated losses are depicted in Figure 4.6a per sector. In addition, total losses were converted to US$ using event day exchange rates (Figure 4.6b) for a better comparison at the international level. According to the adapted model results, floods caused 85.7 million US$ in total economic loss in Turkey within the last five years (January 2015–August 2020), due to the eight very recent events (Figure 4.6b). Owing to incomplete documentation on physical losses for all sectors (Figure 4.4, Appendix C, Table C.2), the total economic losses can be higher than the calculated values.

When the calculated economic losses of the eight recent events are compared with the list of the 25 most severe events in Turkey compiled by Koç and Thieken (2018) (min. economic loss = 6.2 million US$, max. economic loss = 2 billion US$), the 2016 Mersin (economic loss = 52.98 million US$), 2019 Düzce (economic loss = 9.92 million US$) and 2020 Giresun (economic loss = 12.81 million US$) events can be included in this most severe flood events list based on their (estimated) economic impacts, shown in Figure 4.6b.

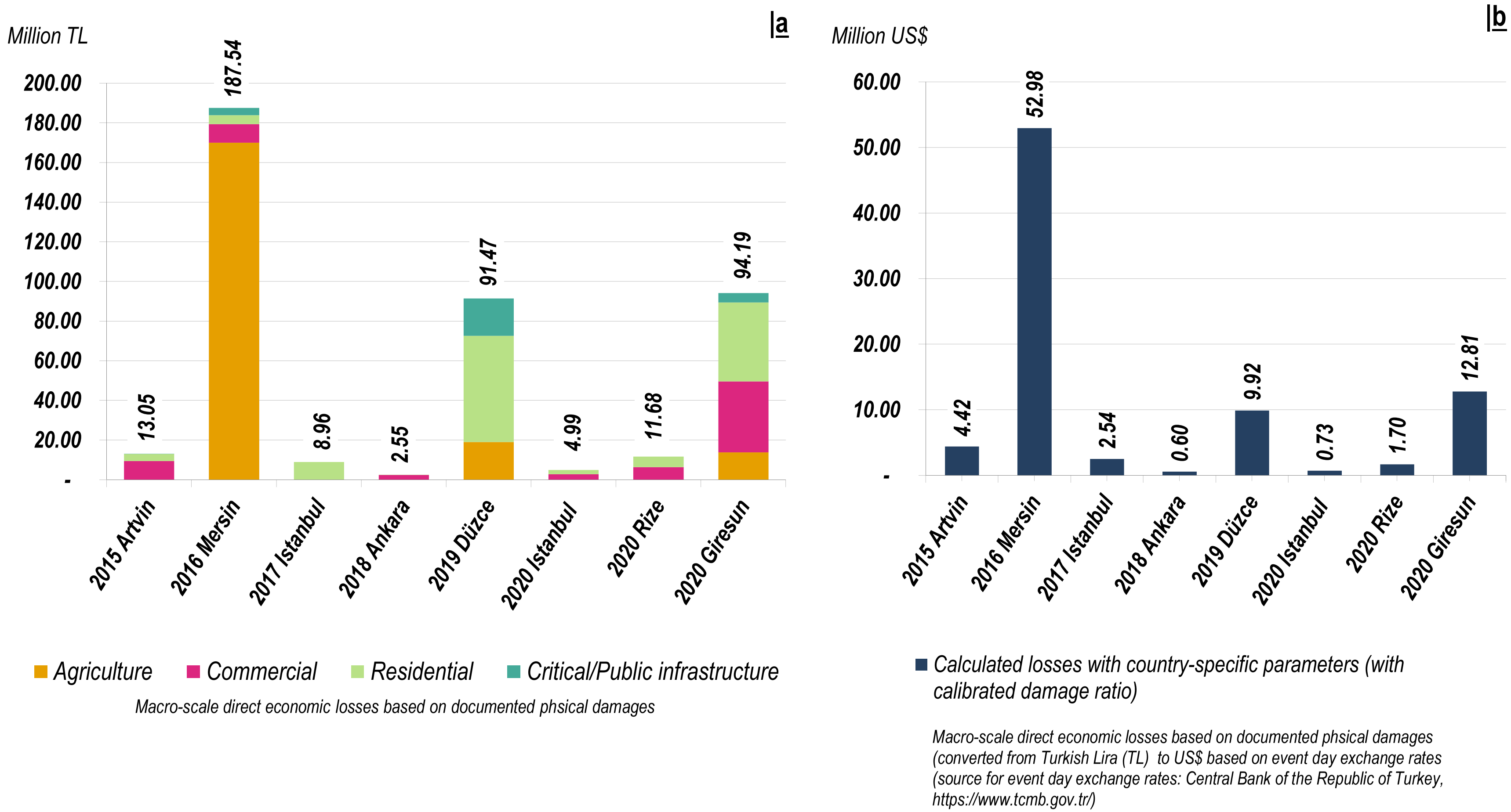


Figure 4.6: Calculated total losses of severe floods in Turkey (2015–2020) (based on documented sectors) with country-specific values and calibrated damage ratios: a) in Turkish Lira (TL), b) in US$.

4.5 Discussion

The study aimed to test and apply the UNDRR direct loss estimation model to severe floods (2015–2020) in Turkey based on documented physical losses per damage sector. Even though the model structure is simple and the requirements for input data are comparatively low for a loss estimation model (UNISDR, 2015a, 2017b), only a small number of case studies could be used for calibration and validation. Still, the adapted model presented very good results. Estimated total losses show consistency when compared with documented losses. Additionally, with the two newly suggested modules (poultry (C2-2-1) and apiculture (C2-2-2)), the basic UNDRR model for the Turkish agricultural sector, which can contribute to a large share of the overall economic damage (see Figure 4.6a), was improved.

Results reveal that the damage ratio is an important model parameter that changes the magnitude of the overall estimated losses significantly (Figure 4.5). Natho and Thieken (2018) suggested an average damage ratio of 6.8% for medium severe floods in Germany, and indicated that the damage ratio of 25% suggested by the UNDRR is too high. However, in contrast to their study and the UNDRR reference, calibrated damage ratios are quite high for crop loss (34%) and the commercial sector (32%) in Turkey (Table 4.1). On the other hand, calibrated damage ratios are comparatively very low for greenhouses (9%), the residential (4%) sector and educational facilities (1%), in contrast to UNDRR reference value. Therefore, damage ratios need to be estimated carefully per sector when the model is applied elsewhere.

Higher country-specific values for the average size and construction costs of facilities (Appendix C, Tables C.5-C.7) are the main reasons for the difference in the calibrated damage ratios and the suggested average damage ratio by the UNDRR. However, that applies to the commercial sector as well. Therefore, the question arises as to why the damage ratio for the commercial sector is so high. The UNDRR method is based on the concept of replacement value, which also includes the value of equipment, furniture and assets stored on the premises (UNISDR, 2017b); in addition, an overhead of 25% is proposed by UNDRR. Natho and Thieken (2018) adapted the methodology to calculate the equipment ratio (called "housing contents" in Natho and Thieken (2018) directly and found that a general application of 25% does not necessarily lead to an improvement of the adapted model.

Accordingly, the significant difference between the damage ratios for the commercial sector, residential sector and educational facilities can be explained by the difference in overhead due to the value of equipment, furniture and products between the different sectors. However, limited event loss documentation and limited case studies do not allow us to further analyse the overhead differences for different sectors.

Similarly, differences in agricultural products (e.g. cereals, vegetables, fruit, etc.) and production type (i.e. field, garden and greenhouse) also play an important role for the damage ratio. According to the calibration results (Table 4.1), damage ratios differ significantly for crop losses (34%) and greenhouses (9%), which affect the average damage ratio and accordingly the share of estimated losses for the agricultural sector.

The variation in agreement between calculated and documented losses for each case study is another remarkable outcome that should be discussed. Based on the calibrated model, the 2015 Artvin case study shows the highest difference between the calculated and documented losses (Figure 4.5a). When the event documentation and case studies were analysed in more detail, it is possible to see that the model that was calibrated with the 2016 Mersin flood event, which had a rainfall intensity of 16.7 mm/h (Appendix C, Table C.2), performed well for the 2019 Düzce and 2020 Rize floods (Figure 4.5b and c), which had rainfall intensities of 17.3 mm/h and 11.4 mm/h, respectively. Hence, it could be concluded that the derived damage ratios (Table 4.1) are valid for rainfall intensities between 11.4 and 17.3 mm/h. In contrast to the Düzce (2019) and Rize (2020) events, Artvin (2015) experienced a much higher rainfall intensity of 44.7 mm/h (Appendix C, Table C.2). This situation suggests that a higher damage ratio (compared to the calibrated one) should be used for the 2015 Artvin event. In order to check the suitability of the calibrated model for the events used for the model application, the relationship between the derived damage ratios and the rainfall intensities was cross-checked. The calibrated model and the derived damage ratios are likely to be valid for the 2018 Ankara and 2020 Giresun events, which saw rainfall intensities of 14.7 mm/h and 15.2 mm/h, respectively, whereas lower damage ratios should be tested for the 2020 Istanbul event, which had a lower rainfall intensity of 9.5 mm/h. Higher damage ratios might be suitable for the 2017 Istanbul event, which featured an extremely high rainfall intensity of 105 mm/h (Appendix C, Table C.2) and caused very severe flooding. This suggestion is very much in line with different damage ratios of severe and very severe floods in Germany, where damage ratios of 6.8% and 15.3% were validated by Natho and Thieken (2018).

Due to all the reasons above, damage ratio calibration requires further attention since it differs among sectors, in terms of the content of assets stored on the premises and the severity of the events. A unified value of 25% might introduce large errors for economic loss estimations, and therefore it is important to calibrate damage ratios carefully with well-documented events. To provide a rainfall intensity-dependent damage ratio, more well-documented case studies and further analyses are needed.

Besides the damage ratios, event day model parameters (i.e. cost, yield, size) are also important for a consistent estimation (UNISDR, 2017b). In the study, we were able to use the event day parameters for the affected locations, which was an important impact on model consistency. Paying attention to the country-specific values (Appendix C, Tables C.5-C.7) changes in the average size and costs of the facilities differ for each year. Therefore, instead of average parameters, event day or event year parameters are recommended.

The inflation rate and monetary value changes over time should also be considered in the calculations. The UNISDR (2015a) provides the average reference parameters in US$ for all countries. However, inflation rates or monetary unit values might differ for each country. The inflation rate has changed considerably in Turkey between 2015 and 2020. The statistics show that the average inflation rate in Turkey was 12% for 2020, while it was 15.2%, 16.3%, 11.2%, 7.8% and 7.7%

for 2019, 2018, 2017, 2016 and 2015, respectively (Statista, 2020). For example, for the 2017 Istanbul flood event, 8.96 million TL and for the 2020 Rize flood event 11.68 million TL in economic loss were calculated (Figure 4.6a). When these values are converted to US$ using the event day exchange rates, they amount to 2.54 million US$ and 1.70 million US$, respectively (Figure 4.6b). Hence, although the 2020 Rize flood event has a higher calculated economic loss than the 2017 Istanbul flood event in Turkish Lira, there is a reverse situation when the calculated losses are converted into US$ (Figure 4.6a and b). Since country-specific parameters were reported in Turkish Lira (TL), we used the local currency (TL) for all calculations to eliminate the confusion due to exchange rates and inflation rates. At the end of the calculations, the results were presented in US$ as well (Figure 4.6b) using event day (exact day/month/year) exchange rates for a better comparison at an international level.

Although the calibrated model presents good results for the documented sectors, limitations of the model should be discussed. Due to incomplete or missing loss documentation, we were not able to perform a calibration for different case studies like Natho and Thieken (2018) did for an average damage ratio. Therefore, we suggest improving loss documentation on physical and economic losses according to the sectors suggested by the UNDRR in the future, so that different case studies based on region, season and event magnitude with information for each sector could be applied in order to verify the damaged ratios obtained in this study.

It should be noted that only sectors with documented physical damage were calculated in the study. Therefore, the total losses presented in Figure 4.6 probably do not represent the overall losses. For instance, most sources used for this study on documented events (Appendix C, Tables C.2-C.3) contain physical loss information about different vehicles types (with different axle sizes), which substantially contributed to the total losses but could not be included in the validation and the adapted model due to incomplete documentation and challenges in determining the average cost of different vehicles. For example, a private transportation module (D5) was introduced by Natho and Thieken (2018) in the case of hail events in Germany in order to better adapt the model to German conditions and estimate reasonable direct economic losses. Similarly, physical loss information about different vehicles could be used to better adapt the model, and new modules such as public transportation (D5-2) or commercial/industrial transportation (D5-3) could be introduced to better estimate the direct economic losses. In general, both our study and that of Natho and Thieken (2018) suggest that a country should first identify the most important damage sectors (from what is known so far) and then develop a consistent documentation and loss estimation approach for all relevant sectors.

An accurate calculation is necessary for disaster risk management studies, such as financial aid coordination during post-disaster or pre-recovery periods after the floods, and can be useful for authorities who are responsible for disaster risk management activities. For instance, the Disaster and Emergency Management Presidency of Turkey (AFAD) is responsible for damage assessment, event documentation, the loss database (TABB) and financial aid after natural hazards in Turkey (Official Gazzette, 2009).The calibrated model could be used by AFAD to calculate the direct economic losses and fill the gaps in its database, as well as to estimate the direct economic losses for recent and new natural hazard events in Turkey.

4.6 Conclusion

With this study, we calibrated, validated and applied the UNDRR loss estimation method for the first time in Turkey to estimate the direct economic losses for severe floods between 2015 and 2020. New modules were suggested and implemented for poultry and apiculture. As a result, the calibrated model performed well when estimates were compared to documented losses. Therefore, the UNDRR loss estimation model with country-specific parameters calibrated the damage ratios, and sufficient event documentation (i.e. physical loss, damaged items) can be recommended for flood risk management studies in Turkey in order to estimate the magnitude of direct economic losses, even shortly after events. Nevertheless, better event documentation for each sector should be considered for more accurate estimations. Damage ratio calibration should also be improved with more data and for different conditions (i.e. event magnitude and rainfall intensities, season, location, etc.).

By testing and adapting the UNDRR method, this study provides an important step to consistently estimate the direct economic losses in Turkey, which can be useful for:

- Filling the data gaps in loss databases,
- Giving an idea of the tangible direct economic impacts of floods in Turkey,
- Demonstrating the great potential of the UNDRR method for quick loss estimates and improving the coordination and distribution of financial aid based on preliminary damage assessment during post-disaster/pre-recovery periods after flood events, as well as other natural hazards in Turkey, such as earthquakes or landslides, and
- Facilitating the monitoring of the progress and achievement of Global Target C of the Sendai Framework for Disaster Risk Reduction 2015–2030.

Chapter 5

Conclusions, Synthesis and Outlook

The major purpose of this thesis was to present a detailed analysis of flood hazards in Turkey that reflects all the processes along the flood risk chain, starting from triggering factors through aggravating pathways to societal and economic impacts on a national scale. One of my main findings demonstrates that floods have considerably high devastating impacts in Turkey in terms of human and economic losses that have not been reflected in the national risk policies. A lack of a unified terminology for operating a national loss database and a lack of standardized methodologies and definitions on loss data collection limit the better understanding of flood risks on a national scale. It is well-known that better event documentation with regards to data quality and accuracy aspects helps to leverage the pre-risk assessment and make better estimates on direct economic impacts (e.g. Guha-Sapir and Below (2002); Merz et al. (2010); Wirtz et al. (2014); UNISDR (2015c)). Therefore, importance should be attached more to national-scale loss databases. Another main finding of my study reveals the importance of identifying sources and pathways of floods, which enables an understanding of the dominant flood-producing mechanisms that also provides useful base information for preliminary risk assessment processes.

An interpretation of the important findings, implications and limitations during my study are discussed in more detail in the following sections.

5.1 Event documentation

In disaster risk management studies, understanding hazards and assessing their impacts play an important role (Guha-Sapir and Below, 2002). As a consequence of increasing devastating impacts of natural hazards including floods, economic loss estimation is gaining more and more attention Merz et al. (2010); CRED and UNDRR (2020), in particular after the agreement on the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015c). National and international loss databases have great importance for monitoring the societal and economic losses from natural hazards (Gall et al., 2009) that can be seen as a metric for the success or failure of risk management studies. Historical data allows analysts to search for trends and causal mechanisms across time and regions (Guha-Sapir and Below, 2002; Wirtz et al., 2014). However, lack of systematic, accurate, consistent and quality event documentation might cause a misinterpretation of hazard data (Gall et al., 2009) which, in turn, would narrow risk management options.

In order to answer the first research question outlined in Section 1.2 and assess the current situation of event documentation regarding the national loss dataset, I presented a comparative analysis (Chapter 2). Before the analysis, all natural hazards data given by TABB were pre-processed, translated into English and classified consistently based on an international peril classification system (i.e. IRDR (2014)), which enabled a better comparison of the national loss database with international data sources.

Comparison results indicate the large mismatches between national and international loss databases in terms of the number of events and, the human and economic losses. Very similar conclusions were reached in the studies by Gall et al. (2009) and Wirtz et al. (2014) regarding the mismatches between national and international loss databases. Although flood hazards are of great importance in Turkey based on global event documentation (i.e. EM-DAT), this is not reflected in the national loss database (TABB), i.e. the importance of flood hazards might be underestimated. Since national and international databases have different definitions of entry criteria or different data sources, mismatches of the comparison results could be explained with biases and fallacies in global and international event documentation. When we look at the current picture of the TABB and EM-DAT databases (Figure 5.1), evidently the large mismatches with regards to number of events and the reported economic losses still remain, which skews the interpretation of loss information and causes fallacies about flood hazards. The Emergency Events Database (EM-DAT) recorded 40 severe floods between 1960 and 2020 which caused 808 fatalities and around 2.2 billion US$ in economic loss (EM-DAT, 2020), whereas the Turkey Disaster Database (TABB) reported 1154 flood events that resulted in 819 fatalities and approximately US$ 900 million in economic loss between 1960 and 2020 (TABB, 2020). Although the number of fatalities is similar in both databases, the number of events and reported economic losses are quite different due to different thresholds, data collection, data sources or data compiling systems (Figure 5.1). This underlines that reliability of economic loss documentation is a weakness of the national database (i.e. TABB).

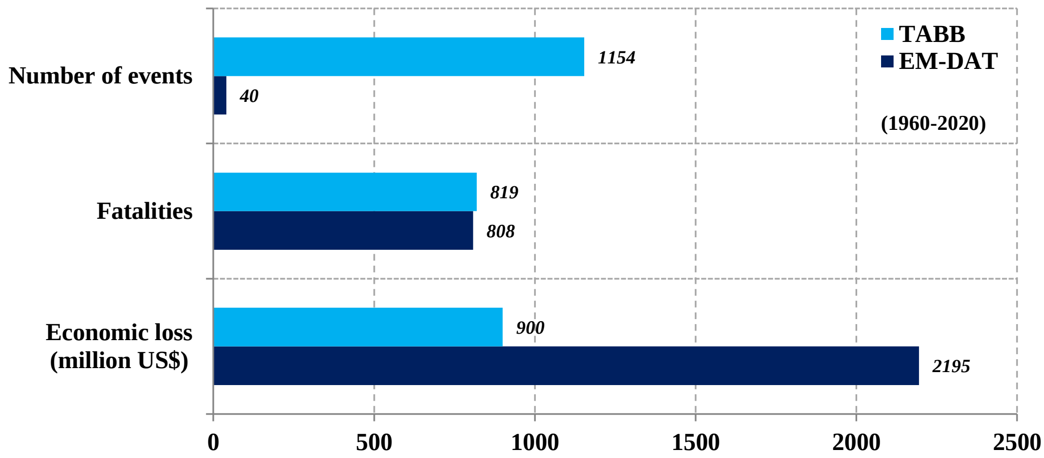


Figure 5.1: Overview of human and economic losses of reported flood hazards in Turkey between 1960 and 2020, based on Turkey Disaster Database (TABB) and Emergency Events Database (EM-DAT).

These findings serve as a good example for the threshold bias and accounting bias of event documentation. Despite the given larger number of events, economic damage is not well reported in the TABB database (Figure 5.1). This illustrates the accounting bias in the TABB database. Although the number of fatalities is similar in both databases, a comparatively very low number of events in the EM-DAT database illustrates the threshold bias (Figure 5.1). Inconsistent threshold criteria of different loss databases and lack of clear threshold definition in the TABB database could be defined as one of the major methodological problems for event documentation.

Threshold and accounting biases together with large data gaps in the TABB database were the biggest limitations of the study presented in Chapter 2. In order to overcome these limitations and fill the gaps in the national loss database, I consulted different international sources (e.g. Dartmouth) and (grey) literature (i.e. published articles, reports, newspaper archives, etc.). Since uncertainties on event documentation challenge the development of tailored risk management studies as well as bottom-up modelling approaches, importance should be attached more to national loss databases (e.g. TABB) considering the standardization processes and completeness suggested in this study.

Event documentation is a key aspect for improved risk management and the importance of a consistent national loss database could be summarized as follows: How can we reduce the devastating impacts of floods in Turkey when we do not know when and where they occurred or how their losses are counted? More precise data collection in terms of physical losses (i.e. number of damaged items for different sectors) and application of loss estimation models presented in Chapter 4 could offer a solution to this question. In parallel with this, a consistent national loss documentation enables a better assessment of the relevance of different hazard types on a national scale, which could be helpful to tailor funds and strategies to the relevance of the different hazard types.

5.2 Triggering Mechanisms and Hazard Classification

Besides reliable numbers on the relevance of different hazard types, a comprehensive classification of flood triggering mechanisms and aggravating pathways could provide a picture for a better understanding of flood generation processes from occurrence to consequence on a spatial scale (Kandilioti and Makropoulos, 2012). However, in Turkey, most of the floods were analyzed as case studies with regard to their (hydro-) meteorological characteristics (i.e. atmospheric conditions, precipitation patterns) (e.g. Türkeş and Tatlı (2011); Kömüşçü and Çelik (2013); Baltacı et al. (2015); Baltaci (2017); Lolis and Türkeş (2016)). And up to now, there has been no study in Turkey reflecting the quantification of all processes along the flood risk chain, from the flood triggering factors (i.e. atmospheric conditions, precipitation patterns, sudden snowmelts) to the hydrologic processes in the catchment such as topography, soil properties, and land use on a national scale. Therefore, in my thesis, I addressed this information gap as the second objective.

The potential triggering mechanisms (i.e., atmospheric circulations and precipitation amounts) and aggravating pathways (i.e., topographic features, catchment size, land use types, and soil properties) of severe floods (1960-2014) in Turkey were classified through hierarchical clustering. A new approach was developed to identify the main influencing factor per event and provide additional information for determining the dominant flood occurrence pathways. As a result, six different clusters were found and characterized. Cluster 1 comprised flood events that were mainly influenced by drainage characteristics (e.g., catchment size and shape); Cluster 2 comprised events aggravated predominantly by urbanization; steep topography was identified to be the dominant factor for Cluster 3; extreme rainfall was determined as the main triggering factor for Cluster 4; saturated soil conditions were found to be the dominant factor for Cluster 5; and orographic effects of mountain ranges characterized Cluster 6.

The main findings of my study demonstrate that most of the floods in Turkey are distributed over the mountain ranges (over the Pontide mountain ranges in the north, over the Eastern Anatolian mountain ranges in the east and over the Taurides in the south) and are triggered by orographic rainfall, highlighting the barrier effect of those mountain ranges. These results are very much in line with the classification of precipitation regimes in Turkey presented by Türkeş and Tatlı (2011) and the classification of flood-generating mechanisms across Europe by Berghuijs et al. (2019). When it comes to the impacts, our results also show that urbanization plays a major role as an aggravating factor, especially in small catchments in western and north-western Turkey, where the highest urbanization rate (Yüceşahin et al., 2004) occurs as a result of internal migration (Anavatan, 2017). These main findings could be the key to understanding past, present and future flood risks in Turkey. For instance, future regional climate projections in Turkey indicate that increased temperatures will affect the snow dynamics in mountain regions, thereby potentially causing a temporal shift in snowmelt runoff and altering the magnitude of snowmelt floods (Bozkurt and Sen, 2013; Bozkurt et al., 2015; Demircan et al., 2017). When this information is merged with the outcomes of the cluster results presented in Chapter 4, it could be said that the regions grouped in Cluster 6 will potentially be more affected by snowmelt floods due to the increased magnitude and temporal shift in snowmelt runoff. Similarly, future projections on population growth and urbanization rate in Turkey (UN, 2018; TÜİK, 2021) show that there will be an increase in internal migration and, accordingly, an increase in urbanized areas (Yüceşahin et al., 2004; Anavatan, 2017). This will affect the aggravating pathways of urban floods together with extreme rainfall events. Hence, the classification of flood triggering mechanisms and aggravating pathways has great importance for presenting the full picture of flood-generating processes, identifying the parameters of the Source-Pathway-Receptor-Consequence (SPRC) model and could be used as base information for flood hazard classification in preliminary flood risk assessment processes. For example, structural mitigation studies on, e.g., floodplain and river restoration might be conducted in the catchments where drainage characteristics (e.g., Cluster 1) and topography (e.g., Cluster 3) are the main aggravating pathways. Existing infrastructure can be maintained (e.g., inlets, sewer pipes creek clearing, storm-water drainage systems, etc.) in the catchments where the share of urban area is high (e.g. Cluster 2), or in the catchments where an increase in urbanized areas are expected. Furthermore, the roads can be improved to provide better access to hospitals or evacuation areas in the case of a severe flood event, especially in urbanized areas (e.g., Cluster 2). In addition to structural mitigation studies, non-structural mitigation practices can be implemented, such as early warning systems, or household emergency plans might be developed in the catchments where the events can be predicted periodically or estimated with regional climate models (e.g., sudden snowmelt during spring/summer in eastern and south-eastern Anatolia, Cluster 6).

Although a structured approach to classifying floods and their characteristics was presented for the first time in Turkey, the limited number of case studies was the main limitation of the study. 25 severe floods with 78 cases (i.e. affected areas) based on reported records were used for the classification. Most probably, the entire variety of floods and their triggering mechanisms could not be presented this way due to biased event documentation or undocumented floods (see Section 4.1, Figure 4.1). Thus, more detailed analyses with more case studies or a comparison with the top-down approach would be useful next step in better understanding the sources and pathways of severe floods in Turkey. Since a top-down modelling approach requires continuous past data (e.g. long-term observations, re-analysis data) (García et al., 2014), this model approach could also be used to validate the aggravating physical processes or critical thresholds determined in Section 3.3.5 (see Table 3.6) that drive hydrological extremes. Further, a top-down modelling approach could be used to quantify the relative contribution of different components of flood triggering mechanisms and aggravating pathways.

5.3 Economic Loss Estimation

Estimating the economic impacts of floods is important for flood risk management studies, since it provides crucial information for decision-making processes, such as decisions on cost-effective risk reduction measures, appraisals of the likely required compensation payments by the re-/insurance sector, coordination of (governmental) financial aid during and immediately after the floods, or prioritizing infrastructure restoration (Thieken, Ackermann, Elmer, Kreibich, Kuhlmann, Kunert, Maiwald, Merz, Müller, Piroth, Schwarz, Schwarze, Seifert and Seifert, 2008; Merz et al., 2010; Lindell, 2013; Wirtz et al., 2014; Yang et al., 2016). However, the scale of losses still cannot be understood well in its full extent due to incomplete, inconsistent or unreported information (Van der Veen, 2004; Meyer et al., 2013; Gall and Kreft, 2013), or significant levels of uncertainty (Merz et al., 2010; Sieg et al., 2019; Molinari et al., 2020).

The main outcomes of Chapter 2 reflect well the necessity of consistent event documentation, and outcomes of Chapter 3 reveal the biases in severe flood events lists due to incomplete, inconsistent or unreported event documentation. These findings challenge bottom-up modelling approaches and underline the need for consistent event and loss documentation. Hence, I aimed to fill the data gaps in the loss documentation, estimate losses as quickly as possible after events for a better coordination of financial aid and thereby propose recommendations to enhance flood loss documentation in Turkey by adapting and applying the UNDRR loss estimation model as the last step. In doing so, I addressed the Receptor and Consequences of the SPRC model for flood hazards in Turkey.

I aimed to test and apply the UNDRR direct loss estimation model for the first time in Turkey to eight severe floods (2015-2020) based on documented physical losses per damage sector. The main model outcomes revealed that the adapted model with country-specific parameters and calibrated damage ratios presented very good results: Estimated total economic losses showed good consistency with documented losses. Model findings demonstrated that floods caused US$ 85.7 million in total economic loss in Turkey due to the eight very recent events within the last five years (January 2015 – August 2020). However, it should be noted that only sectors with documented physical damage were considered in the study. Owing to incomplete documentation on physical losses for all sectors (Chapter 4, Figure 4.4), the total economic losses could be higher than the estimated values.

Although the calibrated model presents good results, limitations of the model should be discussed as well. Damage ratios for agriculture, commercial and residential sectors, as well as educational facilities, were calibrated using only one well-documented event. As also mentioned in Section 5.2, the use of limited case studies was the main limitation of the study. Therefore, I was not able to perform a calibration for different case studies like Natho and Thieken (2018) did for an average damage ratio due to incomplete or missing loss documentation. With the continuous implementation of the UNDRR loss estimation model, data gaps on economic losses in the TABB database (also visible in Figure 5.1) could be filled. Nevertheless, this requires a consistent documentation of physical losses (i.e. number of damaged items) for all affected sectors (e.g. agricultural, residential, commercial, etc.), which is easier than an economic assessment, however.

Another important effect of the study was to discuss a possible relationship between the rainfall intensity and the damage ratio. A major number of studies on flood loss estimation models focused on water depth (e.g. Thieken, Olschewski, Kreibich, Kobsch and Merz (2008); Kreibich et al. (2010); Merz et al. (2010); Gerl et al. (2016); Sieg et al. (2017)), which is the most important hydrological causal factor especially for riverine floods (Kreibich et al., 2009; Spekkers et al., 2014; Van Ootegem et al., 2018; Blumenthal and Nyberg, 2019). However, a few studies also focused on the relationship between the rainfall intensity and flood losses and found that a correlation between rainfall intensity and economic damages for pluvial urban floods (Torgersen et al., 2015; Van Ootegem et al., 2018; Blumenthal and Nyberg, 2019). Furthermore, Torgersen et al. (2015) indicated that short-duration rainfall confirms that the most costly events occur during the most intensive rainfall for urban floods. Ten Veldhuis (2011) suggested that these findings could relate to the fact that intensive rainfall events may cause higher damages for pluvial urban floods due to blockages of inlets, sewer pipes and damages to infrastructures. When I analyzed my model outcomes in light of this information with regard to the rainfall intensity and damage ratio relation, the adapted UNDRR loss estimation model with calibrated damage ratios presented better results for the flood events that had similar rainfall intensities. The adapted model comparatively underestimates the direct economic losses due to the floods with higher rainfall intensities and overestimates the direct economic losses due to the floods with lower rainfall intensities (Chapter 4, Section 4.5). This situation suggests higher damage ratios for high-intensity rainfall events for the UNDRR loss estimation model, especially for residential and critical infrastructure sectors. This suggestion is very much in line with different damage ratios of severe and very severe floods in Germany, where damage ratios of 6.8% and 15.3% were validated by Natho and Thieken (2018). Consequently, a further development of the simple UNDRR loss model should consider linking the fixed damage ratio to the intensity of the hazard process. It is expected that this will further increase model performance without proposing loss models whose sophistication might hinder their practical application.

Overall, I suggest here that the UNDRR loss estimation model with country-specific parameters, calibrated damage ratios, and sufficient event documentation (i.e. physical loss, damaged items) can be recommended for flood risk management studies in Turkey with well-documented case studies. Damage ratios should be calibrated for different sectors and different cases, such as different flood types (i.e. riverine floods, pluvial floods) and different rainfall intensities. AFAD is the only institution responsible for event documentation, damage assessment and financial aid after natural hazards in Turkey (Official Gazzette, 2009). Therefore, I propose that the calibrated model could be used by AFAD to calculate the direct economic losses, to fill the gaps in the TABB database, and estimate financial aid for the recent and new natural hazard events in Turkey.

5.4 Synthesis and Outlook

Global future projections suggest an increasing trend of urbanized areas as a consequence of population growth (Figures 5.2a and 5.2b). Total global population is expected to reach around 10 billion by 2050, which may double the current share of urbanized areas (Chen et al., 2020) by then. When we look closer at the future projections specific to Turkey, we can observe a similar situation (Figures 5.2c and 5.2d). Currently, the population of Turkey is 85 million (TÜİK, 2021) and is estimated to reach 105 million by 2050 (TÜİK, 2021). Future projections show that besides population growth, internal migration from rural areas to urban areas will increase in Turkey, as well (UN, 2018) (see Figure 5.2d). This situation will cause an increase in urbanized areas, especially in western and northwestern Turkey, which already have the highest urbanization rate (Yüceşahin et al., 2004).

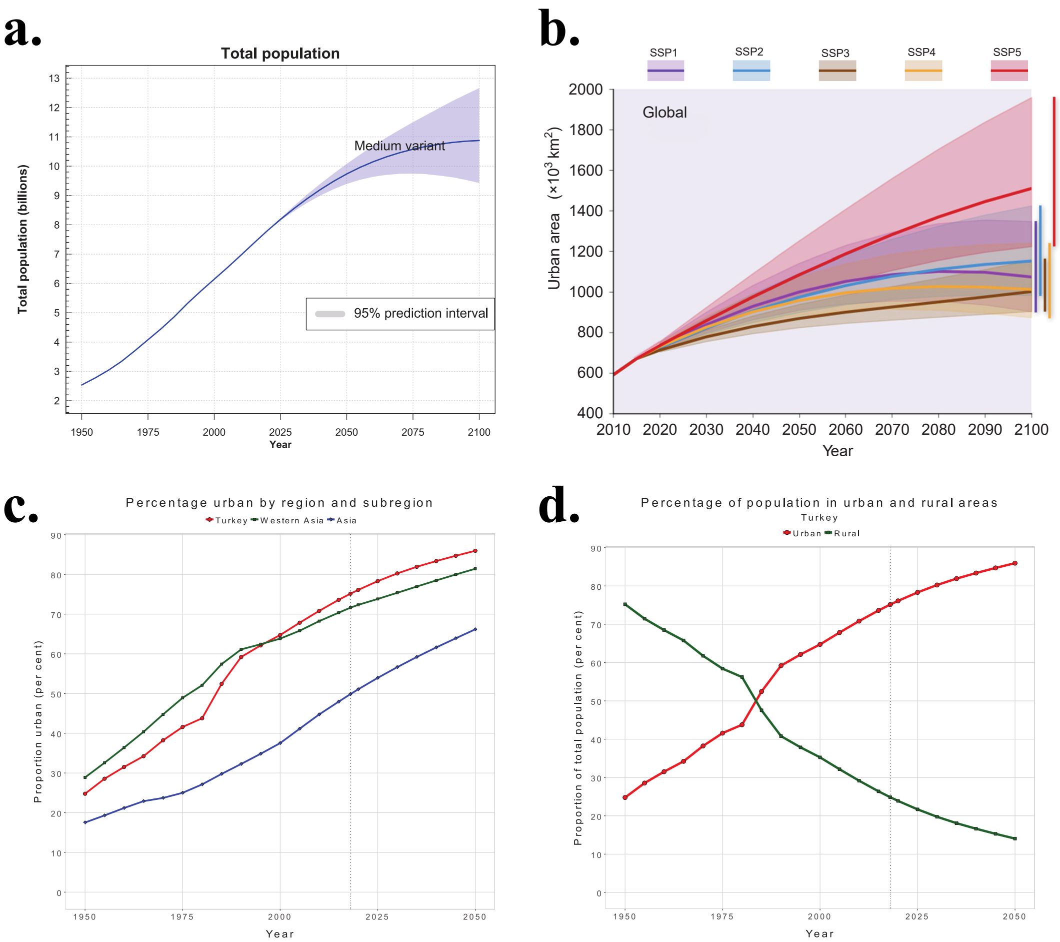


Figure 5.2: Future projections of population growth and share of urbanization a) Global projection of population growth (UN, 2019); b) Global projection of shares of urbanized areas for five different socioeconomic pathway scenarios (Chen et al., 2020); c) Future projection of urban growth in Turkey (UN, 2018); d) Future projection of population shares in urban and rural areas in Turkey (UN, 2018).

In addition to demographic projections, regional climate projections demonstrate that Turkey will be affected more by extreme rainfall events (Demircan et al., 2017). However, despite significant human and economic impacts of floods and future estimates of possible risks, the lack of a national strategic plan on flood risk reduction and prevention studies in AFAD's Strategic Plan on Disaster and Emergency Management 2019-2023 (AFAD, 2019) remain a big policy gap. Therefore, in this study, I aimed to present a comprehensive analysis of flood hazards in Turkey with regard to event documentation, triggering mechanisms and economic impact aspects.

The main findings of my study show that northern Turkey (Black Sea region) has the highest number of flood events and fatalities, and southern Turkey (Mediterranean region) has the highest economic loss in the agricultural sector (especially greenhouses) due to floods (Chapter 2). Analysis of triggering mechanisms and aggravating pathways of floods demonstrates that the orographic barrier effect of mountain regions is the dominant triggering factor for these regions (Chapter 3). When we look at the latest well-documented severe events (2015-2020) in Turkey, flood events occurred in northern Turkey (Black Sea region), where three out of eight severe events between 2015 and 2020 occured (Chapter 4). When we analyzed the economic impacts of these eight severe events, Mersin province, which is located in southern Turkey (Mediterranean region), had the highest economic loss, especially in the agricultural sector (Chapter 4). Future climate and demographic projections suggest that rainfall regimes will change especially in these regions (Bozkurt and Sen, 2013; Bozkurt et al., 2015; Demircan et al., 2017) and a temporal shift in snowmelt runoff will alter the magnitude of snowmelt floods in southern Turkey. Changing climate and social conditions urge consistent flood risk management to overcome these impacts.

Outcomes of this study provide a full picture of flood hazards in Turkey, from the triggering factors to the impacts, and demonstrate the urgent need for a comprehensive national flood risk management plan, especially under the changing climatic and socio-demographic conditions mentioned above. This thesis further provides important suggestions on the standardization of event documentation and filling the data gaps in loss databases, and also presents a visual representation of current picture of flood-generating or aggravating factors on geographic information systems (GIS), which could help to enhance measurement tools and the collection, analysis and dissemination of data in Turkey as also suggested by UNISDR (2015c).

In conclusion, the development (and implementation) of flood risk management policies and strategies should receive more attention in Turkey. I suggest that future work should focus on the following topics: how climate change together with socio-demographic changes will affect the impacts of future floods on national a scale; how urban development growth and socio-economic changes could be implemented as one of the aggravating pathways in the SPRC model; and how the SPRC model could be enhanced together with a top-down modelling approach to quantify the relative contribution of different causal mechanisms and improve the loss estimation models for more consistent risk mitigation measures.

The year 2023 will be the midpoint in implementing the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) and Turkey is requested to prepare a review of the implementation of the SFDRR at its midpoint as one of the signatory countries. In this context, I believe that this comprehensive analysis could contribute to a better understanding of flood hazards and impacts in Turkey and could facilitate the monitoring of the national progress and achievements with regard to the SFDRR targets.

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Appendix A

Supporting information for Chapter 2

Table A.1: Turkey Disaster Database (TABB) loss parameters

	Damage indicators	Sub-classes
1.	Effected areas	
2.	Total deaths	Deaths (child 0-18)
		Deaths (adult +18)
		Deaths (female)
		Deaths (male)
3.	Total injured	Injured (child 0-18)
		Injured (adult +18)
		Injured (female)
		Injured (male)
4.	Total missing	
5.	Number of destroyed buildings	Destroyed public buildings
		Destroyed residential buildings
		Destroyed workplace buildings
6.	Number of damaged buildings	Non-damaged public buildings
		Lightly damaged public buildings
		Moderately damaged public buildings
		Heavily damaged public buildings
		Non-damaged residential buildings
		Lightly damaged residential buildings
		Moderately damaged residential buildings
		Heavily damaged residential buildings
		Non-damaged workplace buildings
		Lightly damaged workplace buildings
		Moderately damaged workplace buildings
		Heavily damaged workplace buildings
7.	Affected	
8.	Evacuated	
9.	Total damage	Total damage ($)
		Total damage (TL)
10.	Destroyed agricultural area (Ha)	
11.	Castle loss	

Table A.2: Most severe flood events in Turkey.

Flood events			EM-DAT			Dartmouth		
Ref. Nr.	Date (mounth/ year)	Location	Fatalities	Affected	Total damage ($)	Fatalities	Affected	Total damage ($)
1	12/1968	Mersin (Icel), Adana (Mediterranean)	147	0	0	–	–	–
2	03/1980	Kayseri (Central Anatolia)	75	60,000	15,000,000	–	–	–
3	11/1995	Izmir, Antalya, Isparta (Western Mediterranean, Western Aegean)	63	306,617	50,000,000	62	–	–
4	08/1998	Trabzon, Rize (Eastern Black Sea)	60	1000	0	50	–	–
5	06/1990	Giresun, Gumushane, Trabzon (Eastern Black Sea)	51	4,500	150,000,000	48	–	150,000,000
6	10-11/2006	Sanliurfa, Diyarbakir, Sirnak, Batman (Southeastern Anatolia)	47	63,015	317,000,000	46	–	310,652,731
7	05/1991	Diyarbakir, Malatya, Adiyaman, Elazig, Bingol, Mus (Eastern Anatolia)	42	500	25,000,000	42	–	25,000,000
8	09/2009	Istanbul, Tekirdag (Marmara)	40	35,020	550,000,000	31	–	–
9	07/2002	Rize (Eastern Black Sea), Corum and Yozgat (Central Anatolia), Kars and Mus (Eastern Anatolia)	34	3,000	0	34	–	–
10[a]	11/1974	Sirnak (Southeastern Anatolia)	33	0	0	–	–	–
11	06/1998	Diyarbakir, Sanliurfa, Agri, Erzincan, Ardahan, Erzurum (Eastern Anatolia, Southeastern Anatolia)	22	0	0	9	–	–
12[a]	02/1990	Kahramanmaras, Bingol, Gaziantep	18	0	0	18	–	–
13	03/2004	Erzurum, Batman, Bitlis, Mus, Konya, Silifke (Southeastern Anatolia)	15	50,000	0	8	–	–
14[a]	06/1988	Ankara (Central Anatolia)	13	1,500	0	16	–	–
15	05/2007	Agri, Van, Bitlis, Gaziantep (Eastern Anatolia, Southeastern Anatolia)	13	750	0	13	–	0
16	07/2012	Samsun (Black Sea)	13	0	0	–	–	–
17	07/2006	Bitlis, Mus (Eastern Anatolia), Kirklareli (Marmara), Trabzon, Rize, Samsun, Giresun (Black Sea)	12	0	0	9	–	0
18[a]	12/1981	Samsun (Black Sea)	10	0	0	–	–	–
19	05/1998	Zonguldak, Karabuk, Bartin, Sakarya (Western Black Sea)	10	1,240,047	1,000,000,000	19	–	2,000,000,000
20	06/2002	Giresun (Black Sea)	–	–	–	–	–	–
21	07/1995	Isparta–Senirkent (Western Mediterranean)	–	–	–	–	–	–
22	12/1997	Antalya (Mediterranean)	–	–	–	–	–	–
23	07/2009	Giresun (Black Sea)	–	–	–	–[b]	–[b]	–[b]
24	05/2000	Samsun, Tokat, Amasya (Black Sea)	2	1000	40,000,000	2	–	40,000,000
25	12/2003	Antalya (Mediterranean)	8	0	0	6	–	–

Table A.2 (Continued): Most severe flood events in Turkey.

Flood events			TABB			Literature			
Ref. Nr.	Date (mounth/ year)	Location	Fatalities	Affected	Total damage ($)	Fatalities	Affected	Total damage ($)	Related references
1	12/1968	Mersin (Icel), Adana (Mediterranean)	0	0	0	–	–	–	–
2	03/1980	Kayseri (Central Anatolia)	0	0	0.084[c]	–	–	–	–
3	11/1995	Izmir, Antalya, Isparta (Western Mediterranean, Western Aegean)	61	0	0	61	–	50,000,000	Kömüşçü and Çelik (2013), Ceylan et al. (2007); Avşar (2014)
						67	–	30,000,000	Gürer (1998)
						63	300,000	1,000,000,000	Ergünay (2007)
						61	–	–	Koçman and Kayan (1996)
						63	–	–	Sezer (1997)
						61	–	–	Mutluer and Işık (2000)
						61	–	–	Zeybek (1998)
						63	–	–	Altundal (2010)
						61	–	50,000,000	Kadıoğlu (2012)
4	08/1998	Trabzon, Rize (Eastern Black Sea)	91	0	20.74[c]	50	–	44,479,204	Yüksek et al. (2013)
						10	–	–	Ceylan et al. (2007)
						43	–	–	Gürgen (2004); Yurt (2012)
						47	–	–	Şahin (2002)
						50	–	60,348,111	DSİ (2008)
						60	1000	–	AFAD (2011); Altundal (2010)
5	06/1990	Giresun, Gumushane, Trabzon (Eastern Black Sea)	51	0	0	57	–	347,863,008	Yüksek et al. (2013)
						57	–	–	Gürgen (2004)
						57	–	471,970,575	DSİ (2008); Avcı and Sunkar (2015)
6	10-11/2006	Sanliurfa, Diyarbakir, Sirnak, Batman (Southeastern Anatolia)	41	0	4,845,297	39	–	300,000,000	Gürer and Uçar (2009)
						10	–	20,765,557	Tonbul and Sunkar (2011)[e]
						46	–	–	Şahinalp (2007)
						44	–	–	Türkoğlu (2009)
7	05/1991	Diyarbakir, Malatya, Adiyaman, Elazig, Bingol, Mus (Eastern Anatolia)	38	157	0	–	–	–	–

Table A.2 (Continued): Most severe flood events in Turkey.

Flood events			TABB			Literature			
Ref. Nr.	Date (mounth/ year)	Location	Fatalities	Affected	Total damage ($)	Fatalities	Affected	Total damage ($)	Related references
8	09/2009	Istanbul, Tekirdag (Marmara)	31	0	0	32	35,000	80,000,000	Kömüşçü and Çelik (2013)
						31	–	–	Turoğlu (2011)
						32	–	–	Kömüşçü (2011)
9	07/2002	Rize (Eastern Black Sea), Corum and Yozgat (Central Anatolia), Kars and Mus (Eastern Anatolia)	33	0	16.77[c]	27	–	11,363,317	Yüksek et al. (2013)
						40	–	20,000,000	Ceylan et al. (2007)
						27	–	7,789,000	Gürer and Uçar (2009)
						27	–	17,881,127	DSİ (2008)
						27	–	8,382691	Reis et al. (2007)[d]
10[a]	11/1974	Sirnak (Southeastern Anatolia)	–	–	–	–	–	–	–
11	06/1998	Diyarbakir, Sanliurfa, Agri, Erzincan, Ardahan, Erzurum (Eastern Anatolia, Southeastern Anatolia)	18	0	0.16[c]	8	–	–	Ceylan et al. (2007)
12[a]	02/1990	Kahramanmaras Bingol, Gaziantep	–	–	–	–	–	–	–
13	03/2004	Erzurum, Batman, Bitlis, Mus, Konya, Silifke (Southeastern Anatolia)	4	132,983	0	–	4,868	–	Türk Kızılayı (2004)
						–	–	6,157,667	Buldur et al. (2007)
14[a]	06/1998	Ankara (Central Anatolia)	–	–	–	–	–	–	–
15	05/2007	Agri, Van, Bitlis, Gaziantep (Eastern Anatolia, Southeastern Anatolia)	3	0	0	8	–	–	AKOM (2007)
16	07/2012	Samsun (Black Sea)	9	0	0	12	–	–	Bahadır (2014)

Table A.2 (Continued): Most severe flood events in Turkey.

Flood events			TABB			Literature			
Ref. Nr.	Date (mounth/ year)	Location	Fatalities	Affected	Total damage ($)	Fatalities	Affected	Total damage ($)	Related references
17	07/2016	Bitlis, Mus (Eastern Anatolia), Kirklareli (Marmara), Trabzon, Rize, Samsun, Giresun (Black Sea)	3	1,520	62,761,245	–	–	–	–
18[a]	12/1981	Samsun (Black Sea)	–	–	–	–	–	–	–
19	05/1998	Zonguldak, Karabuk, Bartin, Sakarya (Western Black Sea)	5	43,547	62.92[c]	20	–	>150,000,000	Kömüşçü and Çelik (2013)
						27	–	2,000,000,000	Ceylan et al. (2007)
						10	1,200,000	1,000,000,000	Ergünay (2007)
						17	–	1,349,125	Zeybek (1998)
						–	–	235,000,000	Altundal (2010)
						–	2,200,000	–	Kadıoğlu (2012)
20	06/2002	Giresun (Black Sea)	0	0	13,432,263	–	–	16,138,949	Avcı and Sunkar (2015); AFAD (2011)
						–	–	3,837,789	Aksoy and Coskun (2010)
21	07/1995	Isparta-Senirkent (Western Mediterranean)	74	0	0	74	–	–	Özden (2004); Zeybek (1998); Ertek (2014)
						10	10,000	65,000,000	Altundal (2010)
						70	–	30,000,000	Ceylan et al. (2007)
22	12/1997	Antalya (Mediterranean)	0	0	177[c]	–	–	–	–
23	07/2009	Giresun (Black Sea)	0	0	0	1	–	97,885,798	Avcı and Sunkar (2015)
						1	–	9,869,720	Önsoy (2011)
24	05/2000	Samsun, Tokat, Amasya (Black Sea)	2	0	11.27[c]	2	–	–	Ceylan et al. (2007)
25	12/2003	Antalya (Mediterranean)	5	0	22.47[c]	5	–	22,173,458	Bianet (2003)

[a]Only in EM-DAT and/or Darthmouth database
[b]This event is also in the Darthmouth database, but no information is given regarding fatalities, affected people or economic loss
[c]Economic losses before 2005 were checked and the mistakes due to monetary value changes have been corrected. For economic loss data, the corrected values and today's rate calculations were considered
[d]This information is only for Rize Province
[e]This information is only for Batman Province

Appendix B

Supporting information for Chapter 3

Table B.1: Most severe flood events in Turkey (1960–2014) and analyzed flood-triggering factors.

			General Information										Land Use Information			
Event Number	Case ID	Case Number	Event Date (Day-Month-Year)	Event Season	Geographic Region	Flood Type	Corrected Event Date (Day-Month-Year)	PREC [1] (mm/day)	ACP [2]	ASM [3] (%)	IN [4] (km/km^2)	IR [5] (%) (%)	UA [6] (%) (CLC [7] 1 **)	WB [8] (%) (CLC 4 **) and 5 **	TCA [9] (km^2)	Cluster No.
1	FH01_01	1	27.12.1968	Winter	Mediterranean	Riverine	26.12.1968	154.30	NZ	56.99	5.43	15.90	0.7	1.2	15,024.10	5
	FH01_02	2			Mediterranean		26.12.1968	199.50	NZ	100	4.71	6.58	1.6	0.0	458.10	5
2	FH02_01	3	30.03.1980	Spring	Central Anatolia	Flash	27.03.1980	45.20	SEZ	0	8.01	2.76	0.8	0.0	126.00	3
	FH02_02	4			Central Anatolia		27.03.1980	48.50	SEZ	0	7.10	13.54	6.7	0.2	1561.20	3
	FH02_03	5			Central Anatolia		27.03.1980	80.60	SEZ	0	4.07	2.54	1.2	0.0	150.40	6
3	FH03_01	6	04.11.1995	Autumn	Aegean	Flash	04.11.1995	108.00	NZ	0	5.22	0.01	25.9	0.0	34.50	6
	FH03_02	7			Mediterranean		04.11.1995	210.00	NZ	0	6.01	7.49	92.5	0.0	8.70	2
	FH03_03	8			Mediterranean		04.11.1995	210.00	NZ	0	4.31	14.98	81.2	0.0	5.20	2
	FH03_04	9			Mediterranean		04.11.1995	40.60	NZ	0	1.03	19.89	14.4	0.0	2.10	6
4	FH04_01	10	10.08.1998	Summer	Black Sea	Flash	08.08.1998	45.50	WA	0	4.76	0.00	0.3	0.0	231.40	6
	FH04_02	11			Black Sea		08.08.1998	45.50	WA	0	4.14	0.72	0.4	0.1	1063.80	6
	FH04_03	12			Black Sea		08.08.1998	45.50	WA	0	4.33	0.00	0.1	0.3	1064.50	6
5	FH05_01	13	18.06.1990	Summer	Black Sea	Flash	20.06.1990	64.80	SWZ	100	4.14	0.72	0.4	0.1	1063.80	5
	FH05_02	14			Black Sea		19.06.1990	43.00	SWZ	0	4.74	0.73	0.6	0.0	19.50	6
	FH05_03	15			Black Sea		19.06.1990	58.30	SWZ	8.2	4.19	0.26	0.3	0.3	3155.60	6
	FH05_04	16			Black Sea		19.06.1990	43.00	SWZ	93.4	4.51	0.00	0.2	0.0	113.40	5
	FH05_05	17			Black Sea		19.06.1990	58.30	SWZ	0	4.65	0.00	0.0	0.1	535.30	6
	FH05_06	18			Black Sea		19.06.1990	58.30	SWZ	0	4.58	0.00	0.4	0.3	801.00	6
	FH05_07	19			Black Sea		19.06.1990	58.30	SWZ	0	5.02	0.00	0.5	0.0	105.70	6
6	FH06_01	20	27.10.2006	Autumn	Southeastern Anatolia	Flash	27.10.2006	35.90	SWZ	0	4.24	16.57	10.8	0.0	111.00	6
	FH06_03	21			Southeastern Anatolia		28.10.2006	64.00	BM	0	5.71	75.32	24.0	0.0	8.20	4
	FH06_05	22			Southeastern Anatolia		28.10.2006	52.00	BM	0	5.17	64.47	1.3	0.0	181.20	6
	FH06_06	23			Southeastern Anatolia		28.10.2006	52.00	BM	0	5.80	51.88	0.9	0.2	1736.90	6
	FH06_07	24			Southeastern Anatolia		29.10.2006	51.00	BM	34.1	5.99	33.35	2.5	0.7	4150.20	6
	FH06_08	25			Southeastern Anatolia		29.10.2006	29.80	BM	0	2.54	0.00	0.0	0.0	18.80	6
	FH06_10	26			Southeastern Anatolia		29.10.2006	37.60	BM	79.7	6.68	36.71	5.4	0.0	310.70	5
7	FH07_01	27	16.05.1991	Spring	Eastern Anatolia	Flash	16.05.1991	28.70	TRM	0	5.54	22.82	1.6	2.9	6232.00	6
	FH07_02	28			Eastern Anatolia		16.05.1991	18.20	TRM	0	6.15	0.00	0.0	0.0	18.40	6
	FH07_03	29			Eastern Anatolia		16.05.1991	28.20	TRM	0	4.43	2.18	0.0	4.2	282.30	6
8	FH08_01	30	07.09.2009	Autumn	Marmara	Flash	09.09.2009	248.00	BM	0	5.63	19.26	20.8	3.1	163.90	4
	FH08_02	31			Marmara		09.09.2009	248.00	BM	0	3.61	73.47	13.1	0.0	37.20	4
9	FH09_01	32	23.07.2002	Summer	Black Sea	Flash	23.07.2002	154.80	WZ	0	4.98	1.80	0.0	2.4	329.20	6
	FH09_02	33			Black Sea		23.07.2002	154.80	WZ	0	4.44	0.00	0.2	1.1	205.70	6
	FH09_03	34			Central Anatolia		23.07.2002	64.30	WZ	0	5.03	65.72	1.3	0.0	844.50	6
	FH09_04	35			Central Anatolia		23.07.2002	64.30	WZ	0	3.11	17.33	2.1	0.1	633.70	6
	FH09_05	36			Eastern Anatolia		24.07.2002	22.80	WZ	0	6.10	6.00	2.1	0.3	2334.70	6
	FH09_06	37			Eastern Anatolia		24.07.2002	12.50	WZ	0	5.63	9.19	1.4	2.3	2267.10	6
10	FH10_01	38	19.11.1974	Autumn	Southeastern Anatolia	NA	19.11.1974	40.70	SWZ	0	5.89	1.41	1.0	7.5	57,593.40	1

Table B.1 (Continued): Most severe flood events in Turkey (1960–2014) and analyzed flood-triggering factors.

Event Number	Case ID	Case Number	General Information: Event Date (Day-Month-Year)	General Information: Event Season	General Information: Geographic Region	General Information: Flood Type	Corrected Event Date (Day-Month-Year)	PREC [1] (mm/day)	ACP [2]	ASM [3] (%)	IN [4] (km/km^2)	IR [5] (%) (%)	Land Use Information: UA [6] (%) (CLC [7] 1 **)	Land Use Information: WB [8] (%) (CLC 4 **) and 5 **	TCA [9] (km^2)	Cluster No.
11	FH11_01	39	12.06.1998	Summer	Southeastern Anatolia	Flash	13.06.1998	26.80	TRM	0	5.54	22.93	1.6	2.9	6232.00	6
	FH11_02	40			Southeastern Anatolia		12.06.1998	0.60	TRM	0	4.24	16.57	10.8	0.0	111.00	6
	FH11_03	41			Eastern Anatolia		12.06.1998	21.50	TRM	0	5.36	6.54	0.9	3.7	519.70	6
	FH11_04	42			Eastern Anatolia		12.06.1998	8.80	TRM	0	5.12	1.85	4.1	0.0	165.80	6
	FH11_05	43			Eastern Anatolia		13.06.1998	12.62	TRM	0	5.86	2.35	1.0	4.0	2195.70	6
	FH11_06	44			Eastern Anatolia		13.06.1998	7.48	TRM	0	9.33	0.00	21.4	0.0	14.80	3
12	FH12_01	45	18.02.1990	Winter	Eastern Anatolia	Flash	18.02.1990	44.50	SWA	100	7.96	40.40	1.5	0.0	10.70	5
	FH12_02	46			Eastern Anatolia		18.02.1990	72.90	SWA	100	4.30	0.35	0.1	0.0	108.60	5
	FH12_03	47			Southeastern Anatolia		14.02.1990	37.20	SWA	0	5.57	24.12	23.0	0.3	124.80	6
13	FH13_01	48	05.03.2004	Spring	Eastern Anatolia	Riverine	05.03.2004	14.20	BM	0	9.33	0.00	21.4	0.0	14.80	3
	FH13_02	49			Southeastern Anatolia		06.03.2004	8.20	BM	0	6.68	36.71	5.4	0.0	310.70	6
	FH13_03	50			Eastern Anatolia		06.03.2004	62.80	BM	0	4.70	0.00	0.5	0.0	47.30	6
	FH13_04	51			Eastern Anatolia		06.03.2004	54.70	BM	0	5.80	9.32	1.4	2.3	2234.40	6
	FH13_05	52			Central Anatolia		05.03.2004	18.20	BM	0	5.42	4.96	0.6	0.5	623.60	6
	FH13_06	53			Mediterranean		05.03.2004	26.20	BM	0	5.41	3.28	0.3	0.6	10,731.60	6
14	FH14_01	54	13.06.1988	Summer	Central Anatolia	Flash	12.06.1988	71.30	HB	0	6.25	12.52	7.4	0.2	1082.70	3
15	FH15_01	55	27.05.2007	Spring	Eastern Anatolia	Flash	27.05.2007	8.60	TRW	0	5.40	6.58	0.6	3.7	516.70	6
	FH15_02	56			Eastern Anatolia		27.05.2007	3.30	TRW	0	5.49	0.64	3.4	4.8	163.80	6
	FH15_03	57			Eastern Anatolia		27.05.2007	1.20	TRW	0	4.70	0.00	0.5	0.0	47.30	6
	FH15_04	58			Southeastern Anatolia		27.05.2007	5.60	TRW	0	5.57	24.12	23.0	0.3	124.80	6
16	FH16_01	59	03.07.2012	Summer	Black Sea	Riverine	04.07.2012	68.40	TRW	100	4.50	2.77	1.4	0.1	817.50	5
17	FH17_01	60	01.07.2006	Summer	Eastern Anatolia	NA	03.07.2006	8.30	SEA	0	4.70	0.00	0.5	0.0	47.30	6
	FH17_02	61			Eastern Anatolia		04.07.2006	12.50	SEA	0	5.80	9.32	1.4	2.3	2234.40	6
	FH17_03	62			Marmara		03.07.2006	74.90	SEA	0	2.72	85.14	14.4	0.0	7.90	4
	FH17_04	63			Black Sea		06.07.2006	26.30	TRW	0	4.50	10.64	4.6	3.2	179.60	6
	FH17_05	64			Black Sea		02.07.2006	95.20	SEA	0	4.98	1.80	0.0	2.4	329.20	6
	FH17_06	65			Black Sea		02.07.2006	9.20	SEA	0	4.15	3.43	1.2	0.0	331.70	6
	FH17_07	66			Black Sea		02.07.2006	77.30	SEA	0	4.46	0.52	0.3	0.0	166.70	6
18	FH18_01	67	17.12.1981	Winter	Black Sea	NA	16.12.1981	18.30	WS	0	4.15	3.43	1.2	0.0	331.70	6
19	FH19_01	68	20.05.1998	Spring	Black Sea	Flash	20.05.1998	73.00	NWZ	32.4	5.39	0.00	1.2	0.4	13,315.60	6
	FH19_03	69			Black Sea		21.05.1998	93.20	NWZ	100	5.43	3.54	1.3	0.9	652.70	5
	FH19_04	70			Black Sea		20.05.1998	59.90	NWZ	0	5.41	5.57	3.3	0.6	913.70	6
20	FH20_01	71	20.06.2002	Summer	Black Sea	Flash	20.06.2002	57.80	SWA	0	4.46	0.52	0.3	0.0	166.70	6
21	FH21_01	72	13.07.1995	Summer	Mediterranean	NA	14.07.1995	28.20	HNFA	0	4.96	0.00	1.0	0.3	306.10	6
22	FH22_01	73	15.12.1997	Winter	Mediterranean	Flash	15.12.1997	31.90	SEZ	24.5	4.50	69.92	29.8	0.0	65.30	4
23	FH23_01	74	20.07.2009	Summer	Black Sea	Flash	21.07.2009	132.20	SWZ	0	4.46	0.52	0.3	0.0	166.70	6
24	FH24_01	75	27.05.2000	Spring	Black Sea	NA	27.05.2000	79.00	WZ	0.2	5.66	1.80	1.0	0.7	36,115.80	1
	FH24_03	76			Black Sea		27.05.2000	40.70	WZ	0	5.26	6.14	0.9	0.5	546.10	6
	FH24_04	77			Black Sea		26.05.2000	17.60	WZ	0	4.79	0.11	7.1	0.0	64.40	6
25	FH25_01	78	24.12.2003	Winter	Mediterranean	NA	24.12.2003	105.40	BM	0	5.55	16.10	1.4	0.2	3847.00	6

[1] PREC, Corrected Event Day Precipitation; [2] ACP, Atmospheric Circulation Pattern Type; [3] ASM, Antecedent Soil Moisture; [4] IN, Infiltration Number; [5] IR, Infiltration Rate; [6] UA, Urbanized Areas; [7] CLC, Corine Land Cover; [8] WB, Water Bodies; [9] TCA, Total Catchment Area.

Number	Province Name	Number	Province Name
1	ADANA	21	ISPARTA
2	ADAPAZARI (SAKARYA)	22	ISTANBUL
3	ADIYAMAN	23	IZMIR
4	AGRI	24	KARABÜK
5	AMASYA	25	KARS
6	ANKARA	26	KAYSERI
7	ANTALYA	27	KONYA
8	ARDAHAN	28	MALATYA
9	BARTIN	29	MERSIN
10	BATMAN	30	MUS
11	BINGOL	31	RIZE
12	BITLIS	32	SAMSUN
13	CORUM	33	SANLIURFA
14	DIYARBAKIR	34	SIRNAK
15	ELAZIG	35	TEKIRDAG
16	ERZINCAN	36	TOKAT
17	ERZURUM	37	TRABZON
18	GAZIANTEP	38	VAN
19	GIRESUN	39	YOZGAT
20	GÜMÜSHANE	40	ZONGULDAK

Province names are numbered in alphabetical order.

Figure B.1: Province names numbered in Figure 3.2.

Table B.2: Hydrologic soil groups according to their major soil group classification (Özer, 1990).

Hydrologic Soil Group	Major Soil Group (BTG)*	Land Use and Mapping Unit Symbols
	L	1–11, 13–15, 17–19, 21, 22
A	A	3, 6, 9, 10
(Low runoff potential)	E, T	17–24
(min. infiltration rate = 7.5–10.0 mm/h)	O	Soil groups that contain one of the symbols m, p r and h, s, a, k v
	KK, ST–IY	-
	P, G	1, 2, 5, 6, 9, 10
	C, D, M, N	1–10, with symbol a
	E, T	1–16
B	B, F, R, Y	1–8
(Medium runoff potential)	U	1, 2, 3
(min. infiltration rate = 3.0–7.5 mm/h)	L	12, 16, 20, 24
	X	1, 2, 3, 4
	K	4, 5, 6, 13, 14, 15, 22, 23, 24
	A	3, 6, 9, 10 with the symbols h, s, a, k, v
	P, G	3, 4, 7, 8, from 11–22
	C, D, M, N	11–18
	B, F	9–23
	U	4–21
C	R	9–21
(High runoff potential)	L, E, T	25
(min. infiltration rate = 0.8–3.0 mm/h)	Y	9–25
	X	5–20
	K	1, 2, 3, 10, 11, 12, 19, 20, 21, 28, 29, 30, 31, 32
	Ç	3, 6, 9
	A	2, 5, 8 with the symbols h, s, a, k, v
	P, G	23, 24, 25
	C, D, M, N	19–25
	B, F	24, 25
	R, U	22–25
	V	1–25
D	Z	1–4
(Very high runoff potential)	A	1, 4, 7 with the symbols h, s, a, k, v, y
(min. infiltration rate = 0.0–0.8 mm/h)	H	H with the symbols h, s, a, k, v
	S	S with the symbols h, s, a, k, v
	X	21, 22, 23, 24, 25
	Ç	1, 2, 4, 5, 7, 8
	L	SB, ÇK

* Please see the Appendix B, Table B.3 for the major soil group symbols.

Table B.3: Mapping units of major soil groups in Turkey (FAO, 2019).

Symbol	Major Soil Groups	Symbol	Major Soil Groups	Symbol	Soil Type	Symbol	Slope-Depth Combination	Symbol	Slope-Depth Combination
P	Red Yellow Podzol Soils	X	Basaltic Soils	h	Brackish	1	Very deep (90+ m)/Slope %0–2	16	Very shallow (20–0 m)/Slope %12–20
G	Grey Brown Podzol Soils	Y	Upland Soils	s	Saline	2	Deep (90–50 m)/Slope %0–2	17	Very deep (90+ m)/Slope %20–30
M	Brown Forest Soils	A	Alluvial Soils	a	Alkali	3	Shallow (50–20 m)/Slope %0–2	18	Deep (90–50 m)/Slope %20–30
N	Non-Calcareous Brown Forest Soils	H	Gleysol	k	Brackish–Alkali	4	Very shallow (20–0 m)/Slope %0–2	19	Shallow (50–20 m)/Slope %20–30
CE	Chestnut Soil	S	Alluvial Coastal Soils	v	Saline–Alkali	5	Very deep (90+ m)/Slope %2–6	20	Very shallow (20–0 m)/Slope %20–30
D	Reddish Chestnut Soil	K	Colluvial Soils	t	Stony	6	Deep (90–50 m)/Slope %2–6	21	Very deep (90+ m)/Slope %30+
T	Red Mediterranean Soils	C	Saline-Alkali Soil	r	Rocky	7	Shallow (50–20 m)/Slope %2–6	22	Deep (90–50 m)/Slope %30+
E	Red Brown Mediterranean Soils	O	Organic Soils	y	Poor drainage	8	Very shallow (20–0 m)/Slope %2–6	23	Shallow (50–20 m)/Slope %30+
B	Brown Soils			f	Very poor drainage	9	Very deep (90+ m)/Slope %6–12	24	Very shallow (20–0 m)/Slope %30+
U	Non-Calcareous Brown Soils			CK	Bare rocks and boulders	10	Deep (90–50 m)/Slope %6–12	25	Lithosolic
F	Reddish Brown Soils			IY	River flood plains	11	Shallow (50–20 m)/Slope %6–12	26	Lithosolic
R	Rendzina			SK	Coastal Sand Dunes	12	Very shallow (20–0 m)/Slope %6–12	27	Lithosolic
V	Vertisol Soil			KK	Ground Sand Dunes	13	Very deep (90+ m)/Slope %12–20	28	Lithosolic
Z	Sierozem			SB	Marshes	14	Deep (90–50 m)/Slope %12–20	29	Lithosolic
L	Regosol			DK	Permanent snow-cover	15	Shallow (50–20 m)/Slope %12–20	30	Lithosolic

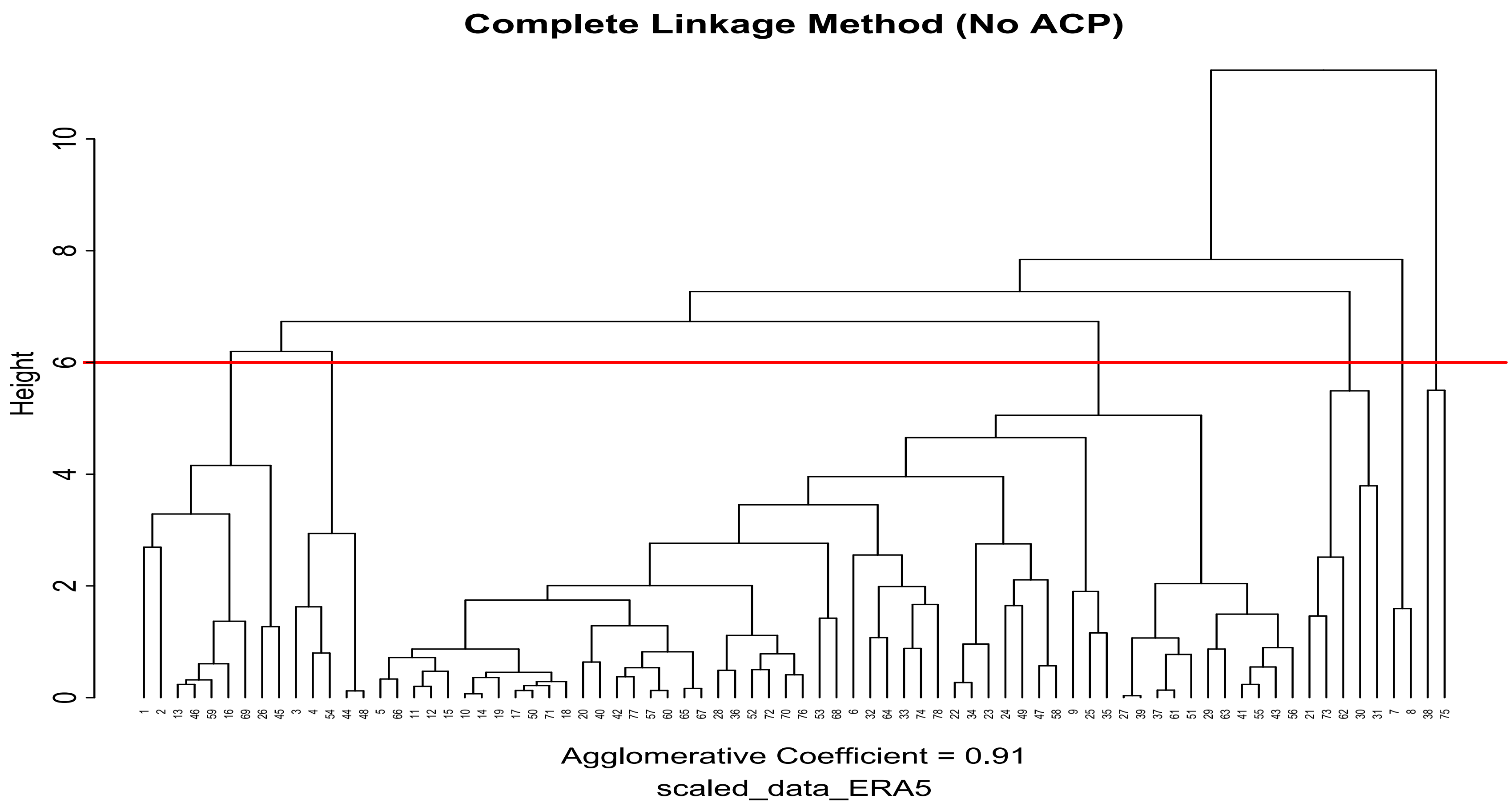

Figure B.2: Dendrogram of the cluster analysis.

Appendix C

Supporting information for Chapter 4

Table C.1: Definition of Hess and Brezowsky's Großwetterlagen (HB-GWL) catalogue of circulation pattern types (CPs) (adapted from Hess and Brezowsky (1977)).

Abbreviation	**Original Definition in German**	**Translated Definition in English**
WA	Westlage, antizyklonal	West wind, anti-cyclonic
WZ	Westlage, zyklonal	West wind, cyclonic
WS	Südliche Westlage	Southern West wind
WW	Winkelförmige Westlage	Angular West wind
SWA	Südwestlage, antizyklonal	Southwest wind, anti-cyclonic
SWZ	Südwestlage, zyklonal	Southwest wind, cyclonic
NWA	Nordwestlage, antizyklonal	Northwest wind, anti-cyclonic
NWZ	Nordwestlage, zyklonal	Northwest wind, cyclonic
HM	Hoch Mitteleuropa	High pressure system, Central Europe
BM	Hochdruckbrücke (Rücken) Mitteleuropa	High pressure bridge over Central Europe
TM	Tief Mitteleuropa	Low pressure system, Central Europe
NA	Nordlage, antizyklonal	North wind, anti-cyclonic
NZ	Nordlage, zyklonal	North wind, cyclonic
HNA	Hoch Nordmeer-Island, antizyklonal	High pressure Iceland-Norwegian Sea, anti-cyclonic
HNZ	Hoch Nordmeer-Island, zyklonal	High pressure Iceland-Norwegian Sea, cyclonic
HB	Hoch Britische Inseln	High pressure, British Isles
TRM	Trog Mitteleuropa	Trough Middle Europe
NEA	Nordostlage, antizyklonal	Northeast wind, anti-cyclonic
NEZ	Nordostlage, zyklonal	Northeast wind, cyclonic
HFA	Hoch Fennoskandien, antizyklonal	High pressure Fennoscandia, anti-cyclonic
HFZ	Hoch Fennoskandien, zyklonal	High pressure Fennoscandia, cyclonic
HNFA	Hoch Nordmeer-Fennoskandien, antizyklonal	High pressure Norwegian Sea-Fennoscandia, anti-cyclonic
HNFZ	Hoch Nordmeer-Fennoskandien, zyklonal	High pressure Norwegian Sea-Fennoscandia, cyclonic
SEA	Südostlage, antizyklonal	Southeast wind, anti-cyclonic
SEZ	Südostlage, zyklonal	Southeast wind, cyclonic
SA	Südlage, antizyklonal	South wind, anti-cyclonic
SZ	Südlage, zyklonal	South wind, cyclonic
TB	Tief Britische Inseln	Low pressure, British Isles
TRW	Trog Westeuropa	Trough, Western Europe
U	Übergang/unbestimmt	Transition, no classification

Table C.2: Severe flood events in Turkey (01/01/2015 – 31/08/2020) with documented physical losses.

Case studies	Event description					Physical losses[1]												Documented loss (Turkish Lira, ₺)
				Weather conditions		C2 Agricultural loss						C4 Commercial facilities		C5 Residential facilities	C6 Residential facilities	C7 Critical/public infrastructure		
	Affected location(s)	Date (Day.Month.Year)	Season	Event day precipitation (mm)	Rainfall intensity (mm/hr)	C2-1 Affected areas (ha)		C2-2 Livestock loss				Damaged	Destroyed	Damaged	Destroyed	D3 Educational facilities	D4 Transportation infrastructures (roads/km)	
						Field	Greenhouse	Cattle	Ovine	Poultry	Bee hives							
2015 Artvin	Hopa	24-25.08.2015	Summer	287.2	44.7 (07:00-11:00) 24.3 (11:00-15:00) 11.9 (15:00-24:00)	–	–	–	–	–	–	276	363	6[3]	1	–	15,000,000	
2016 Mersin	Akdeniz, Yenişehir, Mezitli, Tarsus, Silifke	28-29.12.2016	Winter	107.4	16.7	13,660.40	5,500.00	–	665	4,000	535	275	–	1,141	–	156	187,535,221.90	
2017 İstanbul	Esenyurt	27.07.2017	Summer	118	105	–	–	–	–	–	–	–	–	–	90	–	–	–
2018 Ankara	Mamak	05.05.2018	Spring	44	14.7	–	–	–	–	–	–	61	–	10	–	–	–	–
2019 Düzce	Akçakoca, Cumayeri	17-18.07.2019	Summer	176	17.3	598.9[2]	74.6[2]	72	177	160,550	643	–	–	390	85[3]	–	141	5,000,000[4]
2020 İstanbul	Esenyurt, Çatalca, Silivri	23.06.2020	Summer	108.4	9.5	–	–	–	–	–	–	56	–	362	–	–	–	–
2020 Rize	Çayeli	13-14.07.2020	Summer	272.8	11.4	–	–	–	–	–	–	125	–	23	37	–	–	12,000,000
2020 Giresun	Merkez, Develi, Doğankent, Espiye, Tirebolu, Güce, Görele, Yağlıdere	22-23.08.2020	Summer	137	15.2	–	–	877	–	–	–	–	221	638	262	–	35	–

[1] Data sources are given in Appendix C, Table C.3.
[2] Field data represents only affected hazelnut fields and greenhouse data represents affected vegetable gardens for this event.
[3] These numbers represent the number of entire buildings (not flats).
[4] This information is documented only for crop loss (C2-1).

Table C.3: Sources of information for event description and physical losses in Appendix C Table C.2.

Case studies	Data source(s)
2015 Artvin	Ulupınar et al. (2009); Anonymous (2015); AA (2015); Doğan (2015); Baltaci (2017); TABB (2020)
2016 Mersin	TRT (2017); Bilici and Everest (2017); Boz (2019)
2017 İstanbul	Munich RE (2018); Baltaci et al. (2019); Sezenoğlu (2020)
2018 Ankara	Anonymous (2018); Governorship of Ankara (2018); FloodList (2018)
2019 Düzce	Anonymous (2019); TMMOB (2019); Çelik and Uğurlu (2019); AA (2019)
2020 İstanbul	Güvemli (2020); Anonymous (2020e)
2020 Rize	Anonymous (2020b); AA (2020b); Anonymous (2020d,c); FloodList (2020)
2020 Giresun	Arı (2020); Anonymous (2020a); AFAD (2020); AA (2020a); Blašković (2020)

Table C.4: Values and sources of information for the agricultural sector.

Agricultural sector parameters (C2)		Values		Sources	
		UNDRR parameters	Country-specific parameters	UNDRR parameters	Country-specific parameters
Crop losses (C2-1)	Crop output (TL*/ha)	20,767.2 (2016) 28,320.5 (2019)	Field 20,272.0 (2016) Greenhouse 111,257.4 (2016) Hazelnut garden 24,480.0 (2016) Vegetable garden 7,711.4 (2019)	FAO (2020)	TÜİK (2020)
	Average yield (ton/ha)	3.1 (2016) 3.3 (2019)	Field 10.8 (2016) Greenhouse 79.1 (2016) Hazelnut garden 1.4 (2019) Vegetable garden 2.5 (2019)	IMF (2020) World Bank (2020a)	TÜİK (2020)
Livestock losses (C2-2)	Average livestock price (TL*/kg)	19.3 (2016) 28.9 (2019) 40.8 (2020)	6.4 (2016) 10.3 (2019) 24.6 (2020)	FAO (2020) EC (2020)	TÜİK (2020)
	Average livestock weight (kg)	75	642 (cattle) 66 (ovine) 5.8 (poultry)	UNISDR (2015a)	TİGEM (2017) Özsayın and Karaman (2018) Tarım Kütüphanesi (2020)

* UNDRR parameters were converted from US$ to Turkish Lira (TL) based on event day exchange rates (source for event day exchange rates: Central Bank of the Republic of Turkey (TCMB, 2020), https://www.tcmb.gov.tr/). Country-specific parameters represent the event day prices for effected region only. The prices might differ based on location.

Table C.5: Values and sources of information for the commercial sector.

Commercial sector parameters (C4)	Values (per annum)		Sources	
	UNDRR parameters	Country-specific parameters	UNDRR parameters	Country-specific parameters
Average size of commercial facilities (m^2)	25	164.2 (2015) 153.8 (2016) 158.4 (2018-2020)	UNISDR (2015a)	Deryol (2019)
Average construction cost per unit area (TL*/m^2)	Based on GDP 1,277.9 (2015) 1,528.2 (2016) 1,766.1 (2018) 2,706.4 (06/2020) 2,710.4 (07/2020) 2,903.9 (08/2020)	655.4 (2015) 698.4 (2016) 813.3 (2018) 1,022.2 (2020)	UNISDR (2015a) IMF (2020) World Bank (2020b)	GİB (2020)

* UNDRR parameters were converted from US$ to Turkish Lira (TL) based on event day exchange rates (source for event day exchange rates: Central Bank of the Republic of Turkey (TCMB, 2020), https://www.tcmb.gov.tr/).

Table C.6: Values and sources of information for the residential sector.

Residential sector parameters (C5/C6)	**Values (per annum)** UNDRR parameters	Country-specific parameters	**Sources** UNDRR parameters	Country-specific parameters
Average size of residential facilities (m^2)	45	141.9	UNISDR (2015a)	Çiftçi (2020)
Average construction cost per unit area (TL^*/m^2)	Based on GDP 1,277.9 (2015) 1,528.2 (2016) 1,511.1 (2017) 1,766.1 (2018) 2,706.4 (06/2020) 2,710.4 (07/2020) 2,903.9 (08/2020)	623.7 (2015) 664.6 (2016) 701.7 (2017) 773.9 (2018) 885.9 (2019) 972.8 (2020)	UNISDR (2015a) IMF (2020) World Bank (2020b)	GİB (2020)

* UNDRR parameters were converted from US$ to Turkish Lira (TL) based on event day exchange rates (source for event day exchange rates: Central Bank of the Republic of Turkey (TCMB, 2020), https://www.tcmb.gov.tr/). Average number of flat on each floor was considered as 4.2 based on Çiftçi (2020).

Table C.7: Values and sources of information for the critical/public infrastructure.

Critical/Public infrastructure sector parameters (C7)		**Values (per annum)** UNDRR parameters	Country-specific parameters	**Sources** UNDRR parameters	Country-specific parameters
Educational facilities (D3)	Average size of educational facilities (m^2)	60	12,571.4	UNISDR (2015a)	Official Gazzette (2001)
	Average construction cost per unit area (TL^*/m^2)	Based on GDP 1,277.9 1,528.2	279.7 (2015) 298.1 (2016)	UNISDR (2015a) IMF (2020) World Bank (2020b)	GİB (2020)
Transportation infrastructures (roads) (D4)	Average re-construction cost per unit length (TL*/km)	1,482,000	133,366	ROCKS (2018)	KGM (2020)

* UNDRR parameters were converted from US$ to Turkish Lira (TL) based on event day exchange rates (source for event day exchange rates: Central Bank of the Republic of Turkey (TCMB, 2020), https://www.tcmb.gov.tr/).

Appendix D

Colophon

This thesis was set in the Times Roman typeface using LaTeX composed with cloud-based text editor called Overleaf. All statistical analyses were done using R programming language with RStudio - Integrated Development Environment interface. Visual presentations of the data and the results were prepared using ESRI ArcGIS software. As a citation style, Harvard Referencing System was used.