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Analysis and Classification of Natural Disasters

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Analysis and Classification of Natural Disasters

by

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Abstract

Attaining a sense of the real magnitude of a disaster's severity cannot be easily comprehended, as there is no consistent method to distinguish disaster severity levels. Moreover, no current scale identifies the relationship between severity and impact factors. Consequently, no common system has been developed to help emergency responders measure the impact of natural disasters, to determine the proper allocation of resources, or to expedite mitigation processes.

This novel research develops an universal disaster severity classification, applicable to both civilians and responders, to generate a common communication platform comparing the impacts of disasters. This system provides an overall picture of the severity of natural disasters, yields independent estimates of a disaster’s magnitude, helps understand the disaster continuum, and gauges the need for regional, national, and international assistance. This research aligns with the priority of the Sendai Framework for Disaster Risk Reduction 2015-2030 as it improves understanding of disaster risk.

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Dedication

As a token of my love and respect, I dedicate this thesis to my beloved mother, Thusitha Ramachandra, who is the foundation for my success. She is a strong, loving teacher who has continually guided me, supported me, and trusted me throughout my life.

Table of Contents

List of Tables

List of Figures and Illustrations

List of Symbols, Abbreviations and Nomenclature

If you do not have any symbols, abbreviations, or specific nomenclature in your thesis, you do not need to fill out this table. To add another row to the table, with your cursor in the bottom right cell, press the TAB key (beside the letter Q on your keyboard).

Symbol	Definition
A-D	Anderson-Darling test
AEMA	Alberta Emergency Management Agency
CDF	Cumulative Distribution Function
COV	Coefficients of variation
CRED	Centre for Research on the Epidemiology of Disasters
C-S	Chi-Squared test
DMCs	Disaster Management Centres
DSS	Disaster Severity Scale
EF-Scale	Enhanced Fujita Scale
EM-Dat	CRED global loss database
EPDF	Extreme Probability Distribution Function
EVD	Extreme Value Distribution
EV0	Gumbel Distribution
EV1	Frechet Distribution
EV2	Weibull Distribution
FPP	Fujita- Pearson Scale
GDACS	Global Disaster Alert and Coordination System
GDP	Gross Domestic Product
GEJ	Great East Japan
GEVD	Generalized Extreme Value Distribution
GPD	Generalized Pareto Distribution
GP0	Exponential Distribution
GP1	Pareto Distribution
GP2	Beta Distribution
ITOS/GIST	Integrated Test and Operations System/Geographic Information Support Team Data Repository
km^2	Square Kilo Meters
K-S	Kolmogorov-Smirnov test
MAE	Mean Absolute Error
mph	Miles per hour
MSE	Mean Square Error

MM	Modified Mercalli
NatCatSERVICE	Munich Re’s global loss database
NOAA	National Oceanic and Atmospheric Administration
PDF	Probability density functions
P_L	Pearson scale path length
Pw	Pearson scale width
PP plot	Probability – Probability plot
PTHA	Probabilistic tsunami hazard assessment
QQ plot	Quantile – Quantile plot
r	Sample correlation coefficient
r_s	Spearman's rank sample correlation coefficient
SA	Southern Alberta
Swiss Re	Swiss Re Group
UDSC	Universal Disaster Severity Classification
UN	United Nations
UNDP/GRIP	United Nations Development Programme/Global Risk Identification Program
USD	United State Dollar
VEI	Volcanic Explosivity Index
ρ	Pearson’s correlation coefficient
ρ_s	Spearman's rank correlation coefficient

Chapter One: INTRODUCTION

1.1 Background

Natural hazards such as earthquakes, tsunamis, floods, hurricanes, and so on, are uncontrollable forces of nature that have played a major role in shaping the Earth's evolution. When such natural hazards occur and disturb inhabited areas, they are called natural disasters. That is, a hazard must impact humans, such as by disrupting the food supply or causing fatalities, in order to yield a disaster (Kelman 2008). Natural disasters adversely affect all living beings (human and animal communities) and human land practices exacerbate the effects of such natural disasters.

1.1.1 Problem Definition

Currently it is very difficult to express the level of impact for different types of natural disasters, in different countries, or in different time periods. Some of the reasons for this are, complex infrastructures, population growth and widespread poverty. Moreover, although the impact of natural disasters is quite similar, they come in all shapes and sizes ranging from a community fire to a large-scale tsunami. Therefore, comparing levels of impact for different types of disasters is challenging.

Worldwide, different terminologies such as *disaster*, *catastrophe*, *calamity* and *cataclysm* describe the nature and severity of these events. However, there are no consistent definitions or methods, or clear sense of scale, to differentiate these terms from each other. Therefore, the same event is described using several terms. As such, one observer's "disaster" event might be another's "catastrophic" event, or even "calamity" event, depending on personal feelings, knowledge, and experience towards the event.

Consequently, obtaining a sense of the real magnitude of a disaster's severity cannot be comprehended by merely using the known descriptive terms, because there is no consistent method to distinguish one such term from another (Caldera et al. 2016a).

In addition, some disaster types currently have rating scales based on physical strength (e.g., earthquake, tornado, volcanic eruption). However, a strong tornado may not be a significant disaster when it touches down in a remote area and has no exposure to humans or property. Therefore, scales based on physical strength are *not* the best way to describe the severity level of a disaster because they only indicate the *strength*, but not the *impact*, of a disaster (Caldera et al. 2016a).

Moreover, it is especially problematic to have different types of scales for different disasters because there is no relationship between these scales. In particular, comparing a Richter scale for earthquake with the Volcanic Explosivity Index (VEI) for volcanic eruption, or with the Enhanced Fujita Scale (EF-Scale) for tornado impact, is not possible. Clearly, these individual scales have their usefulness. For example, knowing the range of wind speeds in a hurricane as provided by the Saffir-Simpson scale is a crucial piece of information that allows estimation of potential damage to people and property (Gad-el-Hak 2008a). However, when an area is prone to two or more disasters (e.g., earthquakes, floods, cyclones, etc.), Disaster Management Centres (DMCs) must assess the appropriate combinations of disasters (combinations such as earthquakes and tsunamis, or cyclones, floods, and landslides, or thunderstorms and tornadoes, and any number of possible combinations), and decide which combinations are specific to the area being assessed. They must then rank the most likely combinations that could occur in that area. Then, DMCs must assess the potential impacts of each likely combination to take actions (or to decide) based on the potential combined impacts. These impact assessments, *with their criticality over other combinations* is useful for DMCs who can then allocate the required resources with some justifiable basis. However, this impact assessment is complicated by different type of scales that are not related to each other.

Consequently, a global scale that accurately identifies the severity of all types of disasters is needed to proper mobilize resources, make adjustments as necessary, and more correctly gauge the need for regional, national, or international assistance.

1.2 Gaps in Current Knowledge

1.2.1 Review of Existing Severity Classifications

Over the last three decades, researchers have attempted to classify disasters into a common scale. Some of these scales used qualitative measures while other offers have use quantitative measures.

1.2.1.1 Qualitative Measures

As a foundation to the science of disaster medicine, de Boer (1990) tried to classify disasters, as shown in Figure 1.1. He argued that if the destructive event has causalities and required extra mobilization of medical resources, that the event should be classified as a disaster. In contrast, if the destructive event did not have any causality, but required extra mobilization for other resources, then it should be classified as a calamity; all other scenarios are accidents. Yet, according to this criterion, if the destructive event has causalities and required extra mobilization for other resources, but not the medical resources, then it also falls into accident, which is more severe than the calamity. This complexity creates the need for reassessment of the criterion.

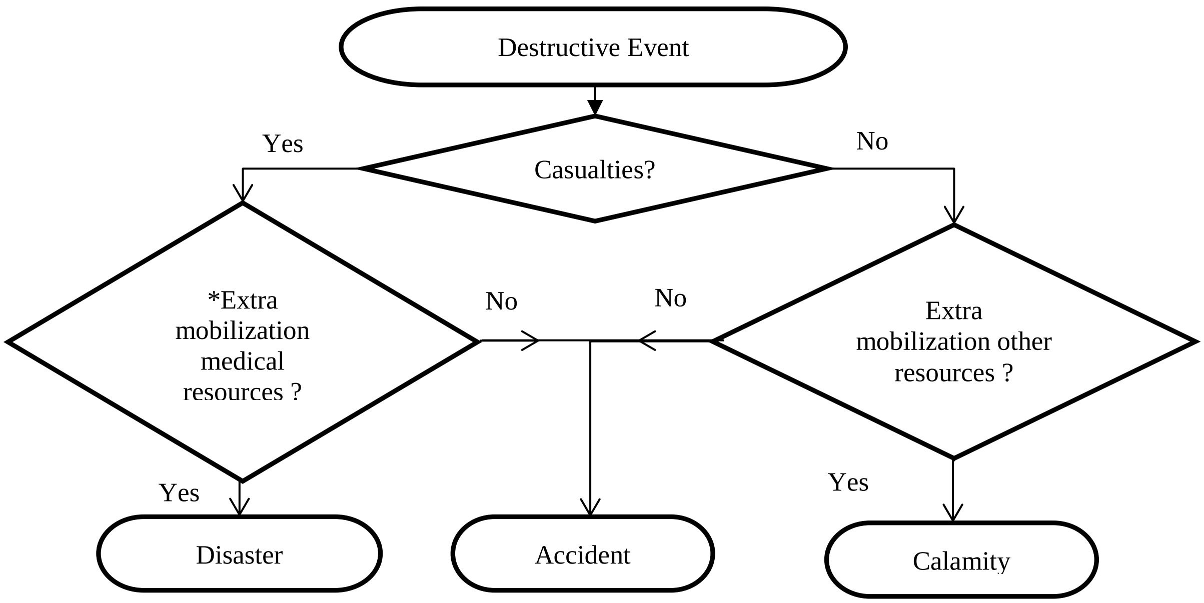


Figure 1.1 Algorithm following a destructive event

In addition, as Kelman (2008) noted:

> Different approaches have been adopted to differentiate among events with different onset times and with different clarity of start and end points. Pelling (2001) differentiates between ‘catastrophic’ disasters that can be identified as specific events and ‘chronic’ disasters that still overwhelm a community’s ability to cope, yet are part of daily life. (p. 95)

After Hurricane Katrina in 2005, Tierney (2008) proposed a qualitative scale of severity that escalated from routine emergencies to disasters, and then to catastrophes, with both the impacts and the management challenges associated with response and recovery, as specified in Table 1.1. The Encyclopedia of Crisis Management improved on Tierney's

(2008) classification (Table 1.2), and has four levels rather than Tierney's three (Penuel et al. 2013).

Table 1.1 Emergencies, Disasters, and Catastrophes

	Emergencies	**Disasters**	**Catastrophes**
Impact	Localized	Widespread, severe	Extremely large physical and social impacts
Response	Mainly local	Multi-jurisdictional, intergovernmental, but bottom-up	Requires federal initiative, pro-active response
Plans and procedures	Standard operating procedures used	Disaster plans implemented, but major challenges remain	Massive challenges exceed those envisioned in standard plans
Management challenges	Vast majority of response resources are unaffected	Extensive damage to, and disruption of key emergency services	Emergency response system paralyzed at local and state levels
Public involvement in response	Generally, not involved	Extensively involved	Extensively involved
Recovery challenges	Not significant	Major challenges	Cascading long-term effects with massive recovery challenges

Source: (Tierney 2008)

Table 1.2 Differentiation of the size of an event by process and impact

	Incidents	**Major Incidents**	**Disasters**	**Catastrophes**
Impact	Very localized	Generally localized	Widespread and severe	Extremely large
Response	Local efforts	Some mutual assistance	Intergovernmental response	Major international response
Plans and procedures	Standard operating procedures	Emergency plans activated	Emergency plans fully activated	Plans potentially overwhelmed
Resource	Local resources	Some outside assistance	Interregional transfer of resources	Local resources overwhelmed
Public involvement	Very little involvement	Mainly not involved	Public very involved	Extensively involved
Recovery	Very few challenges	Few challenges	Major challenges	Massive challenges

Source: (Penuel, Statler, and Hagen 2013)

However, this revised table still may not provide enough categorization. The Indian Ocean tsunami in 2004, which affected 12 countries over a vast area of Asia and Africa, killed about 230,000 people, injured 125,000, and displaced 1.69 million, is classified as a catastrophe. With a limited number of categories, one might similarly classify smaller events such as Hurricane Mitch, which struck eight Caribbean and Central American countries in 1998, and killed 11,000 people (Penuel et al. 2013). This demonstrates that using terms such as emergency, disaster, and catastrophe; or incident, major incident, disaster, and catastrophe, are not sufficient to clearly differentiate the size of a disaster. Nevertheless, the questions about how many levels are enough and their categorization, are unreciprocated questions.

Nevertheless, as mentioned previously there is no clear sense of scale or consistent definitions to differentiate disaster terms from each other, even in dictionaries. For example, almost all well-known dictionaries use disaster terms interchangeably. To demonstrate, the Oxford Dictionary (3rd Edition, 2010) describes a disaster as a catastrophe, and then defines catastrophes and calamities as disasters (see Table 5.3). Moreover, a search on Google reveals many sites that define a disaster as a catastrophe and a calamity as a disaster. In addition, the terms disaster, catastrophe, and calamity are often used as metaphors. Also, denotation and connotation of these words change over time. For instance, when disaster was first added to English language in the late 16th century, it meant 'ill-starrted event' (Cresswell 2009). Because there is no consistent method to distinguish one term from the other, there is no clear sense of scale. Therefore, a clear definitions and order of seriousness for the descriptive terms is an important contribution in order to use these terms to categorize the severity of disasters.

1.2.1.2 Quantitative Measures

Using existing intensity scales, the severity prediction is conducted for each type of disaster. However, for most disasters, overall, magnitude levels *only indicate the hazard potential, not the vulnerability of a region*; that is, the impact depends on where a disaster occurs, (e.g., a populated city or rural area). For example, a small hail storm can significantly impact on area if it affects human, their vehicles and dwellings, when compared to a strong tornado that occurs in an abandoned area. In another example, the most fatal volcanic eruption might not be the largest eruption, because other eruptions may have been as large as (or even larger than) the deadliest, but they did not cause fatalities. Thus, the highest magnitude event may not necessarily be the most disastrous. Aside from location, reasons for this discrepancy are due to better early prediction technology, proper early warning systems, the educational levels of local residents about the disaster, existing technology, readiness, and available resources. In addition, continued research can reduce the destructive capacity of the event, while population growth may increase the number of fatalities in a disaster. Therefore, more than the intensity of a disaster needs to be considered in order to classify disasters according their severity. In addition, the relationship between impact factors and the intensity scales were observed in order to identify whether severity can be predicted using intensity scales (see Chapter 3).

Accordingly, De Boer (1990) developed a Disaster Severity Scale (DSS), which is based on seven parameters. A score was given to the following parameters by assigning the individual classification a grade: 0, 1, or 2. The considered parameters are:

1. the disaster's effect on the infrastructure;
2. the cause (man-made/ natural hazard);
3. the impact time (<1 hour/ between 1- 24 hours/ > 24 hours);
4. the radius of the disaster area (< 1km/ between 1- 10 km/ > 10 km);
5. the number of casualties (between 25-100 causalities alive or dead, or between 10-50 causalities admitted to hospital/ between 100-500 causalities alive or dead, or between 50-250 causalities admitted to hospital/ > 500 causalities alive or dead, or >250 causalities admitted to hospital);
6. the nature of injuries sustained by living victims; and
7. the rescue time.

These seven individual scores are added up to reflect a score between 1 - 13 that indicates the severity of the disaster. Thus, the score itself increases according to the gravity, duration, number, or intensity of the disaster. Consequently, with a classification system that uses DSS, it is possible to assess the impact of a disastrous situation. Nevertheless, "a DSS provides categorization through the application of a generic score. This can be used as a description or indicator of a disaster event. With a classification system using a DSS, it is possible to assess the gravity of a disastrous situation. However, a DSS is not a scientific instrument that can determine the long-term impacts of disasters" (Wickramaratne et al. 2012).

What makes a disaster “large-scale” is the number of people affected by it and/or the extent of the damaged infrastructure and geographical area involved (Gad-el-Hak 2008b). In general, ‘Disaster scope’ (Gad-el-Hak 2008b) is a quantitative scale, which applies to both natural and manmade disasters, and is provided as a combined classification for disasters based on the number of casualties and/or the extent of geographical area affected. In this study, there are five levels from Scope I to Scope V to differentiate the severity of a disaster (Table 1.3). Nonetheless, the selected factors to measure severity, and their proposed ranges are arbitrary in this scale, but are needed to conduct meaningful research. Yet, as previously noted, by definition an environmental event that does not affect people is not considered a “disaster”. However, ‘Disaster scope’ evaluates the severity, using causalities or the geographical area involved. Hence, if an event involves some geographical area, but does not impact humans, then this event may classify within one of the five Scopes, depending on the geographic area affected. However, the event is not actually a disaster according to the previous definition, as it does not impact humans.

Table 1.3 Disaster scope

Scope		**Number of casualties**		**Geographic area affected (km^2)**
I	Small disaster	< 10	or	< 1
II	Medium disaster	10 – 100	or	1 – 10
III	Large disaster	100 – 1000	or	10 -100
IV	Enormous disaster	1000 – 10000	or	100 – 1000
V	Gargantuan disaster	>10000	or	>1000

Source; Gad-el-Hak (2008)

The severity of an event can be also assessed by measuring the negative impact of a disaster on people and infrastructure (Wickramaratne et al. 2012). Yet, there are many factors that need to be considered when addressing the severity of an event. An impact factor that takes into account the number of injuries and fatalities, physical damage, loss of livelihood, homelessness, and related physical/mental illnesses or the extent of the geographical area involved, clearly carries an added benefit, and may all be used in assessing the severity of a disaster. In addition to the degree of the disaster, rapidity is also a concern. Earthquakes, for example, occur over extremely short time periods measured in seconds, whereas global warming and pollution are often slow moving disasters, with their duration measured in years or even decades or centuries (although their devastation - over the long term - can be worse than that of a rapid, intense events) (Gad-el-Hak 2008a). Therefore, answering questions, such as:

- How many factors are needed to clearly distinguish the severity levels of a disaster?
- What are these factors? and
- How do these factors relate to severity?

are difficult due to the deficiency of the current data. A lack of data also prevents establishing a sophisticated scale.

1.2.2 Review of Disaster Information Management

The lack of a common terminology to identify the scale of a destructive event is a major issue in disaster-related information management and processing (Hristidis et al. 2010). Specifically, the vocabulary, context and interpretations regarding the definition of *disaster* are not fixed in the literature (Kelman 2008), which can lead to "…inconsistent reliability and poor interoperability of different disaster data compilation initiatives" (Below et al. 2009).

There are several global databases to record disaster events; these include, the EM-Dat (CRED), Sigma (Swiss Re) and NatCatSERVICE (Munich Re), plus ITOS/GIST, the Joint Research Center (GDACS) and UNDP/GRIP. Centre for Research on the Epidemiology of Disasters (CRED) defines a disaster as “a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering” (Below et al. 2009). Moreover, the entry criteria for a disaster to be included in the CRED global loss database EM-Dat is that 10 or more people have been reported as killed and/or 100 or more people are reported as affected and/or there has been a call for international assistance/declaration of a state of emergency. In contrast, events that are entered in the Munich RE global loss database NatCatSERVICE, have resulted in human or material loss; and these events are then grouped into six categories (Löw and Wirtz 2010). These six damage categories are based on their financial and human impact, ranging from a natural event with very little economic impact to a great natural disaster (see Table 1.4). Further, national databases, such as the Canadian Disaster database, record significant disaster events that meet one or more of the following criteria: 10 or more people killed; 100 or more people affected/ injured/ infected/ evacuated or homeless; an appeal for national/international assistance; historical significance; and significant damage/interruption of normal processes such that the community affected cannot recover on its own (Government of Canada 2015).

Table 1.4 Breakdown into disaster categories

Category	Loss profile	Fatalities
Small-scale loss event	Small-scale property damage	1-9
Moderate loss event	Moderate property and structural damage	>10
Severe disaster	Severe property, infrastructure, and structural damage	>20
Major disaster	Major property, infrastructure, and structural damage	>100
Devastating disaster	Devastating losses within the affected region	>500
Great natural disaster	Region's ability to help itself clearly overtaxed, interregional/international assistance necessary, thousands of fatalities and/ or hundreds of thousands homeless, substantial economic losses (UN definitions). Insured losses reach exceptional orders of magnitude.	

Source: (Löw and Wirtz 2010)

Thus, a given event occurrence recognized as a *disaster*, and logged in one database, is not recorded in another. Events such as those with less than 10 fatalities, with less than 100 people affected, and with monetary impact, but not declared as state of emergency, are archived in NatCatSERVICE but not in EM-Dat. Therefore, the databases that use different entry criteria may give different interpretations for the same event (Below et al. 2009).

Consequently, it is not uncommon for numerous records to exist for the same event, sometimes with differing conclusions. For example, the 1815 volcanic eruption of Mount Tombora in Indonesia has different fatality records in different sources: 'Victims from volcanic eruptions: A revised database' (Tanguy et al. 1998) recorded the direct volcanic effect fatalities as ≈ 11,000 (and other post eruption famine and epidemic disease causing ≈ 49,000 fatalities). However, the National Oceanic and Atmospheric Administration (NOAA) database records the same event as having 10,000 volcanic fatalities (and 117,000 total fatalities). One can count fatalities resulting directly from the volcano, or one can consider fatalities as a result of the aftermath as well (e.g., secondary disasters, such as starvation). Moreover, one disaster may lead to another, resulting in shared disaster records. Therefore, separating the impacts due to one type of disaster from the other is problematic (Wirasinghe et al. 2013).

Furthermore, according to the EM-DAT database, the Colombian eruption in 1985 resulted in the highest economic loss ever recorded at around 1 billion USD. However, NOAA cites the highest economic loss due to a volcanic eruption to be the 1980 Mt. St. Helen’s eruption in Washington, USA, at 2 billion USD. This is another example of inconsistency among databases. Several such discrepancies exist between various sources of information, and they complicate the interpretation of trends in disaster data.

Historical records are the foundational base for understanding disasters, and numerous techniques have been applied to record these events. However, data collection standards of disasters vary among countries and, therefore, comparisons across space and time are difficult. Additionally, databases that compile disaster events at the national scale face issues with disasters that have impacts at the regional or continental scale. The same disaster event can also have very different impacts in various countries (Löw and Wirtz 2010), and thus the interpretation of scale for the same event can be different from one country to the other. Therefore, global disaster classification with common standards is an important contribution to improving the quality and reliability of international disaster databases (Löw and Wirtz 2010).

1.3 Research Questions

Therefore, this research addresses the following primary research questions:

A. How many levels are required to *clearly* differentiate the impact of natural disasters?

B. How are these levels used to clearly distinguish the various degrees of natural disasters?

The second basic questions can be sub-divided into the following questions, and the answers to these questions are the foundation for this research.

a. Are the existing (i) qualitative and (ii) quantitative techniques that emergency responders and others currently use adequate to clearly distinguished the severity levels of natural disasters?

b. If not, is there a substitute (i) qualitative and (ii) quantitative technique to categorize the severity of natural disasters?

c. How does this substitute (i) qualitative and (ii) quantitative technique adequately compare the severity level of natural disasters?

1.4 Research Objectives

This work proposes a severity classification approach for natural disasters by developing a global severity scale to rank and categorize the severity of all types of natural disasters, and to help responders understand the disaster continuum. The UDSC has been developed by answering the above-mentioned research questions. Specifically, the main objectives for the research study are as follows:

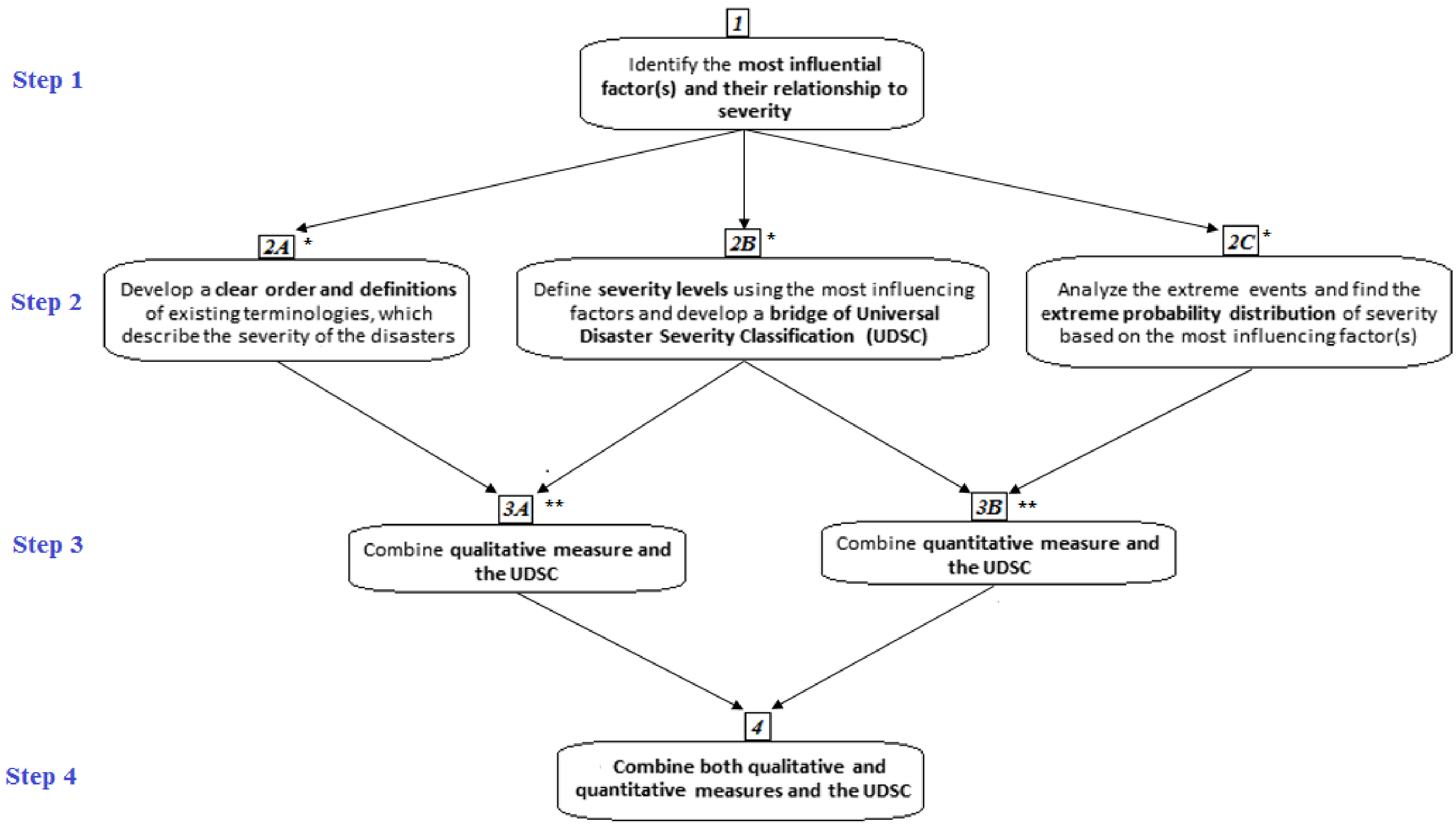
1. To create a foundation for the Universal Disaster Severity Classification (UDSC) with a considerable number of levels and colour coding. The foundation for the UDSC is a bridge between qualitative and quantitative techniques.

2. To develop a qualitative measure: a clear order and definitions of existing terminologies, which describes the severity of disasters.
3. To develop a disaster severity scale (initial quantitative measure) that is based on the most influencing factor(s) that describe the range of severity levels of natural disasters worldwide.
4. To develop the UDSC by combining the qualitative and quantitative measures with the foundation of the UDSC.

1.5 Research Methodology

The process of developing a Universal Disaster Severity Classification (UDSC) is briefly discussed in this section. Figure 1.2 shows the seven components of the UDSC with four main steps that are used to define the UDSC. The left side of the figure (2A and 3A) shows the qualitative branch, the right side (2C and 3B) shows the quantitative branch, the middle section (2B) shows the foundation of the UDSC, and the bottom section (4) shows the UDSC. The steps need to be completed in order, but the components within each step (e.g., 2A, 2B, and 2C for Step 2, and 3A and 3B for Step 3) can be done in any order within that step.

In Step 1, the most important influencing factors related to severity were identified by their relationship to severity (see Chapters 2 and 3). In Step 2A, a clear order and definitions of existing terminologies for the severity of disasters was developed (see Chapter 5), by attaining the Objective 2.



* Components 2A, 2B, and 2C do not need to be completed in sequence, but may be completed in any order, as part of Step 2.
** Similar to Step 2, component 3A and 3B can be completed interchangeably.

Figure 1.2 Key steps to define an Universal Disaster Severity Classification

In Step 2B, the base of a UDSC—a bridge between quantitative and qualitative techniques—is developed by defining the severity levels of extreme events using the most important influencing factors related to severity (see Chapter 4), by attaining the Objective 1. In Step 2C, extreme cases of disaster events, based on the most important influencing factor, are analyzed using extreme value theory, and then the best model fit of the Extreme Probability Distribution Function (EPDF) is selected (see Chapter 6). In Step 3A, the qualitative measure is combined with the UDSC (see Chapter 5). In Step 3B, the severity levels of extreme events are defined by using the EPDF, which offers criteria for an initial quantitative disaster severity scale (see Chapter 6), by attaining the Objective 3. This quantitative measure is combined with the previous (Chapter 5) qualitative scale in the complete UDSC (see Chapter 6) in Step 4, by attaining the Objective 4.

1.6 Research Deliverables

I. Comparative analysis of natural disasters based on physical aspects, disaster prediction, detection, impact, and mitigation methods (see Chapter 2).

II. Analysis of different methods to compare the different types of natural disasters (see Sections 1.2, 3.1, 3.3, 5.1, 5.2, 5.4, 0, and 6.2).

III. Analysis of natural disasters impact factors and their relationship to existing scales (see Chapter 3).

IV. Creation of the foundation of the Universal Disaster Severity Classification (UDSC), a bridge between qualitative and quantitative techniques (see Section 4.2).

V. The order of seriousness and clear definitions of existing disaster terminologies (see Sections 5.3 and 5.4).

VI. The distribution of probabilities of extreme events based on the most influencing impact factor(s) (see Sections 6.2 and 7.1.1.1.3, 7.1.1.2.3, and 7.1.2).

VII. An initial disaster severity scale based on the most influencing impact factor(s) to describe the different severity levels of natural disasters that occur worldwide (see Section 6.2).

VIII. Creation of a UDSC to measure, rank, and compare all types of natural disasters (see Section 6.2.3 and 8.1)

IX. Rankings of different types of natural disasters according to the severity with a UDSC (see Sections 6.2.1, 6.2.3, and 7.1.2).

X. The estimates of the probabilities of extreme natural disasters based on different perspectives (see Sections 6.2.1., 6.2.3, 7.1.1, and 7.1.2).

XI. Improvements of disaster management techniques to properly respond when disaster occur, and improvements of global disaster databases to create/ make more accurate disaster information (see Section 5.1.1 and Chapter 8).

1.7 Importance of Universal Disaster Severity Classification

The primary advantage of having a UDSC is that it provides a consistent method for all stakeholders to measure the severity of all types of disasters. In addition, it can be adapted to any language, country or culture. Moreover, a common scale is more informative than the variety of scales currently used for different disaster types, as the classification applies to all types of disasters. Furthermore, the proposed scale also applies to disasters, where quantitative scales are currently not available to rank and classify their severity.

A common disaster severity scale gives an overall picture of a disaster, because it provides relative comparisons among disasters of various degrees, by using a set of criteria to make comparisons and rankings. Therefore, another advantage of having a universal classification for all types natural disasters is that it yields independent quantitative estimates of the magnitude of a disaster. This unified way of describing disasters will help emergency managers to properly identify the impact of disasters, and allocate the appropriate resources.

In addition, ranking of disasters according to severity is also helpful for disaster compensation and insurance policies, in order to assess disasters in common way. This assessment of severity or the rankings provides decision capabilities to research communities, and to disaster information management processing, because it classifies disasters according to severity. This classification helps to more easily recognize an event occurrence, and manage the associated data. Another advantage of the UDSC is that it generates a common communication platform to compare the impacts of disasters, which will be applicable to diverse groups including civilians and responders. Therefore, severity classification may benefit emergency responders and disaster managers, insurance managers and estimators, national/regional/local governments, NGO's, local relief agencies, media outlets, research community, reporters, and the general public. Figure 1.3 summarize the benefits of a global severity scale. It also provides a foundation to develop an advanced scale to classify and compare disaster occurrences worldwide, though the analysis is subject to many limitations. This research aligns with the priority of the Sendai

Framework for Disaster Risk Reduction 2015-2030 as it improves understanding of disaster risk.

Figure 1.3 Benefits of a common global severity scale

1.7.1 Cyclic effect of Universal Disaster Severity Classification

The previous discussion related to how understanding the disaster continuum has a practical value, however, it also has an academic value. For example, if we have an accurate disaster database, more research can be conducted in the disaster mitigation field, in order to improve disaster preparedness technology, and so on.

Nevertheless, to have a more advanced scale, we need:

- improved disaster data;
- enhanced databases;
- good recording systems; and
- precise disaster terminology;

These requirements do not stand alone, but are interconnected with each other, which means that in order to meet each, all requirements must be developed at the same time. The interconnected nature of these requirements is shown in Figure 1.4.

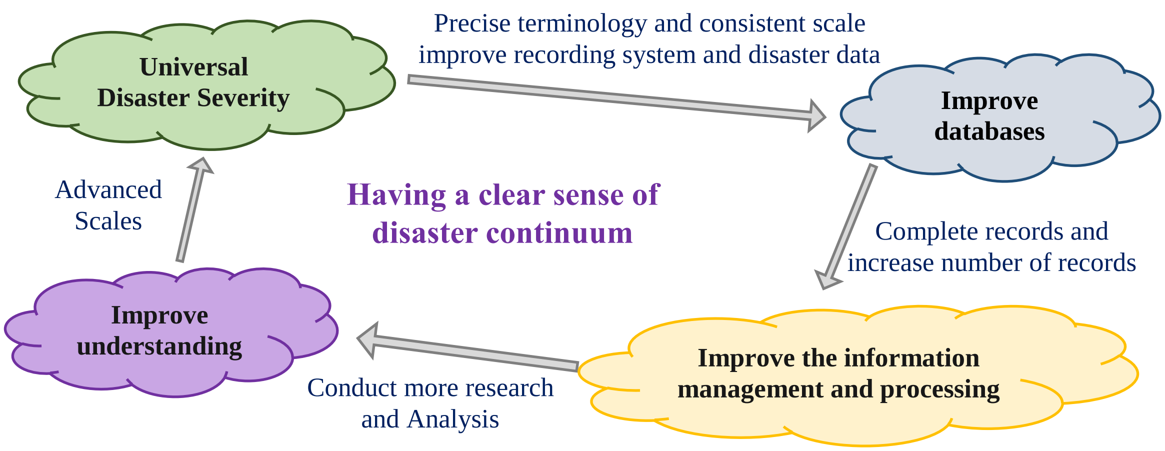


Figure 1.4 Cyclic effect of a Universal Disaster Severity Classification

1.8 Outline of the Thesis

The thesis is organized into eight chapters; the summary of the rest of the thesis is as follows. Chapter 2 presents a comprehensive literature review of natural disaster categories. The different types of natural disasters are compared according to their physical aspects, prediction and detection methods, impact, and mitigation methods.

Chapter 3 reviews quantitative measurements used in disaster mitigation efforts. Then, the weaknesses of existing scales are examined. In this chapter, impact factors that reflect the severity of a natural disaster are defined. The relationship between impact factors and existing individual scales are also analyzed. The key influencing factors that reflect severity are designated.

Chapter 4 addresses the first objective of the research by introducing the foundation of the Universal Disaster Severity Classification (UDSC), a bridge between qualitative and quantitative techniques.

Chapter 5 addresses the second objectives of the research. First, it reviews qualitative measurements used in disaster mitigation efforts. Then, the weaknesses of existing indexes are examined. The order of seriousness of a disaster, and a method to clearly distinguish existing terminologies are also proposed in this chapter. Then, this qualitative measure is combined with the foundation of the UDSC. Finally, a mechanism to use UDSC according the different applications, is introduced.

Chapter 6 addresses the third objective of the research. The most influencing factor (s) of severity is used to create/ develop an initial quantitative disaster severity scale. Then this quantitative technique is combined with the foundation of the UDSC. The classification of different types of natural disasters is also introduced in this chapter.

Chapter 7 addresses the different types of disaster in which are compared and contrasted using extreme probabilities of severe events and the UDSC.

Finally, Chapter 8 summarises the solutions to the research questions of this research. It then discusses the advantages and limitations of the UDSC, and techniques for improvement and development of a more advance scale. The problems of proposing such an advanced scale are discussed, and techniques are outlined to improve the disaster data management system. Finally, the chapter concludes by discussing applications, and making recommendation for future work.

Chapter Two: COMPARATIVE ANALYSIS OF NATURAL DISASTERS

Natural Disasters arise in diverse forms and dimensions. Prior to classifying a disaster based on severity, a comparative analysis was conducted in order to increase understanding of how one disaster differs from another, and how they are similar (as the *Deliverable I*). Thus, this chapter presents a detailed profile of the origins and triggers of various disasters, and reviews physical aspects, prediction/detection, impact and mitigation measures for selected types of disasters.

2.1 Disaster profile

Disasters can be categorised based on the nature of the cause of the events. Therefore, the initial classification of disasters is either the event triggered by nature or human. Human-caused disasters are further divided into industrial accident, transport accident, and miscellaneous. Natural disasters can be grouped based on the origin; biological, climatological, extraterrestrial, geophysical, hydrological, and meteorological. These can be further classified under main type, sub-type and secondary-sub type, which divides broad groups to specific types of disaster (Below et al. 2009; Hristidis et al. 2010) as shown in Figure 2.1.

2.2 Comparative Analysis of Natural Disasters

The selected events in the full comparative analysis include natural events that represent all six "Groups" (Figure 2.1 is based on Below et al. 2009 and Hristidis et al. 2010) of natural disasters mention previously, but not the human caused events. Table 2.1 shows the thirty-six cases of disasters, covering all six groups of natural disasters, which were considered in this comparative analysis.

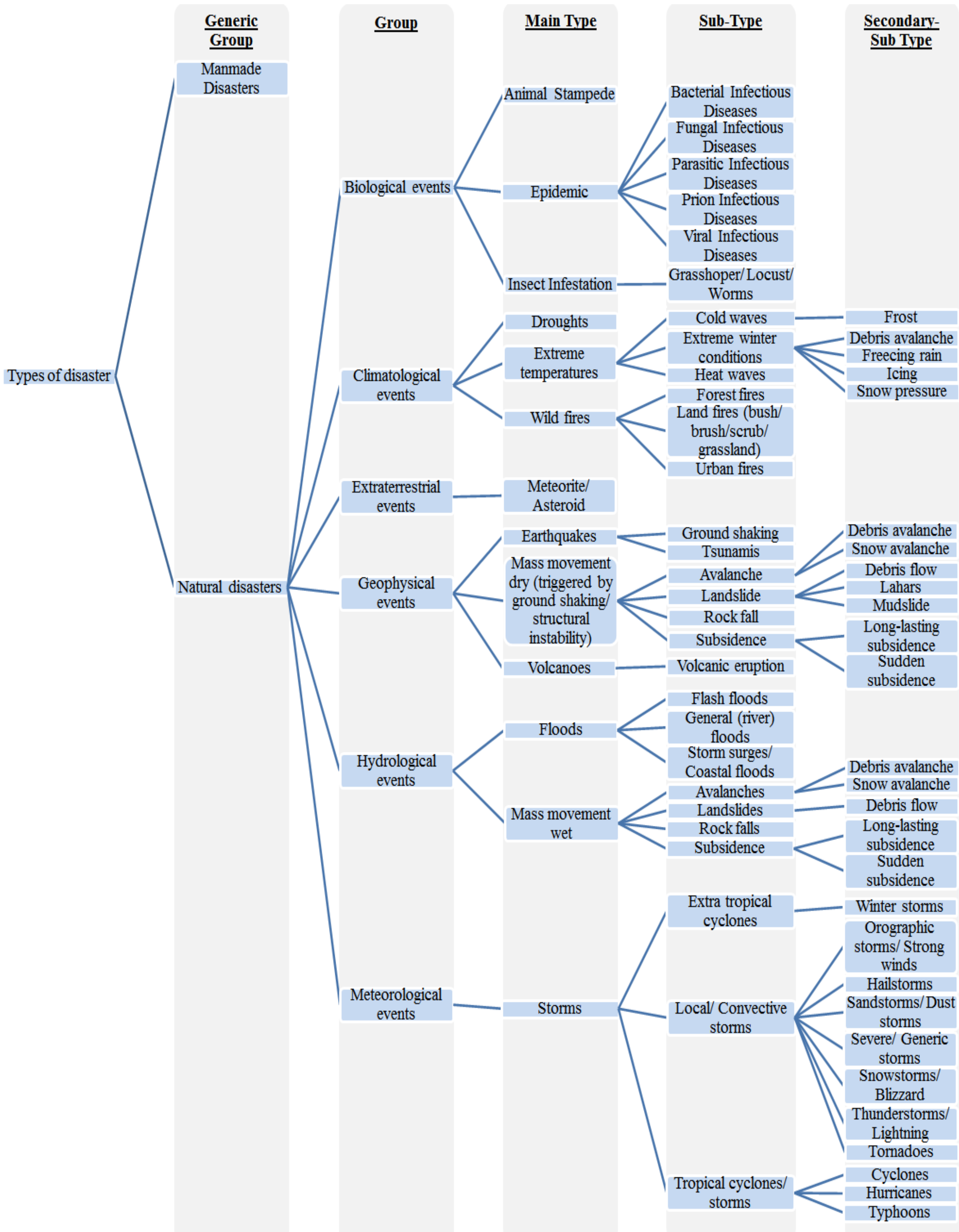


Figure 2.1 Disaster Profile

Table 2.1 Disaster types included in (full/ partial) comparative analysis

Biological	Epidemic	Bacterial disease	Parasitic disease	Viral disease	Insect Infestation		
Climatological	Drought	Cold wave	Extreme winter condition	Freezing rain	Ice storm	Heatwave	
	Wildfire	Forest fire	Land fire	Urban fire	Global warming		
Extraterrestrial	Meteoroid Impact						
Geophysical	Earthquake	Tsunami	Avalanche *	Landslide *	Subsidence *	Rock fall *	Volcano
Hydrological	Flood	Flash flood	Avalanche**	Landslide **	Subsidence **	Rock fall **	
Meteorological	Storm Surge	Blizzard	Lightning	Tornado	Cyclone	Hurricane	

* Mass Movement Dry; ** Mass Movement Wet

A partial comparative analysis was conducted on the possible impact of epidemic (such as bacterial, parasitic, and viral diseases), extreme temperature, global warming, insect infestation, slow-moving disaster (including drought), winter disaster (such as avalanche, blizzard, ice/ freezing rain, cold wave, and ice storm) and impact by a medium/small space object.

This analysis reflects the situation from first detection of an event through to completion of an evacuation, when necessary. It focuses on: definitions, magnitude, region of impact, fatalities, affected population, cost of damage, frequency of occurrence, and intensity of various natural events. This research also considers our ability to: detect a natural event, to estimate the location and direction, to estimate future locations and path of movement, to issue a clear warning, and to evacuate people on time. In addition, this comparative analysis also examines the ability of people to receive a warning and the amount of advance warning time; the ability to the accepted overall mitigation system; and the level of education about a given event. Ways in which existing mitigation systems can be improved, will be discussed for various types of disasters. The following sub-sections cope with different disasters according to their formation, physical aspects, historical impacts, and how they can detect, predict, and mitigate.

2.2.1 Physical Aspects of Natural Disasters

Disasters can be compared using physical aspects, such information is useful to understand how one disaster is different from another. Table 2.2 to Table 2.4 provide definitions, trigger mechanism, magnitude metric, and frequency of disasters with nineteen disaster cases.

Table 2.2 Physical Aspects of Climatological, and Extraterrestrial Events

Type	Definition	Trigger Mechanism	Magnitude Metric	Global Frequency of Occurrence
Drought	A deficiency of moisture that results in adverse impacts on people, animals, or vegetation over a sizeable area [1]	▪ Extremely low precipitation for a long period of time	▪ No quantitative scale [2] ▪ Several qualitative indexes are available: Meteorological Drought Index; Hydrological Drought Index; Agricultural Drought Index; and Economic Drought Index	Greater than 10 drought events per country in most of the African countries (from 1970 to 2004) [3]
Freezing rain	Rain that falls as a liquid but freezes into glaze upon contact with the ground. [1]	▪ Rain that falls when surface temperatures are below freezing [6]	▪ Centimeters [6]	Data not available
Ice storm	Damaging accumulations of ice during freezing rain situations [1]	▪ A layer of warm air is sandwiched between a cold storm aloft and cold air near the ground ▪ Freezing rain [8]	▪ Centimeters [8] ▪ Accumulation of ice (height) on exposed surfaces	Data not available
Global warming	An overall increase in world temperatures due to atmospheric heat being trapped by greenhouse gases [1]	▪ Natural variability ▪ Human influence on Changing in atmospheric composition	▪ Rise in sea levels ▪ Increase in CO_2 Concentrations ▪ Retreat in Snow Cover ▪ Increase in upper Ocean Heat Content [7]	Data not available
Forest fire	A fire in scrub or a forest, especially one that spreads rapidly [2]	▪ Sun's heat ▪ Lightning ▪ Dried-out vegetation ▪ Wind	▪ Damaged area ▪ Intensity ▪ Rate of spread [4]	In Australia, around 52,000 bushfires per year (Bryant 2008) [5]
Meteoroid Impact	A small body travelling in the solar system that enters the earth's atmosphere [2]	▪ Space debris colliding with the Earth	▪ Energy released ▪ Minimum orbit intersection distance ▪ Absolute magnitude [9]	45,458 - In the world - Meteoritical Bulletin Database, April, 6, 2013 [10]

Sources: [1] (National Oceanic and Atmospheric Administration 2009); [2] (Gad-el-Hak 2008a); [3] (Kenya Meteorological Department n.d.); [4] (Commonwealth Scientific and Industrial Research Organisation (CSIRO) n.d.); [5] (Australian Institute of Criminology 2009); [6] ("Wikipedia: The Free Encyclopedia" n.d.); [7] (National Oceanic and Atmospheric Administration -NOAA n.d.); [8] (Hosek et al. 2011); [9] (NASA: National Aeronautics And Space Administration n.d.); [10] (Korotev 2015);

Note: Climatological; Extraterrestrial

Table 2.3 Physical Aspects of Geophysical, and Hydrological Events

Type	Definition	Trigger Mechanism	Magnitude Metric	Global Frequency of Occurrence
Earthquake	A sudden violent shaking of the ground, typically causing great destruction, as a result of volcanic action, or movements within the earth's crust [1]	▪ Volcanic activity or the sudden release of tectonic stress along a fault line [2]	▪ Magnitude is measured using the Richter Scale (0-10.0+) ▪ Intensity is measured using four different scales: Rossi-Forel (I-X); Japanese (0-VII); European (I-XII); and Modified Mercalli (I-XII)]	▪ Smaller earthquakes occur frequently ▪ More severe earthquakes (> Ms 7) occur 18-20 per year [3]
Tsunami	A series of long-period waves (on the order of tens of minutes) that are usually generated by an sudden disturbance that displaces massive amounts of water, such as an earthquake occurring on or near the sea floor [4]	▪ Earthquakes ▪ Undersea landslides ▪ Volcanoes ▪ Meteorite hits [5]	▪ Wave Height ▪ Number of waves ▪ Damage area	▪ 18 events from 1980-2008 [6] ▪ From 2006 – 2008 the Pacific Tsunami Warning Centre issued 52 tsunami alerts for six tsunamis, two of which resulted in significant loss of life [7]
Volcano	A crater on the Earth's crust where hot magma, hot vapour, molten rock, debris, and gases from the planet's interior are emitted [8]	▪ Increase in the magma chamber pressure ▪ Earthquakes	▪ Volcanic Explosivity Index (0-8)	▪ On average 50 - 60 volcanoes are active each year [3]
Avalanche	A mass of snow, rock, and/or ice falling down a mountain or incline [4]	▪ Instability of the snow pack and the terrain ▪ Major temperature changes ▪ Rapid wind speed ▪ Man-made influences	▪ Avalanche size classification (0-5) [9]	Data unavailable
Landslide	A collapse of a mass of earth or rock from a mountain or cliff [1]	▪ Hydrological/ Geophysical events [10]	▪ Damage area [11]	Data unavailable

Type	Definition	Trigger Mechanism	Magnitude Metric	Global Frequency of Occurrence
Flash flood	A rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level [4]	▪ Intense rainfall ▪ A dam or levee failure ▪ An ice jam [4]	▪ Inundation area ▪ Height	Data unavailable
Flood	An overflow of a large amount of water beyond its normal limits, especially over what is normally dry land [1]	▪ Extreme rainfall ▪ A wind storm [12]	▪ Peak level of the water at a particular location in a waterway	▪ Variable but shaped by geography and climate (e.g., monsoon) ▪ The frequency is captured by phrases like "100-year flood" or "500-year flood"

Sources: [1] (Gad-el-Hak 2008a); [2] (Sanjeewa Wickramaratne, 2010 - Encyclopaedia Encarta, 2009); [3] (Bin, Haiyan, & Peng, 2009); [4] (National Oceanic and Atmospheric Administration 2009); [5] (Sanjeewa Wickramaratne, 2010); [6] (Statistic Brain Research Institute 2016); [7] (Bureau of Meteorology 2016); [8] (Caldera and Wirasinghe 2014); [9] (Jamieson 1995); [10] (Löw and Wirtz 2010); [11] (Guzzetti et al. 2006); [12] (Below et al. 2009);
Note: Geophysical; Both Geophysical and Hydrological; Hydrological

Table 2.4 Physical Aspects of Meteorological Events

Type	Definition	Trigger Mechanism	Magnitude Metric	Global Frequency of Occurrence
Storm Surge	An abnormal rise in sea level accompanying a hurricane or other intense storm [1]	Heavy rain and wind	Surge height measured as the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone [1]	Data unavailable
Blizzard	A combination of sustained wind or frequent gusts to 56km/h or greater; and considerable falling and/or blowing snow (i.e., reducing visibility frequently to less than 0.4 Km) for at least 3 hours [1]	Cold air at the surface, lots of moisture, and lift. Warm air must rise over cold air.	▪ Meters of snow ▪ Wind speed Category (1-5)	10.7 blizzards per year [2]

Type	Definition	Trigger Mechanism	Magnitude Metric	Global Frequency of Occurrence
Lightning	The occurrence of a natural electrical discharge produced by a thunderstorm. The discharge may occur within or between clouds, between the cloud and air, between a cloud and the ground or between the ground and a cloud. [1]	Turbulent wind environment and formation of an electric field [3]	Flashes per unit area per unit of time [4]	51 – 55 cloud-to-cloud lightning strikes each second 10 – 14 cloud-to-ground lightning strikes each second [5]
Tornado	A violently rotating column of air, usually descending from a cumulonimbus, with circulation reaching the ground. It nearly always starts as a funnel cloud and may be accompanied by a loud roaring noise [1]	Various meteorological conditions: usually, occur where cold fronts clash with warm fronts, and associated with strong winds and heavy rain or hail [6]	Enhanced Fujita scale (EF-Scale) (0-5)	More than 1000 tornadoes annually in the USA [7] Data for other regions not available
Cyclone	A large-scale circulation of winds around a central region of low atmospheric pressure, counter-clockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere [1]	Low pressure systems	Tropical Cyclone Intensity Scales (categorization depends on what basin the system is located in)	About 90 tropical cyclones (including tropical storms, strong tropical storms, cyclonic storms, typhoons, hurricanes, strong cyclonic storms) occur annually [8]
Hurricane	A tropical cyclone in the Atlantic, Caribbean Sea, Gulf of Mexico, or eastern Pacific, where the maximum 1-minute sustained surface wind is 74 mph (64 knots) or greater [1] ▪ In the western Pacific, hurricanes are called "typhoons," and similar storms in the Indian Ocean are called "cyclones." [9]	Tropical circulation and storms with winds greater than 100km/h	Saffir-Simpson scale (Category 1-5)[10]	30 hurricanes annually [11]

Sources: [1] (National Oceanic and Atmospheric Administration 2009); [2] (Schwartz and Schmidlin 2002); [3] (Environment Canada n.d.); [4] (Mills et al. 2010); [5] (Mackerras et al. 1998); [6] (Caldera et al. 2016b); [7] (NSSL 2015); [8] (Bin, Haiyan, & Peng, 2009); [9] ("Wikipedia: The Free Encyclopedia" n.d.); [10] (Gad-el-Hak 2008a); [11] (NASA 2013)

Note that each of the nineteen disasters in Table 2.2 to Table 2.4 has a separate and unrelated scale classifications, and some have no systemized matrices available and simply measured by geographic measures.

2.2.2 Natural Disaster Prediction and Detection

In this section, disaster detection and prediction is analyzed to understand different types of disaster, using the previously considered nineteen cases. Table 2.5 and Table 2.7 elaborate the aspect of event prediction, detection, confirmation, and the estimated time interval from detection to the actual occurrence. This illustrates how different disasters are spotted, forecast, the mechanisms, and the time between recognizing an event going to occur and the actual occurrence. Considering each of the nineteen categories, disaster impact time vary from extremely short time periods measured in seconds, to years or even decades or centuries.

Table 2.5 Disaster Prediction/Detection of Climatological and Extraterrestrial Events

Type	Ability to Detect and Track	Mechanism	Advanced Estimated Time
Drought	Can be predicted	▪ Analysing the atmospheric variability in the region	Weeks-months
Freezing rain	Cannot be predicted. Freezing rain is one of the most difficult events to forecast [1]	▪ It is possible to estimate the area covered by freezing rain with radars indirectly [2] ▪ Using prediction models and real-time information	0-several minutes
Ice storm	Can be predicted	▪ Using Numerical Weather Prediction (NWP) models [3]	Although it ca be predicted, some storms still occur with little or no warning [2]
Global warming	Can be predicted	▪ Using prediction models	Years-decades
Forest fire	Approximate location and time can be predicted	▪ Using satellite, weather data to predict spread direction and intensity ▪ Using Fire Danger Rating to provide early warning of the potential for serious forest fires based on daily weather data [4]	Up to two weeks [4]
Meteoroid Impact	Only large meteor strikes can be predicted [5]	▪ Space observation by ground based & satellite telescopes	Days-decades [6]

Sources: [1] (Department of Atmospheric Sciences (DAS) the University of Illinois n.d.); [2] (“Wikipedia: The Free Encyclopedia” n.d.); [3] (Hosek et al. 2011); [4] (de Groot et al. 2006); [5] (NASA: National Aeronautics And Space Administration n.d.); [6] (Wirasinghe 2012)

Note: Climatological; Extraterrestrial

Table 2.6 Disaster Prediction/Detection of Geophysical and Hydrological Events

Type	Ability to Detect and Track	Mechanism	Advanced Estimated Time
Earthquake	Cannot be predicted accurately, general location is known but exact time and location is unknown [1, 2]	▪ Detection of foreshocks by dense local monitoring networks [2] ▪ Detection of sudden change in parameters by long term monitoring and examination of various sensors ▪ P-waves	About 20 seconds [1, 3]
Tsunami	Impact areas and arrival times can be predicted	▪ Detecting sea level changes using tide gauge records [4] ▪ Using tsunami modeling techniques	Minutes-hours [5]
Volcano	Cannot be predicted accurately, only the approximate time can be predicted through regular monitoring	▪ By closely monitoring of volcanoes, the risk levels can be estimated [6] ▪ Using thermal imaging techniques and satellite cameras to detect heat [7] ▪ Using gas samples and chemical sensors to measure sulfur levels [7] ▪ Using seismic monitoring to detect earthquakes [8] ▪ Using visual, cameras, survey, ground deformation, chemistry, gas, crater lakes, and remote satellite sense [7, 8]	Hours-days
Avalanche	Can be predicted	▪ Forecasts through snow stability evacuations and predictions of slope instability	Minutes-days
Landslide	Approximate locations can be predicted	▪ Using landslide zoning maps and extreme rainfall measurements ▪ Using the appearance of landslide warning signs	Minutes-days
Flash flood	Can be predicted, but there are sudden onset floods as well	▪ Using data such as rainfall intensity, duration, sudden rise of water levels	Minutes-hours
Flood	Can be predicted [9]	▪ Using Rainfall intensity measurements, river flow data and prediction models	Days-years

Sources: [1] (Gad-el-Hak, 2008a); [2] (Wickramaratne et al., 2012); [3] (Gad-el-Hak 2008a); [4] (Sanjeewa Wickramaratne, 2010); [5] (Wirasinghe 2012); [6] (USGS 2016); [7] (BBC 2016); [8] (GeoNet 2016); [9] (Bin, Haiyan, & Peng, 2009)

Note: Geophysical; Both Geophysical and Hydrological; Hydrological

Table 2.7 Disaster Prediction/Detection of Meteorological Events

Type	Ability to Detect and Track	Mechanism	Advanced Estimated Time
Storm Surge	Can be detected and tracked [1, 2]	▪ Offshore rise of water associated with a low-pressure weather system and wind ▪ It can be predicted using computerized numerical models [3]	Few hours-days
Blizzard	Can be predicted	▪ Detect extreme wind ▪ Numerical weather prediction models	Several hours before the onset of a storm
Lightning	Lightning areas can be detected but exact location is unknown	▪ Using lightning sensors to obtain electromagnetic pulse information [4]	Several hours prior to a thunderstorm.
Tornado	General location is known but exact time and location is unknown	▪ Using Doppler radar, ground truth information, approximate location of a tornado occurrence can be predicted.	Approximately15-30 minutes [5]
Cyclone	Can be detected and tracked [1, 2]	▪ Can be predicted the trajectory, probability of hit using forecast models	Days
Hurricane	Can be detected and tracked [1, 2]	▪ Once formed, the path and intensity can be predicted using heuristic models, empirical observations, and super computers [1]	Hurricane- 1 week [1, 2]

Sources: [1] (Gad-el-Hak, 2008a); [2] (Gad-el-Hak 2008a); [3] (Bin, Haiyan, & Peng, 2009); [4] (Rhome n.d.); [5] (Environment Canada n.d.)

2.2.3 Natural Disaster Impacts

Table 2.8 to Table 2.11 highlight the historical event, and major impacts, by analyzing the disaster events in recorded history. It summarizes the disaster impact considering the highest cases of fatalities, affected population; region of impact; cost of damage for each disaster type. In this section, 'Fatalities' are considered as the number of people who lost their life because of the disaster. In addition, the 'Total Number of Affected People' is the sum of injuries, homeless and affected. Injuries are the number of people suffering from physical injuries, trauma or an illness who require medical treatment as a direct result of a disaster. Homeless is the number of people whose house is destroyed or heavily damaged and therefore, need housing after a disaster. Affected is only the number of people who requiring immediate assistance during a period of emergency, (i.e. require basic survival needs such as food, water, shelter, sanitation and immediate medical assistance; e.g. the number of evacuees who are not injured or homeless). Moreover, the 'Economic Damage' (USD billions) is the amount of damage to property, crops, and livestock, which is given in United States Dollar (USD) in billions. The damage includes only the direct damage from the disaster. It could be different according to the location (e.g. a developed versus an underdeveloped location). Furthermore, 'Area Destroyed' describes the size of the regions affected in known examples. Also, the 'Damage Extent' refers to upper limit or maximum possible zone.

Table 2.8 Disaster Impacts of Biological Events

Type	Fatalities	Total No. of Affected People (in addition to fatalities)	Economic Damage (USD billions)
Epidemic	2,500,000 – 1917 Soviet Union Epidemic [1]	▪ 2,500,000 – 1917 Soviet Union Epidemic [1] ▪ 1,500,000 – 1991 Bangladesh Epidemic [1]	$7*10^{-6}$- 1969 Nicaragua Epidemic [1]
Bacterial disease	2,000,000 – 1920 India Bacterial disease [1]	513,997 – 2010 (to 2011) Jaiti Bacterial disease [1]	
Parasitic disease	3,290 – 1984 India Parasitic disease [1]	18,000,000 – 1923 Soviet Union Parasitic disease [1]	
Viral disease	423,000 – 1926 India Viral disease [1]	▪ 2,000,000 – 1918 Canada Viral disease [1] ▪ 2,000,000 – 1978 Japan Viral disease [1]	
Insect Infestation	N/A	2,300,000 – 2010 (to 2011) Madagascar Insect Infestation [1]	0.12- 2000 Australia Locust [1]

Sources: [1] (CRED 2016);

Table 2.9 Disaster Impacts of Climatological, and Extraterrestrial Events

Type	Fatalities	Total No. of Affected People (in addition to fatalities)	Area Destroyed	Economic Damage (USD in billions)	Damage Extent
Drought	3,000,000 – 1928 China [1]	300,000,000 2016, 2002, and 1987 India [1]	France, Germany, Italy, Portugal, Romania, Spain, United Kingdom [2]	20- 2012 U.S.A. [1]	Country-Continent
Cold wave	900 – 2002 India [1]	4,033,472 – 2011 China [1]		2.8- 1977 U.S.A. [1]	
Extreme winter condition	1317 – Afghanistan [1]	77,000,000 – 2008 China [1]		21.1- 2008 China [1]	
Freezing rain	68 passengers and crew- 1994 American Eagle Flight 4184 [3]	100,000 people were left without electricity, water or heating- 2010 Moscow region, Russia [4]	7,500 to 8,000 trees were completely destroyed and that an additional 5,000 to 7,000 were going to die, 1921 New England ice storm, from severe damage [5]	over 1- 1994, Southern United States a severe ice storm (primarily in Mississippi, Tennessee, and Alabama) [3]	
Heatwave	55,736 – 2010 Russian Federation [1]	3,000,500 – 1993 Australia [1]		▪ 4.4- 2003 France [1] ▪ 4.4- 2003 Italy [1]	
Wildfire	80 – 1949 France [1]	55,020 – 2008 U.S.A. [1]		2- 2008 U.S.A. [1]	
Forest fire	1,000 - 1918 U.S.A. [1]	3,000,000 – 1994 Indonesia [1]	▪ Average 5 million acres burn every year in the US [6] ▪ 5,899.95 km^2, Fort McMurray fire, Canada [7]	▪ 8- 1997 Sumatra & Kalimantan, Indonesia [1] ▪ 4.2- 1989 Labrador, Canada [1]	Village-Region
Land fire	180 – 2009 Australia [1]	640,064 – 2007 U.S.A. [1]		2.5- 2007 California province, U.S.A. [1]	
Urban fire	1,200-1871 U.S.A Fire [3]				
Meteoroid Impact	Not available	1,500 people were injured - 2013 the Chelyabinsk meteor airburst event, Russia [8]	2000 km^2 of Siberian forest – 1908 The Tunguska event 1908 [9]		City-World [10]

Sources: [1] (CRED 2016); [2] (MunichRE 2013); [3] ("Wikipedia: The Free Encyclopedia" n.d.); [4] (Photo-bear.com 2010); [5] (Department of Atmospheric Sciences (DAS) the University of Illinois n.d.); [6] (Pacific Disaster Center (PDC) n.d.); [7] (Government of Alberta 2016) ; [8] (Vergano 2013); [9] (The Planetary and Space Science Centre (PASSC) - University of New Brunswick Canada 2011); [10] (Wirasinghe 2012)

Note: ☐ Climatological; ☐ Extraterrestrial

Table 2.10 Disaster Impacts of Geophysical, and Hydrological Events

Type	Fatalities	Total No. of Affected People (in addition to fatalities)	Area Destroyed	Economic Damage (USD in billions)	Damage Extent
Earthquake	▪ 830,000-1556 Shaanxi Earthquake [1] ▪ 242,000-1976 China Ground movement [2] ▪ 74-2008 Kyrgyzstan Earthquake [2]	▪ 45,976,596-2008 China Ground movement [2] ▪ 13,529-2008 China Earthquake [2]	Port-au-Prince, Petionville, Jacmel, Carrefour, Leogane, Petit Goave, Gressier - 2010-Haiti Earthquake [3]	▪ 210-2011 Japan, Earthquake [2] ▪ 100 billion- 1995 Japan Ground movement [2]	City-Region [4]
Tsunami	▪ 220,000-2004 Indian Ocean Tsunami [3] ▪ 165,708-2004 Indonesia Tsunami [2]	1,019,306-2004 Sri Lanka Tsunami [2]	Sri Lanka, Indonesia, Thailand, India, Bangladesh, Myanmar, Maldives, Malaysia-2004 Indian Ocean Tsunami [3]	210-2011 Japan Tsunami 2011 [2]	10's-1000's Km [4]
Volcano	▪ 92,000-1815 Indonesia-Mount Tambora[1] ▪ 30,000-1902 Martinique Ash fall [2] ▪ 63-2014 Japan Volcanic Activity [2]	▪ 1,036,065-1991 Philippines Ash fall [2] ▪ 800,000-2015 Ecuador Lava flow [2] ▪ 130,042-2016 Ecuador Volcanic Activity [2]		1-1985 Colombia Ash fall [2]	
Avalanche	261-1992 Turkey [2]	1,750-1992 Russia [2]		0.0026-1992 Russia [2]	Village-city
	254-2015 Afghanistan [2]	38,000-1992 Viet Nam [2]		0.685-1999 Switzerland [2]	
Landslide	▪ 100,000-1920 Ningxia, China [5] ▪ 2,000-1962 Peru [2]	8,000-1989 Soviet Union [2]	25% of the city-1903 Heppner Flood, U.S.A [1]	0.2-1962 [2]	Village [4]
	12,000-1949 Soviet Union [2]	4,000,000-1966 Brazil [2]		0.9888-1983 Peru [2]	
Subsidence	34- 1993 Egypt [2]	300-1993 Egypt [2]			Village [4]
	287-2000 Philippines [2]	2,828-2000 Philippines [2]			
Rock fall	160-1983 Colombia [2]	697-2008 Egypt [2]			Village [4]

Type	Fatalities	Total No. of Affected People (in addition to fatalities)	Area Destroyed	Economic Damage (USD in billions)	Damage Extent
	33-2009 Peru [2]	55-2015 Indonesia [2]			
Flash flood	▪ 30,000-1999 Venezuela [2]; ▪ 2,200-1889 Johnstown, Dam Failure, U.S.A [1]	80,035,257-2002 China [2]		9.5-2010 Pakistan [2]	Village [4]
Flood	▪ 3,700,000-1931 China Riverine [2] ▪ 2,000,000 -1959 (to 1961) China [2] ▪ 2,000-1953 Netherlands Coastal flood[2]	▪ 238,973,000-1998 China Riverine [2]; ▪ 128,000,000 1993 India [2]; ▪ 7,200,000-2007 India Coastal Flood [2];		▪ 40-2011 Thailand Riverine [2] ▪ 11.6-2002 Germany [2] ▪ 7.44-2000 Japan Coastal flood [2]	City-Region-Continent [4]

Sources: [1] ("Wikipedia: The Free Encyclopedia" n.d.); [2] (CRED 2016); [3] (MunichRE 2013); [4] (Wirasinghe 2012); [5] (Zhang and Wang 2007)

Note: Geophysical; Both Geophysical and Hydrological; Hydrological

Table 2.11 Disaster Impacts of Meteorological Events

Type	Fatalities	Total No. of Affected People (in addition to fatalities)	Area Destroyed	Economic Damage (USD in billions)	Damage Extent
Storm Surge	▪ 1,222- 1994 Haiti Storm [1] ▪ 800- 1989 Bangladesh Convective storm [1] ▪ 88-1999 France Extra-Tropical Storm [1]	▪ 100,000,000- 2002 China Convective Storm [1]; ▪ 3,400,011- 1999 France Extra tropical storm [1]; ▪ 11,000,038- 1998 China Storm [1];	23,500 square kilometers- Myanmar: Ayeyawaddy, Yangon, Bugalay, Rangun, Irrawaddy, Bago, Karen, Mon, Laputta, Haing Kyi [2]	▪ 8- 2011 U.S.A. Convective Storm [1]; ▪ 14- 1999 France Extra-Tropical Storm [1]; ▪ 5- 1993 U.S.A. Storm [1];	Region -Countries [3]
Blizzard	129- 2008 Blizzard, South of China [3]	1.66 million- 2008, South of China [3]	119 thousand square kilometers of crops were affected, and 485,000 houses collapsed – 2008, South of China [3]	151.65- RBM (Renminbi)– 2008, South of China [3]	
Lightning	4,000-1856 Greece - Secondary explosion - Rhodes [4]	Not available	Several square meters	0.6- 1 CAD $ - Annual lightning-related costs in Canada CAD 600million to CAD 1 billion [5]	Village- City-Region [6]
Tornado	1,300-1989 Daulatpur-Salturia Tornado Bangladesh [7]	11,000,009- from 1980 to September 2008, U.S.A [8]		5- (from 1980 to September 2008), U.S.A [8]	City-Region [6]
Cyclone	300,000- 1970 Bangladesh Bhola Tropical Cyclone [1]	29,622,000- 2006 China Tropical cyclone [1];		125- 2005 U.S.A. Tropical Cyclone [1];	Region-Countries [3]
Hurricane	140,000- 2008 Hurricane Nargis, Burma [2]		Flooded in seven states of the U.S.A; New Orleans, Louisiana was crushed; 2005 Hurricane Katrina [3]		Region-Countries [3]

Sources: [1] (CRED 2016); [2] (MunichRE 2013); [3] (Bin et al. 2009); [4] (WordPress.com 2013); [5] (Mills et al. 2010); [6] (Wirasinghe 2012); [7] (Caldera et al. 2016b); [8] (PreventionWeb n.d.)

Information about the disaster is compared and contrasted to understand the different aspects of historical impacts of disasters, using thirty different events: avalanche, blizzard, cold wave, cyclone, earthquake, drought, epidemic, flash flood, flood, forest fire, freezing rain, heat wave, hurricane, insect infestation, land fire, landslide, lightning, tornado, meteoroid strike, rock fall, severe winter condition, storm surge, subsidence, tsunami, volcanic eruption, wildfire, urban fire, and bacterial, parasitic, and viral diseases. This illustrates the ranges and cumulative impact of several historical disaster events.

2.2.4 Natural Disaster Mitigation

Finally, different mitigation techniques used to cope with disasters are considered in order to understand each type of disaster. Table 2.12 summarizes mitigation measures to cope with the disaster events, using eighteen different classes: avalanche, blizzard, cyclone, earthquake, drought, flash flood, flood, forest fire, freezing rain, global warming, hurricane, landslide, lightning, tornado, meteoroid strike, storm surge, tsunami and volcanic eruption.

Table 2.12 Disaster Mitigation

Type	Mitigation
Drought	Increasing public awareness; Water management [1]
Freezing rain	Safety precautions for drivers and pedestrians; Removal of ice from transmission lines, power cables
Global warming	Cut carbon pollution by reducing our dependence on fossil fuels and increasing our use of clean, renewable energy; Implement policies that help us prepare for flooding, drought, storms and other consequences of climate change [2]
Forest fire	Maintaining a defensible space between houses and the outer edge of surrounding tree crowns; Maintaining a greenbelt immediately around the house using grass; Monitoring and early warning systems [3]
Meteoroid Impact	Early detection and warning systems; path alteration; Safe evacuation methods of cities
Earthquake	Improving earthquake resistance of structures; Early warning systems [1]
Tsunami	Buffer zone; Structural measures such as breakwaters, seawalls; Evacuation shelters, Early warnings; Public awareness programs
Volcano	Avoid being in the path of flow of the molten lava; Avoid use of electronic goods; During a volcanic activity, the best place to be would be indoors; Better housing construction methods to volcanic activity prone areas;
Avalanche	Get to a safe place; Diversion berms, reinforced concrete defense structures for roadside avalanches; Zoning [4]
Landslide	Maintaining the natural slope preserving the forest cover; Hazard zone mapping; Monitoring systems, where applicable; Land-use and building regulations; Early warning systems; Public awareness programs [5]
Flash flood	Maintaining the drainage system; Flood barriers; Delimitation of flood areas and securing of flood plains regulations; "Turn around and don't drown" [6]
Flood	Flood Barriers; Structural measures to improve flood safety in housing construction; Early warning systems; Land use restrictions
Blizzard	Early warnings; Safety precautions for drivers and pedestrians; Safety precautions to avoid wind-chill
Lightning	Take shelter immediately, preferably in a building with plumbing and wiring or all-metal automobile; Stay away from tall objects or anything made of metal, and avoid open water; Take shelter in a low lying area; Once indoors, stay away from electrical appliances and equipment, doors, windows, fireplaces, and anything else that will conduct electricity, such as sinks, tubs and showers; Avoid using a telephone that is connected to a landline; Stay there for 30 minutes following the last rumble of thunder; If you are in a car, do not get out if there are downed power lines nearby; If caught on the water, boats with cabins offer a safer environment, but it is still not ideal, and quickly get to shore [7]
Tornado	Early warning systems; Seeking shelter immediately
Cyclone/ Hurricane/ Storm Surge	Seek shelters immediately. If on water, get to shore as quickly as possible. Better housing construction methods; Public awareness and evacuation programs; Storm-shelters, Early detection and warning systems

Sources: [1] (Bin et al. 2009); [2] (The Natural Resources Defense Council n.d.); [3] (CRED 2013); [4] (Jamieson 1995); [5] (The International Federation of Red Cross and Red Crescent Societies (IFRC) n.d.); [6] ("Wikipedia: The Free Encyclopedia" n.d.); [7] (Environment Canada n.d.)

Note: Climatological; Extraterrestrial; Geophysical; Both Geophysical and Hydrological; Hydrological; Meteorological

2.3 Discussion

The aim of the literature review is to understand a broad range of natural disasters from low (such as lightning) to high (such as earthquake) severity from origin to mitigation. In particular, thirty-six disaster types (Table 2.1), covering all six groups of natural disasters, are considered in this comparative analysis. In addition, because the intention of this study is to provide a global level classification to all type of natural disasters winter disaster events (that are specific to cold areas); regional specific disasters (though they are specific to some regions); slow-moving disasters (including global warming, pandemics, droughts, insect infestation); and combined disaster (such as global warming, and droughts, though they do not usually cause direct fatalities and in many cases it is a secondary cause that leads to fatal incidents); are also included. In this analysis, although meteoroid impact does not have fatalities in recorded history, this research considers the falling of "meteoroids", which have gained much attention after the Russian meteor strike in 2013 that injured 1,500 people.

In order to understand the whole picture of different types of natural disaster, four main aspects are compared and contrasted, and four major information classes are gathered. First, by comparing the physical aspects of natural disasters (in Section 2.2.1) note that the magnitude metric has unrelated scale classifications, some disasters have no systemized matrices available and simply measured by geographic measures. Second, by comparing disaster prediction and detection (in Section 2.2.2) note that disaster impact times vary from extremely short time periods measured in seconds, to years or even decades or centuries. Third, by considering the disaster impacts (in Section 2.2.3) note that the ranges of different types of impact factors (i.e., fatalities, total number of affected people, area destroyed, economic damage) are different, as well, these ranges are wide in considering the damage extent. The different impact factors may give different characteristics of the disasters, because the highest cases of each impact factor gives different level of impact for each disaster. Thus, the cumulative impact of several historical disaster events are evident. Fourth, by considering the mitigation point of view (in Section 2.2.4) note that depending on the physical aspects and characteristics of disaster, the mitigation technique is varied.

2.4 Conclusion

Therefore, the lack of a common classification to measure disaster severity is identified. In addition, the different characteristics of the severity of various disasters can be recognized by using the different impact factors. Therefore, the relationship between severity (i.e., using the major indicators that society has accepted to measure disaster impacts) and the existing measurement system (i.e., using intensity/ magnitude scales) are explored in the next chapter.

Chapter Three: QUANTITATIVE MEASURES AND THEIR RELATIONSHIP TO SEVERITY

There are three main methods currently used to compare two or more natural disasters: using existing intensity/magnitude scales, using statistics, and using descriptive terms to compare the impacts. The first method, using existing scales, and the second method, using statistics, are discussed in this chapter (as part of the *Deliverable II*). The third method uses descriptive terms, is discussed in Chapter 5 (as the other part of the *Deliverable II*). In addition, the *research sub-questions: a(ii)* is answered in Section 3.1; and *b(ii)* is answered in Section 3.3. Also, the *Deliverables III (i.e., analysis of natural disasters impact factors and their relationship to existing scales)* is presented in this chapter.

3.1 Introduction

Research sub-question a(ii) Are the existing quantitative techniques (that emergency responders and so on, currently use adequate to clearly distinguished the severity levels of natural disasters?

Most of the literature is focused on studying science related to natural disasters, but there is little research emphasis regarding the measuring of the impact of these disasters. Expressing the level of impact can be complex because of the level of the impact for various types of natural disasters, in different countries or a range of time periods, changes with development, technology, and population.

3.1.1 Second method: using existing scales

All of the natural disasters range from local fires to massive tsunamis and adversely affect human communities, no matter what their shape and size. They impact human habitat, cause loss of life and injury; displace people, and can lead to depression and other health issues. Although the impact of these disasters are similar, currently, the severity of a disaster is measured on different scales.

3.1.1.1 Existing scales for different types of disasters

Currently, existing scales for natural disasters define severity levels in terms of intensity or magnitude. The Section 3.1.1.1 describes the existing scales for different types of natural disasters such as tornadoes, volcanic eruptions, earthquakes and tsunamis. The Section 3.1.1.2 describes the existing common techniques used to compare disasters.

3.1.1.1.1 Tornadoes

Various meteorological conditions give rise to the formation of tornadoes around the world (Fujita 1973). Usually, tornadoes occur where cold fronts interact with warm fronts, and are associated with strong winds and heavy rain or hail. They are violent rotating columns of air that extend from a thunderstorm cloud to the earth's surface (AMS 2015), and their wind speeds increase as with height. In many cases, more than one tornado is caused by a particular thunderstorm; these are called tornado outbreaks. These are classified as meteorological events (Löw, et. al, 2010).

Although tornadoes are a short-term phenomenon, which affect a limited area, they can move at speeds of 64-512 km per hour (40-318 mph) (NOAA 2007), have a high potential to create damage to property and cause a significant number of fatalities and injuries (Durage et al. 2012). Even a small funnel cloud that briefly touches down has the power to destroy. In addition, they also cause secondary disasters such as fires and floods.

Tornado spotting and reporting methods have changed over the last several decades; however, as Durage et al. (2015) stated, “Some tornadoes go undetected, unreported, or unverified.” The actual average number of tornadoes, or expected worldwide frequency of tornadoes, that occur each year is unknown. The central USA is the most tornado-prone region in the world, and is called Tornado Alley (Brooks et al. 2003). As Fujita (1973) stated, “The density of tornadoes may not represent the true distribution everywhere in the entire world because the public education and awareness toward tornadoes, population density, and the data collection system are quite different from country to country.” Although tornado events have been recorded on all continents except Antarctica, the information on their occurrence is fragmented and, in many cases, contradictory (Goliger and Milford 1998). Several discrepancies between various sources of information were also identified in the historical data on tornadoes. For example, Australia reportedly experiences the second highest number of tornadoes partly because its area is almost as large as the USA, excluding Alaska (Fujita 1973). However, Canada reportedly has the second highest tornado frequency in the world (Durage et al. 2014). In addition, changes in reported path size (Brooks 2004) and other evidence from environmental conditions in which storms form (Brooks and Craven 2002) suggest that data from the 1950s through the 1970s overestimate the damage caused by tornadoes (Brooks 2013). These discrepancies complicate the interpretation of trends in the data (Brooks 2013). Further, a lack of uniformity in standards for data collection in different countries, and changes in the way data are collected, make comparisons across space and time difficult (Brooks and Doswell III 2001a).

Previous to 1971 tornadoes were measured by their rotating speed only. The Fujita (F) scale (Fujita 1971) was created using wind speed as the sole damage indicator from a tornado (Table 3.1, first 3 columns), which made simplicity its greatest strength. However, it did not relate to construction practices in any particular part of the world. Thus, it could be applied to any geographical location and became an international standard. However, wind measurements from tornadoes are relatively rare (Doswell III and Burgess 1988). All of the tornadoes in the USA annually affect only a small total area (250–750 km^2); therefore, the probability of having anemometer measurements of wind speed, is small because even the few sensors within the area can be destroyed by tornadoes. Although the relationship between damage and wind speed is complex, damage continues to be the most useful indicator of tornado intensity and speed. Hence, the most common and practical way to determine the strength of a tornado is to examine the damage it caused. From the damage, the wind speeds can be estimated (Doswell III et al. 2009). In 1973, the Fujita- Pearson (FPP) scale (Fujita 1973) was designed to easily assess tornadoes by taking the product of path length and width of a tornado (Table 3.1, columns 4 to 7). The Pearson scale path length (P_L) is a measurement of the actual path length of a tornado, where L is defined as the total length of a storm's path, excluding the portion where the tornado was not on the ground. The Pearson scale width (Pw) is a measurement of the average width of a tornado damage area in the direction perpendicular to the path. The lifted portion of a tornado is excluded when calculating width. Therefore, the product of the length and mean width gives the tornado damage area. In the event of a tornado outbreak, each tornado is assessed using the FPP scale. However, the FPP scale may not be applicable for certain scale because differences between countries, and even within countries, in terms of construction practices result in inconsistent evaluations.

Table 3.1 F Scale and FPP Scale

Expected Damage	**Maximum Wind Speed (mph)**		**Path Length (mile)**		**Path Width**	
Light Damage	F0	40–72	P0	< 0.1	P0	< 18 yd.
Moderate Damage	F1	73–112	P1	0.1–3.1	P1	18-55 yd.
Considerable damage	F2	113–157	P2	3.2–9.9	P2	56-175 yd.
Severe Damage	F3	158–206	P3	10-31	P3	176-556 yd.
Devastating Damage	F4	207–260	P4	32-99	P4	0.3-0.9 mile
Incredible Damage	F5	261–318	P5	100-315	P5	1.0-3.1 mile

Therefore, an Enhanced Fujita (EF) scale as shown in Table 3.2, was implemented by the National Weather Service of the USA in 2007 to rate the damage of tornadoes in a more consistent and accurate manner. The major strength of the EF scale was that it provided a large set of damage indicators when assigning a wind speed rating to a tornado. It also incorporated 28 indicators include such things as building type, structures, and trees (NSSL 2015). Damage indicators are:

- small barns, farm outbuildings;
- 1 or 2 family residences;
- single-wide mobile homes;
- double-wide mobile homes;
- apartments, condominiums, townhouses (3 stories or less);
- motels;
- masonry apartments or motels;
- small retail buildings (fast food);
- small professional buildings (doctor office, branch bank);
- strip malls;
- large shopping malls;
- Institutional buildings (hospital, government. or university);
- large, isolated ("big box") retail buildings;
- automotive service buildings;
- automobile showrooms;
- school - 1-story elementary (interior or exterior halls);

- low-rise (1-4 story) buildings;
- mid-rise (5-20 story) buildings;
- high-rise (over 20 stories);
- metal building systems;
- service station canopy;
- warehouses (tilt-up walls or heavy timber);
- school - junior or senior high schools;
- transmission line towers;
- free-standing towers;
- free standing poles (light, flag, luminary);
- tree - hardwoods;
- tree – softwoods.

Table 3.2 EF Scale

Expected Damage	**Light**	**Moderate**	**Considerable**	**Severe**	**Devastating**	**Incredible**
Maximum Wind Speed (mph)	EF 0	EF 1	EF 2	EF 3	EF 4	EF 5
	65-85	86-110	111-135	136-165	166-200	Over 200

For each damage indicator, there were eight degrees of damage ranging from the beginning of visible damage to complete destruction (NSSL 2015). Even though the EF scale rates the strength of tornadoes by determining the wind speed based on property damage, it does not take into account the number of fatalities, injuries, or any human related factors. The EF scale can be used to compare the intensity of different types of tornadoes. However, it cannot be used to compare tornadoes with other types of natural disasters.

According to Durage (2014), "the frequent occurrence and high intensity of natural disasters can impose irreversible negative effects on people. Taking mitigation actions taken well in advance can avoid or significantly reduce the impacts of disasters." Introducing a severity scale that accounts for the human impact, in addition to property damage, is important for accurate, numeral impact assessment.

3.1.1.1.2 Volcanic Eruptions

The “fire from the earth”, a volcano, can be describe as a crater of the earth’s crust. Hot magma, hot vapor and gasses escape through a vent when they erupt. Volcanoes have played a major role in the formation of the Earth's atmosphere, ocean and continents throughout history. They are one of the natural disasters classified as a geophysical event (Löw and Wirtz 2010).

Volcanoes grow by adding extra layers and height with the accumulation of lava or ash. They can be classified according to the level of activity, as follows according to Siebert, Simkin, and Kimberly (2010):

- active (presently erupting),
- dormant (not presently erupting but could at future date), and
- extinct (no eruptions in recorded history).

In addition, volcanoes can be categorized according to their shapes and sizes such as:

- compound volcanoes (complex of cones),
- stratovolcanoes (composite alternating layers of lava and ash),
- somma volcanoes (a new central cone outgrowing the original caldera), and
- caldera (volcanic collapse crater).

Special types of volcanoes are also distinguished, such as super volcanoes or hot spots. Historical evidence of super volcanoes does not currently exist, however evidence for these massive phenomena have been observed in the geological record. Examples of some hot spots are Hawaii, Yellowstone National Park (United States), Iceland, Samoa, and Bermuda. Self (2006) has explained the possible aftermath of super volcanic eruptions, “It is more likely that the Earth will next experience a super-eruption than an impact from a large meteorite greater than 1 km in diameter. Depending on where the volcano is located, the effects will be felt globally or at least by a whole hemisphere”.

Volcanoes are found both on land and in the ocean (e.g. seamount volcanoes). Sigurdsson (2000) note that about 94% of known historical eruptions in the planet’s surface are concentrated in linear belts (total length: 32,000 km and width: 100-km), which cover less than 0.6% of the Earth's surface. In addition, he claims that 80% of the world's population lives in a nation with at least one Holocene volcano (active since the end of 'ice age', i.e. approximately 11,700 years) and that the resources for dealing with volcanic hazards are not evenly distributed. Moreover, he noted that, because of the generality of the word ‘active’, the exact figure of the world's active volcanoes cannot be accurately identified. However, an approximate number of 1,500 historically active or Holocene volcanoes are identified on the Earth’s surface. On average, 50-60 volcanoes are active each year (Natural Environment Research Council 2006). Mauna Loa in Hawaii is the world's largest active volcano, rising 13,677 feet above sea level; its top being over 28,000 feet above the nearby depth of the ocean floor (“Volcanoes” 2006).

For the most part, volcanoes are primary disasters; however, they can also be secondary disasters when triggered by earthquakes. Volcanoes can in turn, result in secondary disasters such as

- tsunamis (e.g. 1883- Krakatau in Indonesia),
- famines (e.g. 1815- Tambora in Indonesia),
- climate anomalies (e.g. 1815-Indonesia's Tambora causing June snow falls and crop failures in New England, U.S.A.),
- volcano collapses (e.g. 1792-Unzen in Japan),

- roof collapses,
- disease (e.g. 1991- Pinatubo in Philippines), and
- ash clouds (e.g. threat to air traffic–such as great circle routes to Japan over Alaska).

Volcano eruptions can also lead to

- pyroclastic flows (mixtures of hot gas and ash flowing at very high speeds, e.g. 100 to 200 km/h, leading to extreme heat and oxygen loss),
- lava flows (which are slow-moving but can destroy houses, roads, and other structures),
- pollution (emission of strong poisonous gasses such as sulfur dioxide, hydrogen chloride, and hydrogen fluoride),
- mudflows (e.g. 1985- Ruiz, Colombia),
- ash flows (e.g. 1902-Mt. Pelee, Martinique), and
- ash falls causes respiratory problems and coverage of houses, buildings, roads, and crops with ash, (e.g.1991-Chile's Cerro Hudson, Argentina and 79AD-Vesuvius in Italy).

The eruption risk level for a volcano can be estimated through close monitoring of temperature around the volcano, seismic activities, earthquakes, and so on. Nevertheless, the accurate estimation of volcano eruption is not currently possible; only the approximate time of eruption can be estimated. The estimated time to a volcanic eruption may be given in hours-days, or can simply be a 30 second warning alarm (Wirasinghe et al. 2013).

Volcanic Explosivity Index (VEI) is a general indicator of the explosive character of an eruption. This is shown in Table 3.3. Newhall and Self (1982) introduced this scale, which rates all eruptions in a range from 0 to 8. Intensity (column heights), magnitude (descriptive terms), and rate of energy release during an eruption (blast durations) are noted in this scale. When developing the VEI scale, researchers identified a requirement of quantitative or a semi-quantitative method for comparing eruptions. VEI can be used to compare the intensity of different types of volcano eruptions, however, VEI cannot be used to compare volcanic eruptions with other types of natural disasters.

Volcanology, unfortunately, has no instrumentally determined magnitude scale, like that used by seismologists for earthquakes. This may account for literature in subjective observation analog a “major” eruption might be another’s “moderate,” or even “small” event (Siebert et al. 2010). Therefore, it is not uncommon for numerous records to exist for the same event, sometimes with differing conclusions as explained in Section 1.2.2. For example, the 1815 eruption of Mount Tombora in Indonesia has different fatality records in different sources. Tanguy et al. (1998) recorded the direct volcanic effect fatalities as 11,000 (and other post eruption famine and epidemic disease causing 49,000 fatalities). However, this is given as 10,000 volcanic fatalities (117,000 total fatalities) in the NOAA database. Similarly, according to the EM-DAT database, the Colombian eruption in 1985 resulted in the highest economic losses at around US$ 1 billion. Whereas NOAA cites the highest economic losses due to a volcanic eruption to be the 1980 Mt. St. Helen eruption in Washington, USA, at US$ 2 billion. This is another example of inconsistency among databases.

Table 3.3 Volcanic Explosivity Index (VEI) criteria

VEI	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
General Description	Non- Explosive	Small	Moderate	Moderate-Large	Large	Very Large			
Volume of Tephra (m3)	<104	104-106	106-107	107-108	108-109	109-1010	1010-1011	1011-1012	1012<
Cloud Column Height (km) Above crater Above Sea level	<0.1	0.1-1	1-5	3-15	10-25	← >25 →			
Qualitative Description	Gentle	Effusive	← Explosive →		← Cataclysmic, paroxysmal, colossal →				
				← Severe, violent, terrific →					
Eruption Type		← Strombolian →			← Plinian →				
	← Hawaiian →			← Vulcanian →		← Ultra-Plinian →			
Duration (continuous blast)	← < 1hr →				← >12 hrs →				
			← 1-6 hrs →						
				← 6-12 hrs →					
Maximum explosivity	Lava flow	← Explosion →							
		← Phreatic →		- - - - - - - - →					
	Dome or mudflow								
Tropospheric Injection	Negligible	Minor	Moderate	← Substantial →					
Stratospheric Injection	None	None	None	Possible	Definite	← Significant →			
Eruptions	976	1239	3808	1083	412	168	50	6	0

Source: Table 8 from Siebert, Simkin, and Kimberly (2010)

Understanding of the mechanisms involved with volcanism is essential to predict severity levels of volcanic eruptions with use of available resources and technology,. The volcanism of a certain region is characterized based on its history; therefore, it is necessary to document its full breadth. Unless eruptions are documented at the time of their occurrence, essential data required for prediction may be lost (Siebert et al. 2010). Historical reports contain some, but not all of the necessary data; however, most reports contain only a brief and often ambiguous description of the eruptions (Newhall and Self 1982). Volcanoes of the World has (Simkin 1981) significantly contributed to the understanding of the classification of past volcanic events by using the VEI scale, on existing historical records. However, it was noted that that the VEI was inadequate with respect to some aspects of disaster classification, for example the climate effect.

3.1.1.1.3 Earthquakes

An earthquake is a consequence of a sudden energy release in the earth's crust. It creates seismic waves with destructive power that cause buildings to collapse. Every earthquake has five different measures (Esfeh et al., 2016):

- Epicenter: The latitude and longitude of the point where an earthquake originates. In historical events, it may be referred to as the location of maximum ground motion.
- Focal depth: The depth below the earth's surface where the first motion of the earthquake happens.
- Magnitude: A measure of the size of the event, which refers to the amount of energy released during an earthquake.
- Origin time: The time when the earthquake started.

There are a number of ways to measure the magnitude of an earthquake. The most widely used method is the Richter scale which was developed by Charles F. Richter and refers to the maximum energy release at the epicenter (Richter 1935). Specifically, the magnitude of an earthquake is evaluated based on the logarithm of the amplitude of the largest waves recorded by seismographs and the distance between the seismograph, and the epicenter of the earthquake. Because magnitude is representative of the earthquake itself, there is only one magnitude per earthquake. The Richter scale is ranges from 0 to 9.9, and it is determined soon after an earthquake (i.e., once scientists can compare the data from different seismograph stations). However, this scale only gives an approximation of the actual impact of an earthquake because it does not address the physical damage caused by the earthquake.

The destructive power of an earthquake varies depending on the composition of the ground in an area, and the design and placement of man-made structures. Therefore, by considering the effects and consequences of an earthquake at a given place, several intensity scales were developed (see Table 3.4). All these intensity scales are linear. The most commonly used intensity scale in the United States is the Modified Mercalli scale which was developed by the American seismologists Harry Wood and Frank Neumann (Wood and Neumann 1931). Intensities are expressed as Roman numerals and the common feature of the intensity scales are based on largely subjective interpretations. Intensity is determined using the information obtained after the occurrence of the seismic event, via questionnaire surveys and field investigations. It is based on observations from the people who experienced the earthquake. In this scale, the lower numbers indicated the intensity felt by the people, and higher numbers were based on the degree of structural damage. The further from the earthquake the less the damage.

Table 3.4 Comparison of Modified Mercalli (MM) and other intensity scales

Modified Mercalli	**Rossi-Forel**	**Japanese**	**European**
I	I	0	I
II	I-II	I	II
III	III	II	III
IV	IV-V	II-III	IV
V	V-VI	III	V
VI	VI-VII	IV	VI
VII	VIII- VIII+ to IX-	V	VIII
IX	IX+	V-VI	IX
X	X	VI	X
XI	-----	VII	XI
XII	-----	-----	XII

Source: (NOAA. 2015)

Table 3.5 shows the MMI scale. However, the amount of damage caused by the earthquake may not accurately record how strong it was. Therefore, both magnitude and intensity scales of an earthquake is needed to describe the power of the earthquake from two different perspectives.

Intensity scales estimate the physical damage caused by the earthquake, whereas magnitude scales evaluate the strength of the earthquake. Magnitude scales are considered scientific, while the Intensity scales are subjective. Also, unlike the magnitude, which is one number for each earthquake, there are many intensities, depending on the location. Nevertheless, none of these scales evaluate the impact such as fatalities, injuries, and property damage nor can they be compared with other disaster impacts.

Table 3.5 Modified Mercalli (MM) Intensity scale, Source: USGS, 2016

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

3.1.1.1.4 Tsunami

Generally, tsunamis are caused by undersea earthquakes or landslides, although there are very rare instances of volcanic eruptions, icebergs calving, or meteorites that displace a large water masses. A tsunami can travel thousands of kilometres over the sea. They can even pass unnoticed at sea, forming only a slight increase, approximately 0.3 m above the normal sea surface, because they have a small altitude (wave height) offshore and a very long wavelength (often 100 to 500 km). Tsunamis can have a period in the range of ten minutes to four hours. When they reach shallower water, their speed decreases and the height of the wave grows. Tsunamis may reach a maximum vertical height onshore above sea level (run-up height) of 100m elevation. The disastrous consequences of tsunamis can shatter lives and livelihoods and incur massive damage to properties and infrastructure.

Although the impact of tsunamis is limited to coastal areas, their destructive power entire ocean basins. For example, the 2004 Indian Ocean tsunami was among the deadliest natural disasters in human history; the death toll rose to nearly 300,000 in 14 countries bordering the Indian Ocean. During the 2004 tsunami, no evacuation order was issued for the South and South East Asian region (Wickramaratne et al. 2011), which resulted in thousands of deaths. This tsunami was caused by the third largest earthquake in recorded history, with magnitude of 9.2, that struck off the west coast of Sumatra, Indonesia. Indonesia observed a maximum onshore wave height of 50m (Wickramaratne 2010). Although tsunamis are secondary disasters, they can also be a source for tertiary disasters. An example of tsunamis, the Great East Japan earthquake, with a magnitude 9.0, which occurred on March 11, 2011. It generated a major tsunami that devastated large parts of Japan's north-eastern coastline, inundating over 400 km^2 of land, and resulting in 18,550 people killed or missing. At its highest point, the tsunami reached a height of 40.5 m. This tsunami caused a large number of tertiary disasters, including more than 80 fires, and the largest nuclear disaster (Fukushima Daiichi), since the Chernobyl (1986).

There is a lack of literature that analyses tsunami events in terms of severity. Currently, databases record tsunami parameters according to the following criteria (NOAA 2015) to measure the tsunami intensity: (i) the maximum water height above sea level is measured in meters; (ii) the total number of run-ups that display the run-up locations associated with a particular tsunami event; and (iii) tsunami intensity, $\log_2(2^{0.5} * h)$, which is defined by Soloviev and Go (1974), ranging from -5 to 10, where h is the maximum run-up height of the wave.

Each tsunami is unique and cannot be precisely predicted. Not all undersea earthquakes produce a tsunami. Though tsunamis have occurred throughout history, their unpredictability and infrequency make them difficult to study. There has been an increased focus on tsunami science and a rapid expansion in the tsunami modelling community since the 2004 Sumatra-Andaman Earthquake and subsequent Indian Ocean Tsunami. A tsunami hazard assessment considers not only how large a tsunami affecting a particular community may be, but also the likelihood of occurrence of a tsunami of a given magnitude. Thus, this assessment is known as a probabilistic tsunami hazard assessment (PTHA). Geist and Parsons (2006) used PTHA to determine the likelihood of tsunamis. PTHA was discussed from the viewpoint of integrating computational methods with an empirical analysis of past tsunami run-up. Craw (2008) used a probabilistic approach for tsunami inundation mapping. The method generates events of equal probability of occurrence by symmetric sampling of the source extremal distribution curve. According to Craw, this approach is useful for assessing risk and generating quantifiable results for mitigation efforts. Parwanto and Oyama (2014) conducted a statistical analysis and compared historical earthquake and tsunami disasters in Japan and Indonesia. The historical trend of these disasters from 1900-2012 was reviewed by taking into account earthquakes and tsunamis occurrences, and the numbers of deaths and missing people. It was found that the exponential distribution fitted the data of inter-occurrence times between two consecutive disasters, implying that the number of tsunamis in a given period had a Poisson distribution. Finally, results showed that the average number of inter-occurrence times for earthquakes and tsunamis were

186.23 days and 273 days, respectively. Burbidge et al. (2008) calculated the probability of a tsunami hazard for the coast of Western Australia. Tsunamis from great earthquakes along the Sumbawa, Java, and Sunda trenches have affected the western coasts of Australia. A probabilistic tsunami hazard was used to estimate offshore wave heights as a function of the return period. The tsunami heights along the Australian coasts results from a magnitude 8 earthquake with a return period of about 100 years were not high. However, those from a magnitude 9 earthquake, similar to the 2004 Sumatra-Andaman earthquake, with a return period of about 1000 years, would be very large and potentially cause damage.

3.1.1.1.5 Existing scales for different types of disasters in order to compare the severity

As briefly explained in Chapter 1, it especially is problematic to have different types of scales for different disasters because there is no relationship between these scales. Therefore, comparing levels of impact for different disasters is challenging. For example, the severity of earthquakes measured on the Richter scale cannot be compared to the severity of tornadoes measured on the F-scale or the severity of volcanic eruptions measured on the Volcanic Explosivity Index (VEI). These unrelated scales mean that emergency managers cannot properly identify the impact of disasters when responding to an event and allocating resources. Therefore, they cannot inform the general public as to the degree of the emergency.

The existing intensity/magnitude scales are not sufficient to assess the severity unless there is a direct relationship to impact factors, because there are many aspects that need to be considered such as, the number of fatalities, injuries, homeless, and evacuees, affected population, size of the affected area, and cost of damage. Therefore, the relationships between existing intensity/magnitude scales and impact factors are analyzed in Section 3.3 and its sub-sections.

3.1.1.2 Existing common severity scales

By using some statistics, which is discussed in Section 3.1.2, Disaster scope has been presented to differentiate the destructive capacity of a disaster by Gad-el-Hak (2008). As shown in Table 1.3, the disaster scope has five levels (from scope 1 to 5), which differentiate the severity of a disaster according to the number of displaced/ tormented/ injured/ killed people or, the adversely affected area of the event. However, the ranges proposed for casualties and the area affected are arbitrary. There is no scientific research to support why casualties and affected areas are chosen over other factors. Therefore, there is no right answer to scale selection, because there are a lot of factors that need to be considered when addressing the severity. Nevertheless, there is no scale that is supported by data to scale up the disasters based on severity.

3.1.2 Third method: using statistics

Historical data, or statistics, can be used to study trends, and to understand the behaviour of the severity of the natural disasters. The most common statistics, to compare the impacts of two or more disasters, are the number of fatalities, the cost of damage, and affected population. The following is an example of a comparison of three disasters: the 2004 tsunami that struck Sri Lanka, the 2011 Great East Japan (GEJ) earthquake and the 2013 flood that struck the Southern Alberta (SA), Canada. Table 3.6 illustrates the impact of the three disasters taken from EM-Dat global database of Centre for Research on the Epidemiology of Disasters (CRED). Comparing the number of fatalities and the total cost of damages gives a contrasting idea of the level of impact (in the Sri Lankan tsunami of

2004, more than 35,000 people lost their life, more than 1 million people were affected and the estimated cost of damage was US$ 1.32 billion. However, in the SA flood, the estimated cost of damage was US$ 5.7 billion with only 4 fatalities and 100,000 people affected). Therefore, some people tend to label some disasters, such as 2011 GEJ earthquake and SA flood, as economic disasters and some disasters, such as 2001 Indian Ocean tsunami, as fatal disasters by comparing damage and fatality only. This example clearly illustrates that one impact factor alone cannot represent the severity of an event because different factors gives different idea of the level of impact of an event. Thus, comparison of statistics required a proper technique to scale up the disasters by using most influencing impact factors. Therefore, multi-dimensional scale is essential for this purpose. However, currently, there is no technique or scale, that is supported by data, which can rate any natural disaster based on severity.

Table 3.6 Comparison of three disasters

Event	Fatalities	Injuries	Homeless	Total affected population	Damage (USD in billions)
2004 Tsunami impact - Sri Lanka	35,399	23,176	48,000	1,019,306	1.32
2011 Earthquake, tsunami and industrial accidents - Great East Japan	19,846	5,933	0	368,820	210.00
2013 flood impact - Southern Alberta, Canada	4	0	0	100,000	5.70

Source : EM-Dat database

A lack of data can prevent in depth analysis. If there is more accurate and detailed information available, a more advanced scale can be introduced (see Section 1.7.1). Though, the number of reported natural disasters is increasing, in general, records are incomplete. Historical reports contain some, but not all, of the necessary data; most contain only a brief and often ambiguous description (Newhall and Self 1982). In addition to incompleteness of the data, there is inaccuracy, ambiguousness in the current records or statistics, which complicates the relationship between influencing impact factors, and the severity of a natural disaster. An example of inaccuracy, is the reported number of homeless people is zero in the GEJ earthquake, as shown in Table 3.6. Several thousand houses were washed away in the GEJ earthquake, which caused hundreds of deaths, injuries and property damaged. I observed that temporary housings are still in use 4 years after the event. Moreover, there are no injuries or homeless in SA flood, according to the database, which is also inaccurate. The statistics in this example give an indication that there are some concerns about information management, and its processing, as well as how these variables are defined in global databases. It is not uncommon for numerous records to exist for the same event, sometimes with differing conclusions (see Section 1.2.2) for more details). Therefore, comparing different events and obtaining a sense of scale are problematic due to the deficiencies that reduce the quality of the dataset. Although historical inaccuracy of past records is unavoidable, there should be a focus on avoiding such inaccuracies in the future. Hence consistent interpretation, proper scale, good understanding of each disaster, and an expanded recording system, are required to accomplish this goal.

3.1.2.1 Factors that reflect the severity

Several factors need to be considered when measuring the impact of a disaster. The severity of the impact of natural disasters increases with an increase in human impact, and with increasing power of the event, while the severity level decreases with preparedness for the given disaster. Therefore, the severity directly or indirectly relates to all the factors that can be grouped into socio-economic factors (i.e., that reflect human impacts), strength-measuring factors (i.e. that reflect the power of the event), and preparedness factors (i.e., that reflect the region's preparedness). These factors are outlined in Figure 3.1.

1. *Socio-economic factors* impacting the affected population. These factors include the number of fatalities, the number of injuries, the amount of property damage, the number of people affected by the disaster, and so on (as shown in Figure 3.1, Part A).
2. *Strength-measuring factors* for the disaster. These factors indicate the physical strength and intensity of the disaster to the affected area(s) and include elements such as magnitude (how strong winds are, height of tsunami, Richter scale measurement for an earthquake, etc.), disaster duration/speed (of earthquake, tsunami, etc.), location (distance from disaster site to affected population area(s), and so on (as shown in Figure 3.1, Part B).
3. The *Preparedness factors* for the disaster. These include the regions' available technology, available resources, whether the area(s) could be evacuated before being affected, mitigation methods (e.g., whether or not a warning was issued prior to the disaster), response rate (percentage of people who acted on the warning), experience (are the responders trained to respond to the disaster?), education level (i.e., how well is the population trained on how to respond to the disaster, such as residents need to go to the basement during a tornado, and go to higher ground in the case of a tsunami, and so on), etc. (as shown in Figure 3.1, Part C).

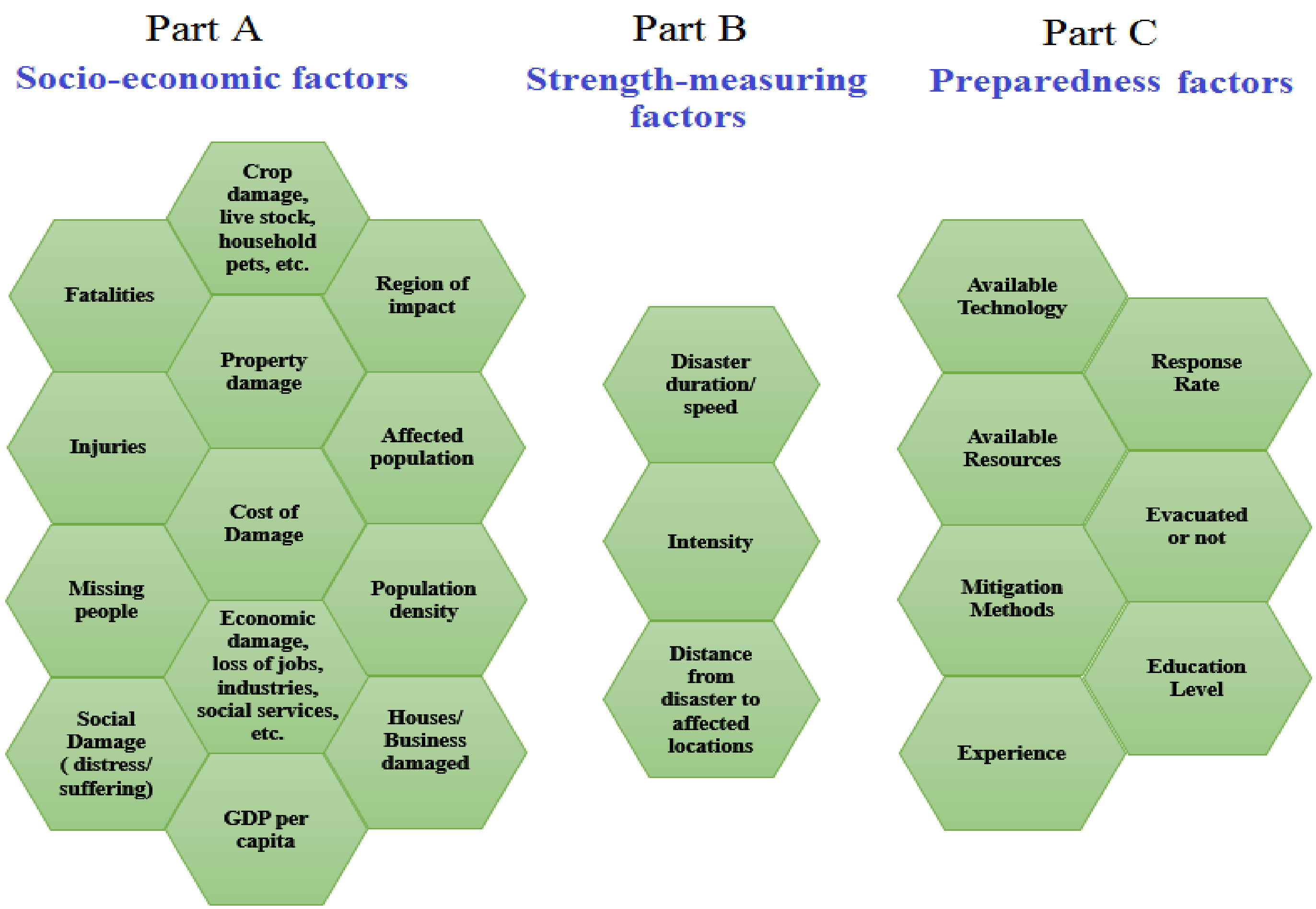


Figure 3.1 Factors Affecting the Severity of a Disaster

Hence, a multidimensional scale that presents the severity of natural disasters is based on a cross-section of these data. However, as previously noted a scale representing all these factors, is complex. In addition, a lack of data in current databases prevent in depth analysis. Techniques to record preparedness are absent in global databases. Nevertheless, some disaster types currently have rating scales based on physical strength (e.g., earthquake, tornado, volcanic eruption), which can be used to measure the physical strength of a disaster. Therefore, by discovering the relationship between impact factors and severity, a multidimensional universal severity scale is vital, and should consider many human exposure factors, such as the number of fatalities, injuries, homeless, evacuees, affected population, and cost of damage, common to all types of natural disasters. Hence, the relationships between impact factors (socio-economic and strength measuring factors), are analyzed in Section 3.3 and its sub-sections, in order to identify the most influencing factors relates to severity and should consider for multi-dimensional scale.

As a solution to previously mentioned inconsistencies, a global severity scale, is developed and combined with clearly defined terminologies (quantitative measure) through the foundation of the UDSC in order to compare different types of disasters. This universal scale can be further expanded to advanced scale considering all impact factors such as number of fatalities, injuries, homeless, affected population, and cost of damage.

3.2 Methodology for identifying the relationships

Different methods can be used to identify the direct relationship between intensity/magnitude scales and impact factors. Correlation can be used to identify the degree of linear relationship, and regression analysis can be used to identify the specific relationship. Different types of regression analysis and correlation methods, are employed according to the type of variables used for the analysis. Following sub-sections further described the used method for this analysis.

Identification of the relationships between factors that reflect the severity of an event, are extremely important. Intensity, fatalities, affected population, impacted region, cost of damage, GDP per capita, are independent variables and initial factors that could be considered to determine severity levels, which is a dependent variable. However, the above are only candidates, and are not necessarily included when the multidimensional scale is developed. Therefore, it is necessary to identify the relationships between factors that reflect the severity of a disaster in order to decide what factors can be included in the multidimensional scale. The most influencing factor of severity is selected to develop the common basic scale.

3.2.1 Correlation

Correlation indicates the degree of a linear relationship. Correlation coefficient quantifies the strength of a linear relationship between two variables from -1 to +1. For this work, if the correlation is from 0 to 0.25 (or 0 to -0.25) it shows weak or no relationship, from 0.25 to 0.5 (or -0.25 to -0.5) it shows fair degree of relationship, from 0.5 to 0.75 (or -0.5 to -0.75) it shows moderate to good relationship, from 0.75 to 1 (or -0.75 to -1) it shows strong to perfect relationship (Colton 1974). There are three correlation coefficients commonly used to determine the correlation.

- **Pearson's correlation coefficient (ρ):** common measure of association between two continuous variables X and Y. It is the ratio of the covariance of the two variables to the product of their standard deviations σ_x and σ_y (Equation 3.1).

$$\rho = \frac{Cov(X,Y)}{\sigma_x \sigma_y}$$

Equation 3.1

The sample correlation coefficient (r) is shown in Equation 3.2:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \ where\ \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}, \bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}, and$$

$$n = number\ of\ random\ variables$$

Equation 3.2

- **Spearman's rank correlation coefficient (also known as Spearman's rho):** obtain the relationship between ordinal interval variables X and Y. It is the ratio of the covariance of the two variable ranks to the product of their standard deviations $\sigma_{\text{rank (x)}}$ and $\sigma_{\text{rank (y)}}$ (Equation 3.3).

$$\rho_s = \frac{Cov[rank(X), rank(Y)]}{\sigma_{rank\ (x)} \sigma_{rank(y)}}$$

Equation 3.3

The sample correlation coefficient (r_s) is shown in Equation 3.4:

$$r_s = \frac{\sum_{i=1}^{n}\left(rank(x_i) - \overline{\text{rank(x)}}\right)\left(rank(y_i) - \overline{\text{rank(y)}}\right)}{\sqrt{\sum_{i=1}^{n}\left(rank(x_i) - \overline{\text{rank(x)}}\right)^2 \sum_{i=1}^{n}\left(rank(y_i) - \overline{\text{rank(y)}}\right)^2}}$$

$$where\ \overline{\text{rank(x)}} = \frac{\sum_{i=1}^{n} rank(x_i)}{n}, \qquad \overline{\text{rank(y)}} = \frac{\sum_{i=1}^{n} rank(y_i)}{n}, and$$

$$n = number\ of\ random\ variables$$

Equation 3.4

- **Kendall's tau correlation coefficient:** capture the association between two ordinal (not necessarily interval) variables.

3.2.2 Ordinal Logistic Regression

Ordinal logistic regression model is for the categorical dependent variable with ordinal nature (the variable values has a rank, however the real distance between the ranks are unknown) and have more than two categories. For example, in a volcanic explosively index (VEI scale) ranks from 0 to 8, and the distance between these ranks is complicated. Ordinal logistic regression should be considered when modelling the VEI scale (candidate variable to measure the severity of volcanic eruptions) with respect to certain independent variables such as fatality, injuries, number of houses damaged and cost of damage. One way to take account of the ordering is the use of cumulative probabilities, cumulative odds, and cumulative logits. Considering m ordered categories, these quantities are defined by:

- $P(Y \leq i) = p_1 + p_2 + \cdots + p_i$;
- $Odds(Y \leq i) = \frac{P(Y \leq i)}{1-P(Y \leq i)} = \frac{p_1+p_2+\cdots+p_i}{p_{i+1}+p_{i+2}+\cdots+p_m}$;
- $ln\left(\frac{P(Y \leq i)}{1-P(Y \leq i)}\right); i = 1, 2, \ldots, m-1$

Equation 3.5 shows the log odd ratio called logits (or cumulative logistic model) for the ordinal response data for n independent variables.

$$logit(Y \leq i) = Ln\left(\frac{P(Y \leq i)}{1-P(Y \leq i)}\right) = \alpha_{\mathrm{i}} + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n;$$

$$where\ i = 1,2, \ldots, m-1\ and\ \beta_0, \beta_1, \ldots, \beta_n\ \ are\ logistic\ coeffitients$$

Equation 3.5

Equation 3.5 is mathematically equivalent to the expression $P(Y \leq i) = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n}}{1+e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n}}$.

When fitting an ordinal logistic regression, it is assumed the relationship between the independent variables and the logits are the same for all categories of the dependent variable logits. In other words, the fitted models are parallel for different levels for the ordinal dependent variable.

To fit the ordinal logistic regression model, SPSS statistical software is used. Following are the list of tests that will be carried out to check the suitability of the model.

3.2.2.1 Test the parallelism assumption:

Hypothesis test: H_0: Models are parallel vs. H_1: Models are not parallel

Test Statistic: $\lambda = -2Log\frac{L_{H_0}(\beta_i;x)}{L_{H_1}(\beta_i;x)}$

Equation 3.6

Decision Criteria: Reject H_0 if and only if $\lambda < \chi^2_{1,1-\alpha}$ (Chi-Squared distribution with 1 degree of freedom for (1-α) 100% confident interval). If the model is adequate, then H_0 is not rejected

3.2.2.2 Goodness of Fit Test

Hypothesis test: H_0: β_k=0 vs. H_1: $\beta_k \neq 0$

Test Statistic: Deviance goodness-of-fit measures is shown in Equation 3.7

$$D^2 = 2\sum_i \sum_j O_{ij}\left[Log(E_{ij}) - Log(O_{ij})\right]$$

Equation 3.7

Where Log (E_{ij}) is the maximum log likelihood function for the fitted model, Log (O_{ij}) is the maximum log likelihood function for the saturated model, E_{ij} is the expected cell count, and O_{ij} is the observed cell frequency.

Decision Criteria: Reject H_0 if and only if $D^2 < \chi^2_{k,1-\alpha}$ (Chi-Squared distribution with k degree of freedom for (1-α) 100% confident interval and k is the difference between the number of parameters in the saturated model and the number of parameters in the fitted model). If the model is adequate, then H_0 is not rejected

3.2.2.3 Parameter Estimation

Hypothesis test: H_0: $\beta_i=0$ vs. H_1: $\beta_i \neq 0$, where i=1, ..., m and m= number of categories in dependent variable + number of independent variables

Test Statistic: Wald test statistic χ^2_w

Decision Criteria: Reject H_0 if and only if $\chi^2_w < \chi^2_{1,1-\alpha}$(Chi-Squared distribution with 1 degree of freedom for (1-α) 100% confident interval. If the coefficients are adequate, then H_0 is rejected

3.2.3 Multicollinearity

Multicollinearity (also called collinearity) occurs when two or more independent variables in the model are correlated. In other words, one variable can approximately predict by the linear combination of others. The degree of the multicollinearity varies. Multicollinearity is fairly common and it affects the fitted model differently. When it occurs, the standard errors of the coefficient are inflated, and the estimated coefficients in logistic regression may be unreliable. Including an interaction term (extra variable representing the multiple of the two variables) may benefit to the model in this scenario. However, it is impossible to obtain a distinctive estimate of regression coefficient with all the independent variables in the model with their interaction terms.

Multicollinearity might occur due to deficiencies of sample data, inherent characteristics of the interrelationship among variables, and so on. Multicollinearity should be dealt with only after the model specification has been made. However, there could be an indication of multicollinearity that are encountered during the process of model building. Indications of multicollinearity that appear as instability in the estimated co-efficient are as follows:

- Large changes in the estimated co-efficient when a variable is added or deleted
- Large changes in the co-efficient when a data point is altered or dropped

Multicollinearity can be addressed using the following methods:

- Remove highly correlated predictors from the model. Because they supply redundant information, removing one of the correlated factors usually does not drastically reduce the R-squared. Using stepwise regression, best subsets regression, or specialized knowledge of the data set to remove these variables can be used for this process and select the model that has the highest R-squared value
- Use Partial Least Squares Regression or Principal Components Analysis, regression methods that cut the number of predictors to a smaller set of uncorrelated components

3.3 Analysis of variables that reflect the severity

Research sub-question b(ii) Is there a substitute quantitative technique to categorize the severity of natural disasters?

The severity of the impact of natural disasters increases directly in proportion to the impact to humans and their possessions (fatalities, injuries, homeless, cost of damage and so on), and with the strength of an event for a given population density (Caldera et al. 2016a). Commonly to most natural disasters, the destructive power or the strength of the disaster impact depends on the distance from the effected site, the duration, and the strength of the disaster. Strength depends on the characteristic of a disaster. For example, wind speed, height and width are characteristics of a tornado, which determine its strength; column heights, rate of energy release during an eruption and blast durations are characteristics of a volcano; energy released at the epicenter and the duration are characteristics of an earthquake; wave length, wave height, run-up elevation and run-up distance are characteristics of a tsunami. Therefore, the intensity or the strength of a disaster may have some relationship to the impact or the severity of a disaster. To investigate this hypothesis, the statistical properties and relationship of the characteristics, behaviour, and consequences of natural disasters are examined in the following section. Variables are identified that reflect the severity of a natural disaster. The variables that directly and indirectly relate to severity are analyzed to determine if there are one-to-one relationships.

Tornadoes are selected to demonstrate the statistical properties, the relationship between impact factors and the characteristic of a disaster. The same analysis has been conducted on volcanoes earthquakes and tsunamis; however, these are not demonstrated here in detail. Tornadoes and volcanic eruptions are selected to demonstrate a more detailed relationship between impact factors and the characteristic of a disaster. The same analysis has been conducted on earthquakes (Esfeh et al. 2016) and tsunamis (Caldera et al. 2016a); however, these are not demonstrated here in detail. Tornadoes, earthquake, tsunamis and volcanic eruptions are considered to find a relationship between intensity/magnitude scale and impact factors.

If existing scales demonstrate the severity of a given disaster, then there should be relationship between the existing scale and the impact parameters, such as fatalities, injuries, economic damage. Otherwise, a different scale is mandated to measure the severity of a disaster.

3.3.1 Tornadoes

It will not be useful to develop a relationship between factors using the existing global data because the data reflect inconsistencies. Therefore, a sample with good data is selected for this analysis. When small areas on the surface of the earth are examined in detail, research shows that there are favorable locations for tornado formation (Brooks 2013).

Tornadoes can occur in both hemispheres between the latitudes of 20^{o} and 60^{o}, but they predominantly occur in the east of the Rocky Mountains USA (Goliger and Milford 1998). The geographical location and features of North America create favorable conditions for their development (Durage et al. 2013). Cold, dry air from the Rocky Mountains meets the warm, moist air from the Gulf of Mexico creating atmospheric instabilities that induce severe thunderstorms and tornadoes (Durage et al. 2013).

The records indicate about 1,200 tornadoes occur in the USA per year (NSSL 2015). Therefore, this sub-section focuses on North American tornadoes to characterize and demonstrate the behaviour of a disaster. The National Oceanic and Atmospheric Administration (NOAA) database (NOAA 2013) was used to analyze North American tornado impacts from 1996 to 2013. The database was restricted and only 500 entries were accessible. If the whole NOAA database were available, it would be possible to conduct a more comprehensive analysis. The database was searched using fatalities and injuries as the variable; the top 500 entries ordered starting from the highest number of fatalities and injuries to the fewest. The impact factors are limited in this study due to a lack of data: Fatalities, injuries, and damage in United States dollars (USD) are the only impact factors available in the database. Intensity, location, duration, speed, and dimensions (length and width) are some factors that could be considered to measure the power or intensity of tornadoes.

3.3.1.1 Statistical properties of the characteristics, behaviour, and consequences

In this section, the statistical properties of the consequences, characteristics, and behaviour of tornadoes are examined. Factors are identified that reflect the severity of tornadoes fatalities, injuries, and damage (property and crop damage) factors were considered human impacts, while length, width, and F scale/EF scale were considered measurements of the power or intensity of a tornado. According to NOAA (2013) the length and width of a tornado or tornado segment is measured in a minimum of one tenth of a mile while on the ground, and in feet while on the ground, respectively.. The F scale/EF scale of damage will vary in the destruction area; therefore, the highest value of the F scale/EF scale is recorded for each event (NOAA 2013). In NOAA database from 1996 to 2006, the F scale was used and from 2007 to 2013, the scale was recorded using the EF scale. In this analysis, both F scale and EF scale are noted hereafter as the EF scale for simplicity, because they both describe the strength of a tornado based on the amount and type of damage caused.

The top 500 events, ranked by the number of fatalities and injuries from tornadoes in North America between 1996 and 2013, were used as data in this analysis; hence, the results show the extreme end of tornado impact on people. Table 3.7 shows the descriptive statistics of random variables, which represent tornado behaviour, characteristics, and consequences. The mean numbers are: fatalities, 3 per tornado; injuries, 29 per tornado;

property damage, 31.68 millions of USD per tornado; length of a tornado impact, 11.5 miles; width of a tornado impact, 651 feet; and EF scale 3.

Table 3.7 Descriptive statistics of tornado data

	Fatalities	**Injuries**	**Damage (USD)**	**Length (miles)**	**Width (feet)**	**EF scale**
Sample size	500	500	500	499	500	500
Minimum	0	0	0	0.10	1.50	0
Maximum	158	1150	2,800,000,000	41.79	4,400	5
Mean value	3.06	28.95	31.68M	11.50	651	2.67
Standard Deviation	8.15	78.87	157,762,229	8.25	578	1.03
Skewness	14.47	9.26	13.22	0.91	1.70	-0.114
Kurtosis	264.63	109.84	208.28	0.44	4.80	-0.251
COV	2.66	2.72	4.98	0.72	0.89	0.385

Although the standard deviation of tornado width is high compared to the tornado length standard deviation, tornado length and width have a very close coefficients of variation (COV) less than one. A similar pattern can be observed between fatalities and injuries because both of them have COVs close to 3; the spread around the mean is similar for tornado length and width and for tornado fatalities and injuries. Property and crop damage shows a comparatively high dispersion around the mean as indicated by a COV of 4.98.

All the factors, with the exception of the EF scale, are positively skewed. Higher positive values of skewness in impact factors (fatalities, injuries, and damage) show that the impact values above the mean are more widely spread than the impact values below the mean. The kurtosis value for the impact factors is also higher than other factors, which means that the probability distribution function of these factors tends to have a very high peak close to the mean and rapidly declines around the mean. The kurtosis of the EF scale is negative, indicating the EF scale is not very peaked near the mean.

Figure 3.2 to Figure 3.7 show the histograms of the factors and a fitted distribution. Determining the initial distribution for historical data is important as it can contribute to the estimation of the properties of future tornadoes. For example, the consequences of an event in terms of fatalities, injuries, and damage, and the tornado characteristics in terms of length, width, and scale, can be determined, which will assist in mitigation planning.

To fit the best distribution impact factors (fatalities, injuries and damage) are transformed into natural logarithms, after eliminating the values of zeros, that can violate the assumption of the normality. Because all the tornado events between 1996 and 2013 that record zero number of fatalities and injuries, are not included in the 500 records considered in this analysis, it may mislead the conclusions of the results.

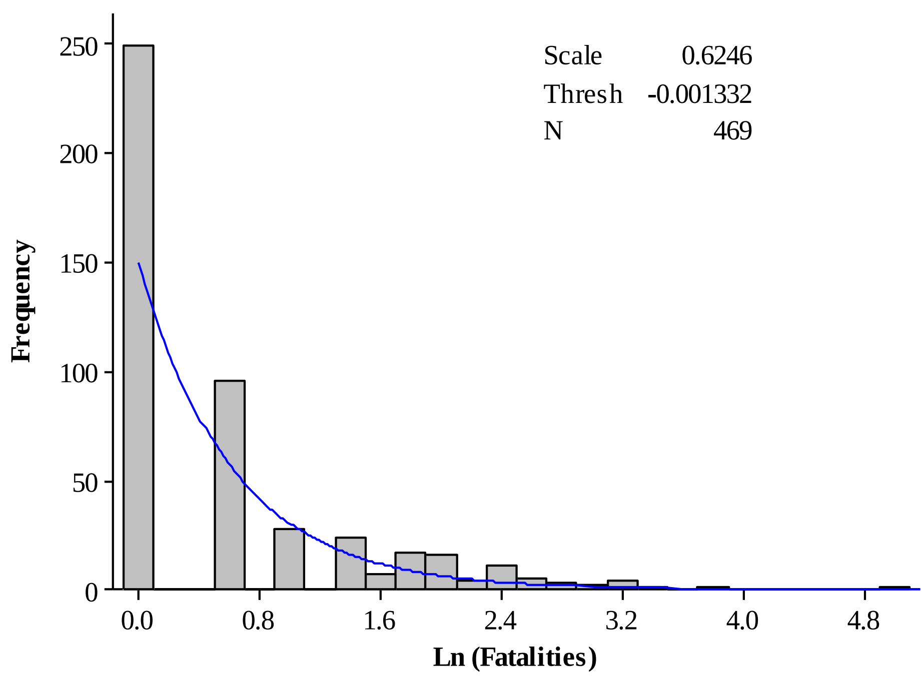


Figure 3.2 Histogram of number of fatalities in a natural logarithm scale with an approximate 2-Parameter Exponential distribution

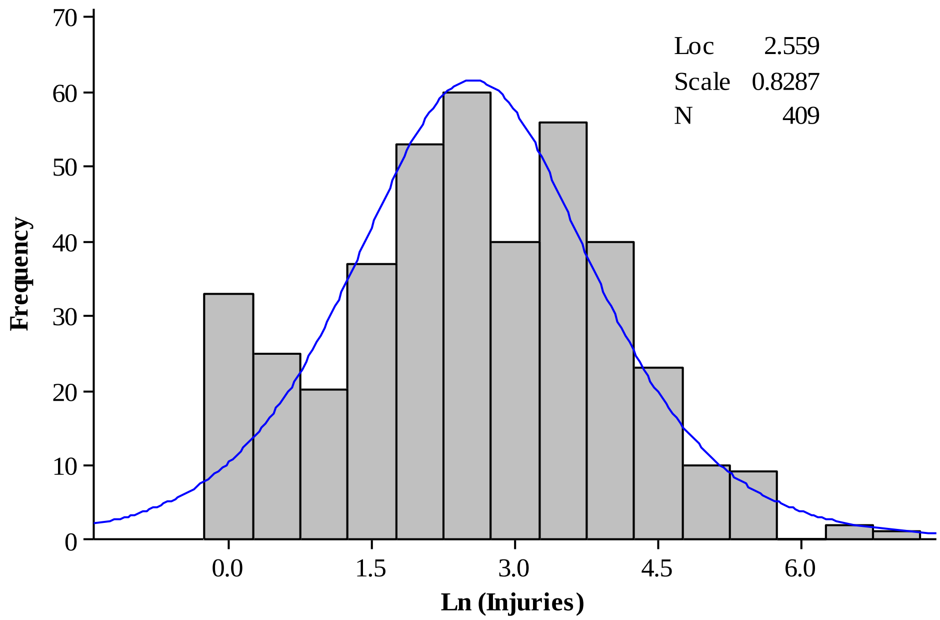


Figure 3.3 Histogram of number of injuries in a natural logarithm scale with a fitted Logistic distribution

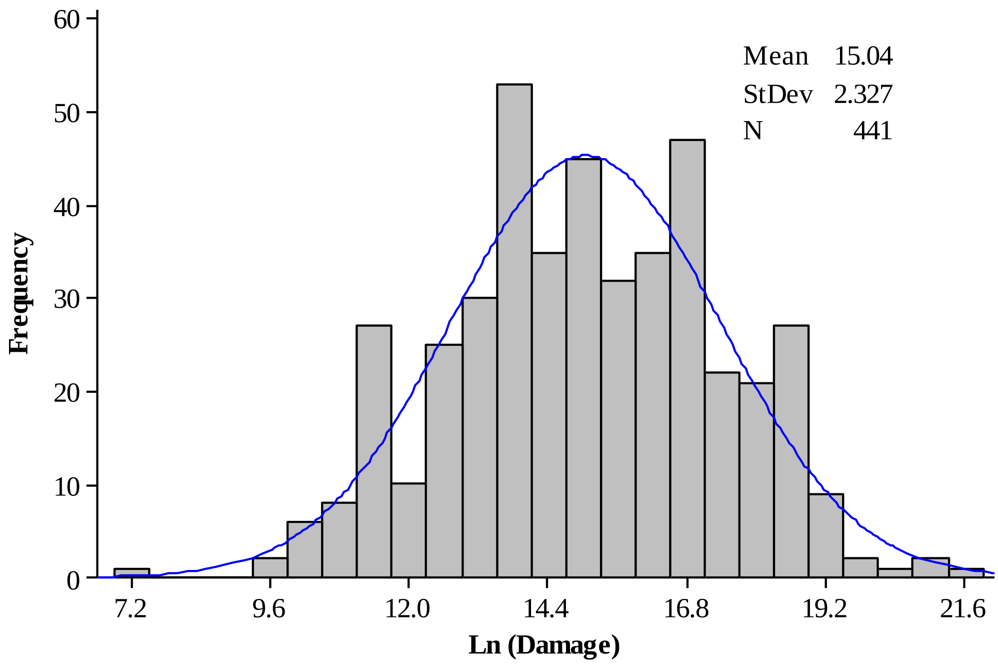


Figure 3.4 Histogram of cost of damage in a natural logarithm scale with a fitted Normal distribution

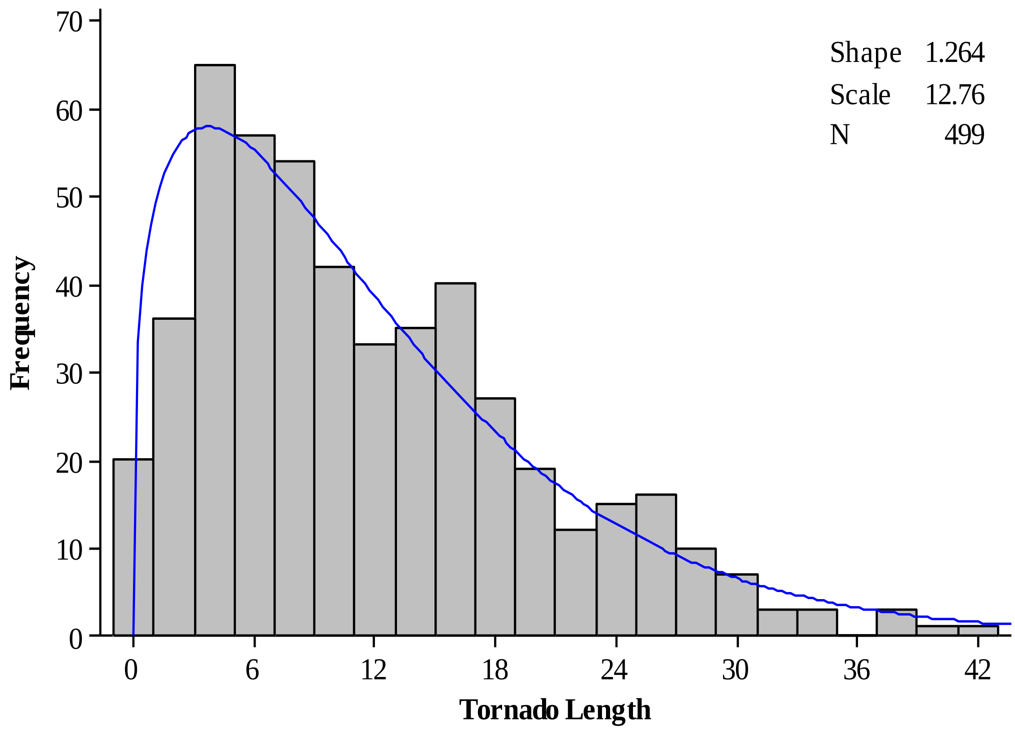


Figure 3.5 Histogram of tornado length with a fitted Weibull distribution

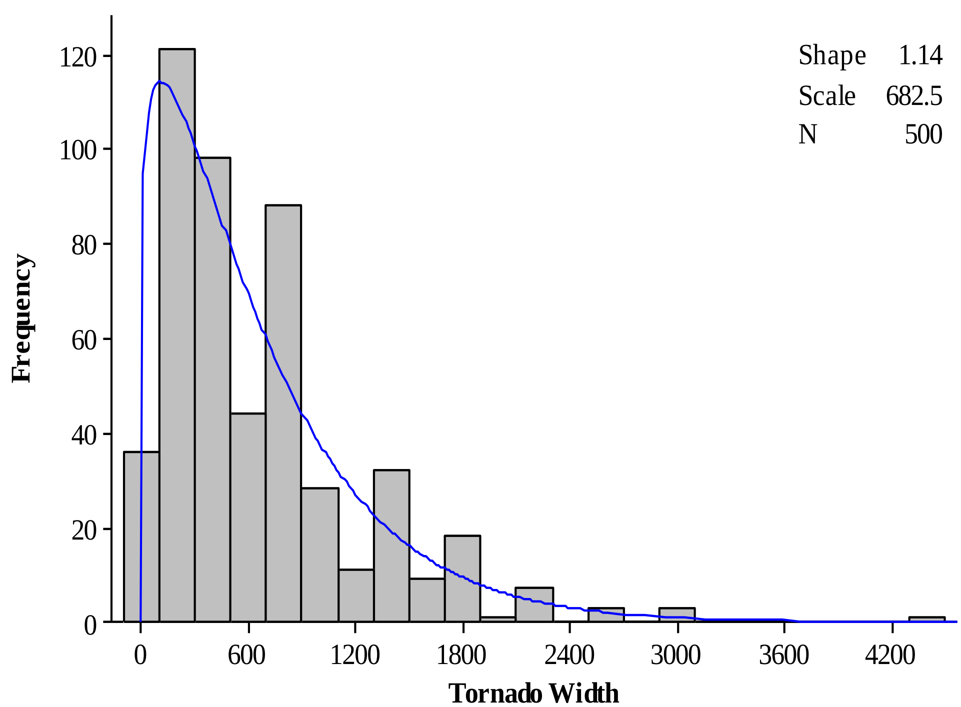


Figure 3.6 Histogram of tornado width with a fitted Weibull distribution

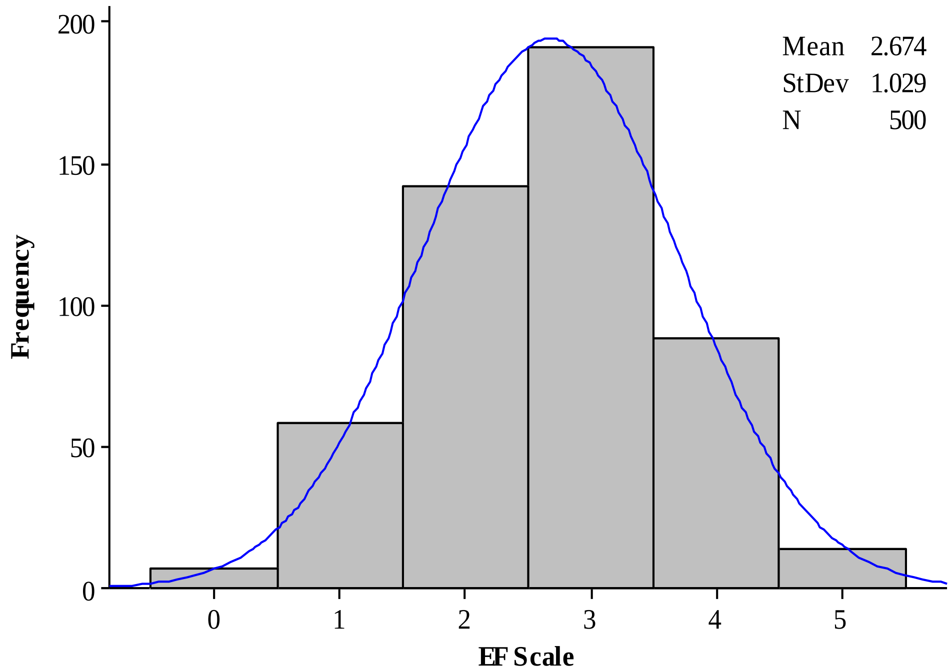


Figure 3.7 Histogram of the EF scale with an approximate Normal distribution

Hypothesis testing with a 95% confidence level, PP plots, QQ plots, and the Anderson-Darling (A-D) test are carried out to determine which distribution best fits the historical data. A-D goodness of fit test is chosen as it gives more weight to the tails. Injuries, damage, and tornado length and width are fitted to the shown distribution according to the above-mentioned criteria. Although fatalities and EF scale could not be fitted to a known distribution with a 95% confidence level, close approximate distributions are shown in Figure 3.2 and Figure 3.7.

The fact that many tornadoes do not strike populated areas raises serious challenges for estimating the intensity of such events. If a tornado fails to hit a recognized damage indicator defined in the EF scale, a rating is nevertheless required. In practice, this fact means that many tornadoes are given a default rating, often either EF0 or EF1, unless there is some compelling reason to give another value (Doswell III et al. 2009). In the absence of any information, it is more appropriate to assign an intensity rating of “unknown”; however, every tornado is assigned an EF scale rating, irrespective of the affected area (Doswell III et al. 2009). Therefore, the actual intensity will in some cases deviate from the recorded intensity. In addition, in 2007, the new EF scale was introduced, and this change affected historical continuity, because it was not identical to the original F scale. The F5 tornadoes rated prior to 2007 were still an F5, but the wind speed associated with the tornado may have been somewhat less than previously estimated (NSSL 2015). Therefore, the criteria used to assess the severity before and after 2007 may have affected the recorded values. This change in scales, and challenges for estimating the intensity scale, could explain why the EF scale data deviated to the left (i.e., Figure 3.7 shows a shift to the left of the fitted normal distribution from the actual data).

3.3.1.2 Linear dependency between factors

To respond to a future disaster, one must know the consequences of tornadoes. In addition, dependency between factors needs to be identified to select which factors should be considered on a multi-dimensional severity scale. Correlation analysis discovers any linear dependency between random variables in a data set. The Pearson Correlation coefficient (ρ) is used for all factors except the EF scale; Kendall’s tau correlation coefficient (ρ) is estimated to capture the association between the other factors and the EF scale. This coefficient is used to quantify the linear relationship between two factors because the EF scale is an ordinal variable and the others are continuous variables. Table 3.8 shows that all the factors are positively correlated, which means when one factor increases, the other factor is expected to increase as well. For example, an increase in the number of fatalities predicts an increased number of injuries and damage.

Table 3.8 Correlation coefficient metric for tornado factors

	Fatalities	**Injuries**	**Damage**	**Length**	**Width**	**EF scale**
Fatalities	1	0.781	0.829	0.151	0.205	0.339
Injuries	0.781	1	0.845	0.245	0.253	0.336
Damage	0.829	0.845	1	0.152	0.234	0.320
Length	0.151	0.245	0.152	1	0.497	0.374
Width	0.205	0.253	0.234	0.497	1	0.492
EF scale	0.339	0.366	0.320	0.374	0.492	1

First, linear relationships between impact factors are examined. It is anticipated that the impact factors have a direct relationship with each other. Impact factors show a higher linear dependency when ρ is greater than 0.75 (Colton 1974). A natural linear relationship between these factors can be investigated using a multiple regression analysis (this analysis explains in more details for volcanic eruptions in Section 3.2.2.3).

Second, linear relationships between tornado characteristic factors are examined. The destructive force of a tornado, in terms of wind speed, is usually represented by the magnitude of the EF scale. However, the EF scale, tornado width, and tornado length have a ρ between 0.25 and 0.5, which is a fair degree of linear relationship.

Third, the impact factors were investigated to determine if they have a linear dependency on tornado characteristic factors (length, width, and EF scale). A higher magnitude tornado is more likely to demonstrate higher impact factors. Table 3.8 shows that the EF scale is related to impact factors; however, they have a fair degree of linear relationship as ρ ranges from 0.32 to 0.339. Tornado width has a ρ value between 0.205 and 0.253 showing a slightly weaker relationship to impact factors. Impact factors also have a minimal (or week) relationship to tornado length as ρ is between 0.151 and 0.245. The low value of the correlation coefficients indicates there is not enough evidence to confirm a linear relationship between these factors.

As the impact factors are highly correlated, analyzing one factor can determine another using their linear dependency. If one of the factors (fatalities, injuries, or damage) relates to the existing EF scale, then the EF scale can also be used to measure the severity of tornadoes.

3.3.1.3 Non-linear dependency between impact factors and EF scale

The impact factors are investigated to determine if there is any dependency on the EF scale. Figure 3.8 to Figure 3.10 show the scatter plot of impact factors with the EF scale. Figure 3.8 Figure 3.9, and Figure 3.10 show that the relative number of fatalities, injuries, and damage is low for EF 0, 1, 2, 3 when compared to EF 4 and 5. Even though EF 4 and 5 show a higher number of fatalities, injuries, or damage, these higher values are still low in frequency: there were only three incidents where more than 30 fatalities were recorded; only six incidents where more than 225 injuries were recorded; and only six incidents where more than USD $4*10^8$damage out of a total of 500 incidents. No difference is observed between EF 4 and 5. There is not enough evidence to confirm a nonlinear relationship between the EF scale and impact factors.

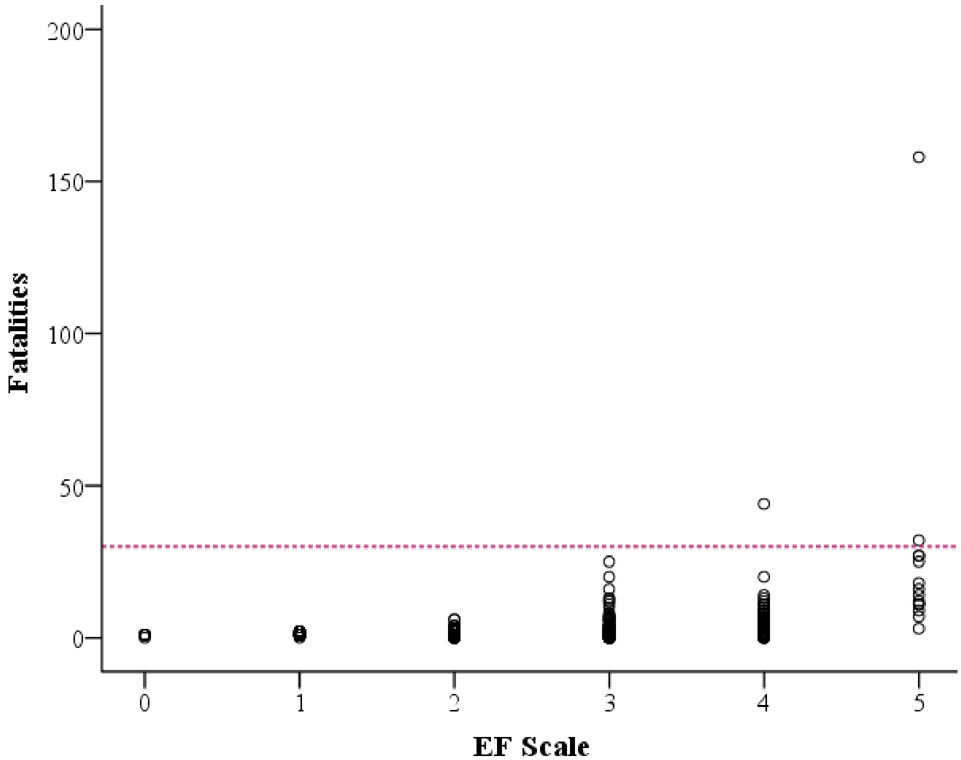


Figure 3.8 Scatter plot of fatalities Vs EF scale

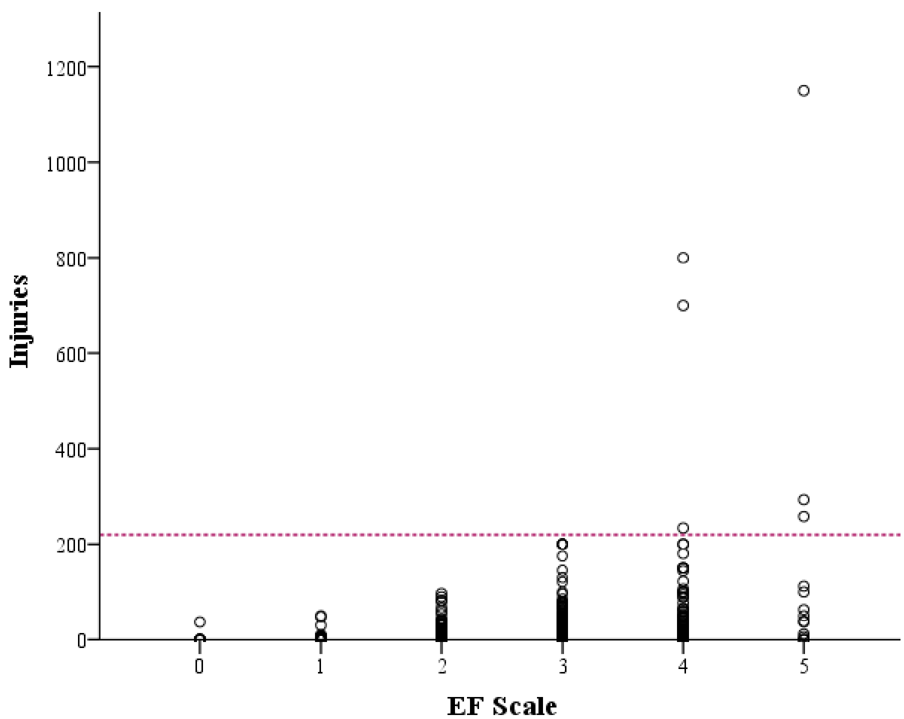


Figure 3.9 Scatter plot of Injuries Vs EF scale

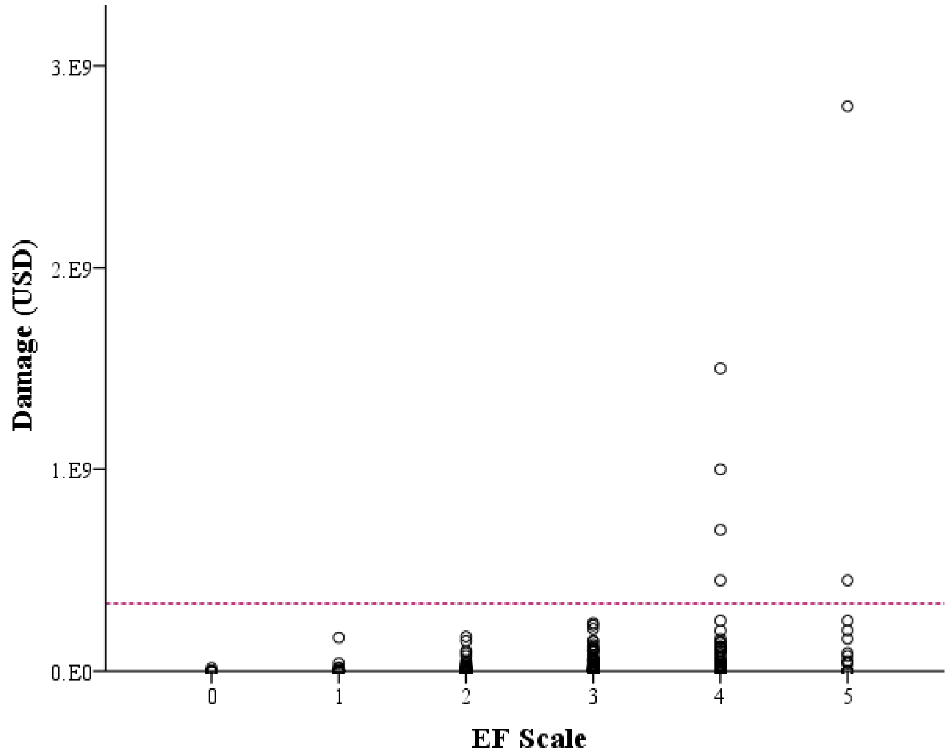


Figure 3.10 Scatter plot of Damage Vs EF scale

The human impact factors considered in this study are fatalities, injuries, and damage measured in dollars. As there is not enough evidence to confirm a direct relationship between impact factors and the EF scale, another scale is needed to measure the severity of tornadoes. Because fatalities, injuries, and damage are highly correlated, one factor can be used to predict the other two. Therefore, severity can be measured by either using the "multi-dimensional" scale based on several independent combined factors or by using the initial scale based on one of these correlated factors.

Damage in USD can be considered in a one-dimensional severity scale, but damage also has a close relationship with time and inflation (Caldera and Wirasinghe 2014). In general, economic damage from tornadoes tends to increase with time for at least three reasons (Katz and Herman 1997). First, inflation means that the prices of goods increase; second, except for periods of recession or depression, people and institutions tend to acquire more wealth over time (Katz and Herman 1997); and third, population increases over time. Compared to inflation, wealth has been increasing more rapidly since 1925 (Brooks and Doswell III 2001b). However, because damage is measured as a dollar value, it is not the best factor to assess the severity of tornadoes. Further, injuries can range from ‘small’ to ‘moderate’ to ‘severe.’ Therefore, since the terms damage and injuries are ambiguously defined, fatalities is a better choice. Moreover, fatalities and injuries for a disaster can increase as population density increases. It is assumed that the censers the population density is relatively constant between 1996 and 2013. In addition, populations are most sensitive to disastrous events with high fatalities. In other words, more attention is given to disaster records with high fatalities when compared to disasters with low fatalities, and attract public attention. Considering all the above facts, the factor ‘fatalities’ can be selected as the most influencing factor to measure the severity of tornadoes. Extreme tornadoes are further studied using the extreme value theory in terms of fatalities in Chapter 7.

3.3.2 Volcanic Eruptions

In previous hypothesis, the intensity or the strength of a disaster may have some relationship to the impact or the severity of a disaster. This is further tested using 652 volcanic eruptions records from 4360 B.C. to 2014 A.D. in the NOAA database, with five impact factors: the number of fatalities, injuries, houses damaged, missing people and damage (in millions of USD). Volcanic eruptions are measured using the VEI scale, which is currently the best available factor that distinguishes one eruption from the other (Caldera and Wirasinghe 2014).

3.3.2.1 Relationship between direct impacts and combine impacts

As previously explained in Section 3.1.1.1.2, there are conjoint impacts as well as direct impacts because of an eruption. Therefore, the relationship between direct impact and combined impact were first studied prior to testing the above hypothesis. Spearman's rho correlation coefficient (ρ_s) was used to observe the correlation because all factors tested are ordinal variables. Each ordinal interval variable for “direct volcanic effects” showed a linear relationship with the corresponding variable for “total effects” with $\rho > 0.9$ for all pairs as shown in Table 3.9. Thus, the direct volcanic effects alone can be used to explain the relationship between the VEI scale and the impact factors.

Table 3.9 Spearman’s rho correlation coefficient (ρ_s) for combined effects vs. volcanic effects

		Combined effects				
		Deaths	**Missing**	**Injuries**	**Damage Million USD**	**Houses**
Volcano direct effects	**Deaths**	0.984				
	Missing		1			
	Injuries			0.984		
	Damage Million USD				0.925	
	Houses					0.963

3.3.2.2 Relationship between direct volcanic effects

It was necessary to determine the relationships between each impact factor, before evaluating the relationship between the VEI scale and the combination of impact factors. Table 3.10 shows the correlation coefficient (ρ) and the number of data points (N) used to calculate ρ for each pair of factor. Damage measured in millions of USD has a linear relationship with houses damaged (ρ=0.9). One factor (i.e., the number of houses damaged) stayed in the model while the other (i.e., damage in millions of USD) is omitted because of the high correlation between the two variables (ρ=0.9). Damage in millions of USD has a close relationship with time and inflation, recession, depression, and so on. Thus, damage is hard to estimate; therefore, it is omitted from the model. The number of missing people and number of fatalities are also highly correlated (ρ=0.9). The number of pair wise data (N) used to evaluate ρ is fairly low with the presence of missing number of people. This may explain the higher ρ value for some pairs. Therefore, the number of missing people is also omitted from the model. Other pairs, for example fatalities and houses damaged, are not highly correlated but have a moderate to good ($0.5 \leq \rho < 0.75$) relationship. Therefore, fatalities, injuries and houses damaged are selected to test the relationship between impact factors and the VEI scale.

Table 3.10 Spearman's rho correlation coefficient (ρ_s) and the number of data points (N) for volcanic effects factors

Factor	Missing		Injuries		Damage Million USD		Houses Damaged	
	ρ_s	N	ρ_s	N	ρ_s	N	ρ_s	N
Fatalities	0.90	9	0.71	77	0.54	69	0.50	63
Missing			0.92	5	0.50	3	1.00	2
Injuries					0.64	22	0.54	28
Damage Million USD							0.90	53

3.3.2.3 Relationships between direct impact factors and the VEI scale

To find the relationships between the VEI scale and other impact factors that represent the human impact of an eruption, ordinal logistic regression analysis was employed because the VEI is an ordinal categorical variable ranging from 0 to 8. In ordinal logistic regression, it is assumed that each level of VEI is parallel to the other, as shown in Figure 3.11. More details about ordinal logistic regression is explained in Section 3.2.2

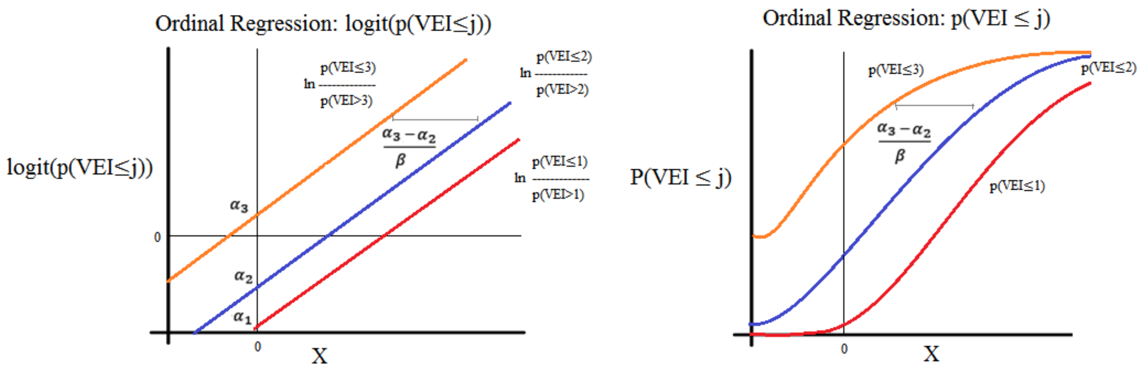


Figure 3.11 Example of proportional odds model, which are parallel in ordinal logistic regression

In this analysis, with the presence of one variable, the other variable give unfeasible coefficients (i.e., negative values); therefore, the correlated factors are removed from this analysis to address the multicollinearity affect. Several other approaches have also been tried to select a good relationship between the VEI scale and other factors.

- Different link function (logit, probit, complementary log-log, negative log-log, Cauchit (inverse Cauchy))
  - The Link Function for the logit model is shown in Equation 3.8

$$Logit[p(VEI \leq j)] = Ln\left[\frac{p(VEI \leq j)}{p(VEI > j)}\right] = \alpha_j + \beta x$$ where j = 1, 2, …, 8 and α, β are regression parameters.

Equation 3.8

- Log transformation of fatalities, houses damaged, injuries
- Different periods
  - The last 32 years (after 1982), after the VEI scale was introduced
  - The last 114 years (after 1900), after a significant improvement in recording data

- The last 514 years: after 1500

  Records of different periods have been analyzed to observe whether there is a difference between the sample before and after three specific time periods: 1500 (i.e., last 514 years); 1900 (i.e., after a significant improvement in recording data); and 1982 (i.e., after the VEI scale was introduced).

- Include/ exclude interaction terms to the model (to address the multicollinearity effect). More details about multicollinearity effect is previously discussed in Section 3.2.3.
  - Fatalities*Houses Damaged
  - Fatalities*Injuries
  - Houses Damaged*Injuries
- VEI grouping (lack of data in lower and higher levels of VEI)
  - VEI (6,7,8→5)
  - VEI (0, and 1→1) and VEI(5,6,7, and 8→5)

To select the best model (relationship) out of the above approaches three different hypothesis tests were conducted: tests of parallel lines (testing the assumption), goodness of fit tests, and overall model fits, each at the 95% confidence level. In addition, the co-efficient of the factors was also investigated when selecting a best model because, with the presence of one variable, the other variable give unfeasible coefficients (i.e., negative values). Therefore, one of the correlated variables had to be removed. The best models were given when the link function is logit (Equation 3.8); that is, with the assumption that the residuals are logistically distributed, and some of the VEI scale are grouped (VEI 0,1 as VEI 1 and VEI 5,6,7,8 as VEI 5). P values for the tested hypotheses and the Pseudo R-Square values for model fatalities, injuries, and houses damaged individually with the grouped VEI scale are shown in Table 3.11. Ordinal interval variables of fatalities, injuries and houses damaged individually formed good ordinal regression models with the VEI scale; because, calculated p-values are greater than 0.05 for the test of parallel lines and goodness of fit test, and the calculated p-values are less than 0.05 for model fitting. Thus, the best three models are fatalities, injuries, and houses damaged individually, with the grouped VEI scale, and using a 95% confidence level.

Table 3.12, shows the estimated parameters α (threshold) and β (location) in Equation 3.8 with the corresponding p-values for the best selected models. All the p-values corresponding to the estimated parameters are less than 0.05 in fatalities and injuries models, whereas they are less than 0.1 in the houses damaged model. Hence, the estimated α and β in Equation 3.8 is suitable for the three models at a 95% confidence level for fatalities, injuries and at a 90% confidence level for houses damaged.

Table 3.11 P-values, criteria for each test and the Pseudo R-Square of the individual ordinal logistic models

	Model 1 (Fatalities)	**Model 2 (Injuries)**	**Model 3 (Houses Damaged)**	**All p values**
Test of Parallel Lines	0.171	0.801	0.825	>0.05
Goodness-of-Fit (Deviance)	0.105	0.685	0.888	>0.05
Model Fitting	0	0.001	0.003	<0.05
Pseudo R-Square (Cox and Snell)	0.131	0.152	0.113	-

Table 3.12 Parameter Estimates for volcano effects categorised data

		Model 1 (Fatalities)		**Model 2 (Injuries)**		**Model 3 (Houses Damaged)**	
		Estimate	**P-value**	**Estimate**	**P-value**	**Estimate**	**P-value**
Threshold (α)	VEI 1	-1.312	.000	-1.353	.021	-1.440	.037
	VEI 2	.869	.000	1.024	.029	.991	.090
	VEI 3	2.559	.000	2.948	.000	2.515	.000
	VEI 4	4.211	.000	4.918	.000	4.130	.000
Location (β)		.706	.000	.906	.001	.706	.004

The results highlight the fact that individual factors of fatalities, injuries and houses damaged are better than the combinations of the aforementioned factors in explaining the relationship with the VEI scale. Moreover, one factor becomes significant with the presence of another factor, because of the multicollinearity between two factors (e.g., injuries become significant with the presence of fatalities; houses damaged become significant with the presence of fatalities; and houses damaged become significant with the presence of injuries). Therefore, there may be evidence of an unexplainable component in this relationship. Prior experience, preparedness, awareness, evolving technology, mitigation methods, early warning systems and distance to the original event may minimize the number of fatalities and injuries. The magnitude and the intensity of a disaster may maximize the impact. The multicollinearity effect remains the same for all applied approaches, hence the combination of impact factors could not be achieved as expected. Therefore, the results show that the VEI scale can only partially evaluate the severity, which means a scale is required to compare the impact of a single disaster event, as well as to compare the impacts of several different disasters.

Similar to tornado analysis (Section 3.3.1), the results of volcanic eruptions demonstrate that an individual factor is better than a combination of factors (fatalities, injuries and houses damaged) in explaining the relationship with the existing scale. In addition, fatalities are easy to define; it is the finality of death. Houses damaged closely relates to the location, time, material, size and so on. Of the two most common factors (i.e., fatalities and injuries), injuries are ambiguously defined because injuries can range from ‘small’ to ‘moderate’ to ‘severe’. Therefore, the factor ‘fatalities’ is selected to measure the severity in common basic scale. Extreme volcanic eruptions are further studied using the extreme value theory in terms of fatalities in Chapter 7.

3.3.3 Combined Analysis

If existing scales demonstrate the severity of a given disaster, then there should be a relationship between the existing scale and impact parameters, such as fatalities, injuries, and economic damage. Otherwise, a different scale is mandated to measure the severity of disasters that occur. The relationship between the available impact factors with the existing scales have been studied further using the data in the NOAA database for different disasters (i.e., earthquakes and tornadoes together with volcanic eruptions and tornadoes). As shown in Table 3.13, the impacts of a disaster are not highly correlated with the existing scales for volcanic eruptions, earthquakes, tsunamis, and tornadoes because the Pearson correlation coefficients are less than 0.5. This means there is no evidence that there is a linear relationship between impact parameters and the existing intensity scale, according to the available data. However, a nonlinear relationship between existing scales and impact factors may exist. This hypothesis was already tested using volcanic eruptions [652 eruption records from 4360 B.C. to 2014 A.D. with five impact factors: number of fatalities, injuries, houses damaged, missing people and damage (in million dollars)], and tornado impacts [500 tornado records from 1996 to 2013 with three factors: fatalities, injuries, and damage (property and crop damage)] using two different approaches. However, none of those disasters demonstrated a direct relationship as shown in Section 3.3.1 and Section 3.3.2. Similarly, the detailed correlation analysis and regression analysis conducted to for earthquakes (5841 earthquake incidents between 2150 BCE and 2015 CE with six impact factors: fatalities, missing people, injuries, damage, house damaged and house destroyed) and tsunamis (2520 tsunamis occurred between 2000 BCE and 2015 CE with five impact factors: fatalities, injuries, damage, house damaged and house destroyed); however, the results do not show any direct relationship with impact factors and intensity/ magnitude scales. Therefore, a common severity scale to measure the impact of any disaster is necessary.

Table 3.13 Correlation between intensity scales and impact factors

Disaster	Existing Scale	Fatalities	Injuries	Damage	House Destroyed	House Damaged	Missing
Volcano	VEI scale	0.33	0.39	0.09	0.33	-	0.45
Earthquake	Richter Scale	0.13	0.285	0.488	0.23	0.237	-
Tsunami	Intensity Scale	0.248	0.134	0.168	0.043	-	-
Tornado	EF Scale	0.339	0.366	0.32	-	-	-

3.4 Discussion

The severity of a disaster increases with an increase in the intensity/power of the event and with increased human exposure; however, the severity level decreases as preparedness for the given disaster increases. The severity directly relates to the human exposure, and relates indirectly to the power of disasters and preparedness. Therefore, a multi-dimensional scale should include a cross-section of human impact factors. The following factors could be considered human impact factors to determine severity levels, but a lack of historical data allows only limited analysis: fatalities, injuries, missing persons, evacuees, affected population, homeless, population density, region impacted, cost of damage, number of houses damaged, and GDP per capita. However, due to the lack of a recording system for those factors, the factors considered in this study were fatalities, injuries, missing persons, houses damaged, houses destroyed and total damage in USD, which are the human impact factors in the NOAA database.

In summary, by studying the historical records of different disasters, the use of "or" between the impact factors (i.e., fatalities, injuries, and damage or houses damaged) is more efficient when compared to the use of "and" in describing the relationship between impact factors and intensity/magnitude scales. Therefore, measuring the severity of a disaster using the intensity scale is problematic, because the intensity/magnitude scale indicates the strength of a disaster, but not its severity. In addition, the impact depends on where a disaster occurs, (e.g., a populated city or rural area). Moreover, assessing the severity is complex because some disasters have no systemized matrices available whereas those that do have matrices are not related to each other. Therefore, the intensity/magnitude scales are not suitable for differentiating between the severity levels of a disaster. Consequently, a new scale using impact factors should be introduced to define the severity levels. The potential severity levels of a disaster are studied using extreme value theory in Chapter 6 and 7 in terms of fatalities, as the most influencing factor that reflect severity.

3.5 Conclusion

This chapter described the initial step in developing a multidimensional scale to understand the disaster continuum. It demonstrated that there is not enough evidence to show the direct relationship between impact factors and intensity/magnitude scales. Hence, intensity/magnitude scales are not the best way to describe the severity of a disaster.

According to the analysis, the impact factors fatalities, injuries, cost of damage, and houses damaged are selected as the most influencing common impact factors that can be consider for a multi-dimensional scale. However, these impact factors are highly correlated, hence, one factor can represent the variation of the other factors. In addition, fatalities is selected out of four impact factors as the most influencing factor representing severity in order to develop the initial severity scale.

Chapter Four: FOUNDATION OF THE UNIVERSAL DISASTER SEVERITY CLASSIFICATION

In this chapter, the *Research Question A (i.e., how many levels are required to clearly differentiate the impact of natural disasters?)* is answered in Section 4.2. By introducing the *Deliverable IV (i.e., creation of a foundation of a Universal Disaster Severity Classification, a bridge between qualitative and quantitative techniques)* in the Section 4.2, the *Objective 1* of this research is achieved.

4.1 Introduction

As discussed in Chapter 3, the existing intensity/magnitude scales are not sufficient to assess the severity, because they are an indication only of the strength, but not the impact. There is no way to relate one magnitude/intensity scale to the other in order to compare the impact of different types of disasters. Therefore, the severity of a disaster need to be measured using a common scale, by observing the similarities of impact of various natural disasters.

4.1.1 Significance of a common technique

The common severity scale is developed by focusing on clear definitions introduced in Chapter 5 and by analyzing extreme events (Chapter 6). It will give a set of criteria to use to make comparisons and rank of natural disasters. This unified way of describing disasters will provide an overall picture of the severity of each type of disaster. Therefore, officials, specifically emergency responders and disaster managers, first identify the disaster potential and respond accordingly by allocating resources for mitigation measures. No matter the type of disaster, similar kinds of resources are managed by personnel who allocate available emergency vehicles, essential sources (food, water, cloth, sanitary, etc.), temporary hospitals, temporary housing, and so on. All mitigation efforts are dependent on the estimated disaster impact. Identifying the disaster impact properly, and in a timely manner, is crucial because lives depend on these decisions. Inconsistent identifications of disaster impact mean that disaster managers may either over or undercompensate in their allocation of resources for mitigation. Overcompensation could result in a large waste of resources, while undercompensation could increase the severity of impact. In addition, one city can have different types of disasters, but the same personnel respond to these events. Thus, a common method to measure the severity of different types of disasters is necessary.

In addition, populations are most sensitive to disastrous events with high human impacts. In other words, more attention is given to the disasters with high human impact when compared to disasters with high intensity. Therefore, defining a severity scale using human impact will attract more public attention. Thus, public awareness, education level, and response rate to warnings can be increased using the proposed scale, because a direct relationship between a disaster and the probability of human impacts are made explicit. Further, the severity scale based on human impacts should also be used as a mitigation method, which can help change public opinion regarding the impact of disasters. Warnings indicating the severity of a natural disaster can be communicated using the severity scale, which may improve public response. Proper communication regarding life-threatening situations will attract public attention, and will provide time and information to attain a safe location, during a disaster subject to proper pre-planning.

Currently the disaster information management system is deficient and, therefore, a common global scale is needed. Some of the deficiencies in global databases are due to:

- missing data because some events are not qualified to enter into a database, according to the definitions or requirements;
- incomplete data because some databases do not record all the necessary information;
- inaccurate data because global databases lack common standards. A lack of common terminology is a major issue in disaster related information management and processing (Hristidis et al. 2010).

Moreover, estimations of the range of severity, based on disasters' characteristics and human impacts, are a matter of expediency. A better scale is necessary to improve the poor quality of reporting databases. Improvements in the scale can help to directly apply an emergency response management system to disaster events, and to develop relationships based on information management processing. The current data quality is insufficient for many purposes and any efforts to improve that situation needs to be supported. Thus, there is no substitute for improved data quality.

As discussed in Chapter 1, having a common disaster severity scale will benefit emergency responders, disaster managers, disaster compensation and insurance policies (insurance managers and estimators), national/regional/local governments, non-governmental organizations (NGOs), international/local relief agencies, information managers, database managers, media outlets, researchers, reporters, general public, and so on.

4.2 Universal Disaster Severity Classification

Research Question A: How many levels are required to clearly differentiate the impact of natural disasters?

Before introducing the different techniques that can be used to differentiate the various levels of impact of an event, the question, "how many levels of seriousness are needed?" is first explored. Then, the impact on humans and their environment is considered to describe the severity of an event. However, more attention is given to human factors such as the number of the following: fatalities, missing people, injuries, homeless people, evacuees, and affected populations. These human factors range from 0 up to 7.347 billion, the world's population (World Bank 2015). Next, attention is paid to human possessions or monetary factors such as the number of houses damaged or destroyed, the cost of the damage in United States dollars (USD), and what areas are affected. Damage can range from 0 to 78.089 trillion USD (World Bank 2016) according to maximum Gross Domestic Product (GDP) in 2014.

Both the ranges of human factors and material damage factors are very large and the interval system is the best suitable technique to consider both human and monetary factors. The log scale interval is used to address these long ranges and ten different levels of categorizing events are used according to this technique. To explain further, the 10 different levels of human factors (H) mentioned above are shown in Table 4.1. In addition, the 13 levels of the cost of damage (D) are shown in Table 4.2. However, the severity of a natural disaster is measured by the adverse effects of the event on a community or an environment, not the severity of the event on an individual person. Therefore, the first three ranges of damage, which are at most 1,000 USD, can be ignored. Consequently, the damage factor ranges are reduced to 10 ranges starting from 1,000<D≤10,000 and ending at 1 trillion < D. Therefore, 10 different levels representing both human and material damage impacts are considered in designing a Universal Disaster Severity Classification, as shown below in Table 4.3.

Table 4.1 Ranges of human factors in different levels

	Human factors (H)
1	0<H≤10
2	10<H≤100
3	100<H≤1,000
4	1,000<H≤10,000
5	10,000<H≤100,000
6	100,000<H≤1 million
7	1 million<H≤10 million
8	10 million<H≤100 million
9	100 million<H≤1 billion
10	1 billion<H

Table 4.2 Ranges of damage factors in different levels

	Damage factors (D)
1	0<D≤10
	10<D≤100
	100<D≤1,000
	1,000<D≤10,000
2	10,000<D≤100,000
3	100,000<D≤1 million
4	1 million<D≤10 million
5	10 million<D≤100 million
6	100 million<D≤1 billion
7	1 billion<D≤10 billion
8	10 billion<D≤100 billion
9	100 billion<D≤1 trillion
10	1 trillion<D

Table 4.3 Levels and their colour coding in the Universal Disaster Severity Classification (UDSC)

Seriousness level/ UDSC level	Colour code
1	Turquoise
2	Dark Green
3	Light Green
4	Yellow
5	Amber
6	Red
7	Maroon
8	Light Purple
9	Dark Purple
10	Black

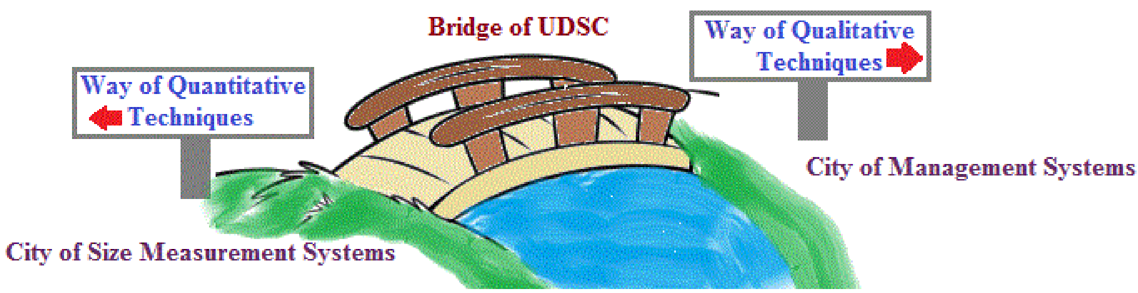


Figure 4.1 UDSC: the bridge between qualitative and quantitative techniques

For each level, colour coding reflects the seriousness of the event because it is easier to explain severity levels to citizens of diverse countries and languages by using a colour coding scheme, rather than words. However, there is no consistent method of colour coding. Different fields have different colour coding—there are even different colour codings within the same field. Nevertheless, the UDSC is designed for use by all stakeholders including policy makers, governments, responders, civilians, and so on. As this system is used by almost everyone in civilized society, and they are familiar with the consistent colour coding of traffic signals (i.e., green, red, and amber), the same colour coding system was selected. Then, turquoise was added together with green and amber to represent lesser severity levels, and black and purple were added together with red to represent higher severity levels. The resulting 10 colours (6 primary and 4 sub-colours) represent the 10 levels of severity as shown in Table 4.3. This colour coding is similar to the following medical triage code tags:

- black tags—are used for the deceased and for those whose injuries are so extensive that they will not be able to survive given the care that is available;
- red tags—are used to label those who cannot survive without immediate treatment, but who have a chance of survival;
- yellow tags—are used for those who require observation (and possible later re-triage). Their condition is stable for the moment and they are not in immediate danger of death. However, these victims will still need hospital care and would be treated immediately under normal circumstances;
- green tags—are reserved for the "walking wounded" who will need medical care at some point, after more critical injuries have been treated; and
- white tags—are given to those with minor injuries for whom a doctor's care is not required.

Introducing colour coding with the level of seriousness eliminates language barriers and confusion that could arise due to the diverse meaning of the terms. Therefore, the proposed Universal Disaster Severity Classification (UDSC) in Table 4.3 can be adapted to any language, country, or society. The most important advantage of the UDSC is that it can be integrated with qualitative techniques and also with quantitative techniques (Figure 4.1). The integration of a qualitative technique is shown in the Solution 1 and Solution 2 in Section 5.5.1. The integration of a quantitative technique is discussed in Section 6.2.

4.3 Discussion

The confusions can be minimized when there is an adequate number of levels to distinguish between different levels of seriousness and when a consistent number of levels exists.

As explained in Chapter 3, the severity of an event can be evaluated by measuring the negative impact of a disaster on people and infrastructure because the severity of a disaster directly relates to its human impact (concentrated in socio-economic factors), and indirectly relates to preparedness for and the power of the disaster. Even a very large range of socio-economic factors (e.g., human and material damage factors) can be concentrated into 10 different levels using the log scale, as explained previously. In addition, this scale is easy to remember as the levels increase by a power of 10 between levels. Moreover, people are most comfortable with a 10 level representation rather than some random number of levels such as 8, 9, 11, or 12. Furthermore, it is easy to integrate the foundation of the UDSC with quantitative and qualitative measures with 10 levels. Therefore, defining the foundation of the UDSC with 10 severity levels is well suited, meaningful, and easy to remember for users.

For each level, the colour coding system is also used to reflect the seriousness of the event because it is easier to explain severity levels to citizens of diverse countries and languages by using a colour coding scheme, rather than trying to explain through words or numbers. Although matching words in many languages can be found to represent each level of seriousness, there will be some people working or involved in disaster recovery who are not literate, or cannot understand the local language or dialect. Therefore, colour coding is the most effective means of communication between people and organizations since almost all can distinguish and understand this UDSC through colour.

4.4 Conclusions

This chapter described the Step 2B (see Section 1.5) of developing an UDSC. The foundation of the UDSC will serve as a bridge between qualitative and quantitative techniques used in emergency management systems. Qualitative and quantitative techniques can be integrated to create management and size measurement systems respectively (see Figure 4.1). Therefore, UDSC will avoid inconsistencies and, most importantly, will connect severity metrics in order to generate a clear understanding of the degree of emergency and the potential hazards.

Chapter Five: QUALITATIVE MEASURE OF THE UDSC

There are three main methods for comparing natural disasters. The third method, using descriptive terms, is discussed in this chapter (as the other part of the *Deliverable II*). The first method, using an intensity scale, and the second method, using statistics, are discussed in Chapter 3 (as part of the *Deliverable II*).

In this chapter, the qualitative part of *Research Question B (i.e., how are these levels used to clearly distinguish the various degrees of natural disasters?)* is answered in Sections 5.5, 5.6, and 5.7. *Research Objective 2 (i.e., Develop a qualitative measure: a clear order and definitions of existing terminologies, which describe the severity of disasters)* including *Deliverable V*, is achieved in this chapter.

5.1 Introduction

Research sub-question a(i) Are the existing qualitative techniques that emergency responders and so on, currently use adequate to clearly distinguished the severity levels of natural disasters?

It is equally important to understand emergency management from a comparative perspective for several reasons. First, the size of the disaster matters for an emergency management system. For instance, the Alberta Emergency Management Agency (AEMA) uses ‘Incident Management Teams – Typing’ as a way to classify all hazards and assign a type number to the incident, in order to address response and recovery activities as shown in Table 5.1 (AEMA 2015). In particular, a Type 1 Incident Management Team (Table 5.1) can manage a small community fire; however, to manage a major flood may require a Type

3 or higher Type Incident Management Team. A concern arises because one ranking system is used for management (for example, AEMA's incident management teams typing), and another ranking system is used to measure a disaster (for example, Richter, VEI, and EF scale). However, the relationship between these two systems is not clear.

Table 5.1 Incident Management Teams - Typing

Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 5**
National - Provincial / State level	National - Provincial / State level	All hazard	Regional	Local
Self-contained, all-hazard team	Self-contained, all-hazard team	Multi-agency/multi-jurisdiction team	City or county level	City or county level
35-50 trained personnel	20-35 trained personnel	10-35 trained personnel	7-10 trained personnel	7-10 trained personnel
Incidents of national significance and other incidents requiring a large number of resources over multiple operational periods (500-1000)	Incidents of regional significance and other incidents requiring a large number of resources (200 - 500)	major and/or complex incidents	expanded incidents	Incidents contained within one operational period

Source; AEMA 2015

Second, a nation's ability to manage extreme events, including natural disasters and other perils, is more effective when there is a good, mutual understanding between different countries of emergency management systems at all levels: international, continental, regional, national, provincial, and local. The ability of different countries to manage extreme events can be dependent on the technique the countries uses.

However, natural disasters do not have boundaries and different countries use different techniques to manage extreme events; therefore, either a mutual understanding of the techniques used by other countries, or a common global standard, is required in order to better prepare and manage global disasters that affect more than one country. For instance, if there were a mutual understanding of emergency management systems when, in 2004, the Indian Ocean tsunami struck 12 countries over a vast area of Asia and Africa, it may have saved thousands of lives. In particular, disaster management teams use different methods to assess a disaster before responding. As an example, the AEMA uses 'Incident Management Teams – Typing' as a way to classify all hazards, and to assign a type number to the incident, in order to address response and recovery activities, as shown in Table 5.1 (AEMA 2015). The type is assigned by internal personnel and can be subjective due to the experience of the personnel, and the internal processes that are used. The decisions made can delay the adoption of appropriate actions needed to mitigate a disaster; in other words, assistance from international governments, NGO's, relief agencies, and volunteer communities can be delayed (Caldera et al. 2016b). The consequences of failing to identify a potential hazard are devastating. For example, regarding Hurricane Katrina, Tierney (2008) explained that "… Katrina's devastating impacts were worsened by a sluggish and ineffective response by all levels of government and by a lack of leadership on the part of high-ranking federal government officials and others who were incapable of recognizing Katrina's catastrophic potential, even after the storm made landfall."

Third, warning indications should be given in plain language so that everyone can understand the seriousness of a coming disaster, and the urgency of evacuation. In warning indication communications, the intensity of a disaster is commonly used as the measure of the destructive power because the intensity/magnitude is assumed to be the most meaningful to the general public. However, intensity/magnitude levels are not the best way to describe the severity level of a disaster because they are an indication only of the strength, but not the impact, as mentioned previously in Chapter 1 and 3. The impact depends on where a disaster occurs: an impact can be quite different in a populated city, when compared to a rural area. Specifically, a considerable body of research presents data indicating that people often underestimate or ignore natural disasters and other low probability events (Camerer and Kunreuther 1989; Meyer 2006). Severe natural disasters are low probability, high consequence events. Therefore, a new technique is required to communicate the warnings issued by emergency management systems to the general public so that there is a mutual understanding between both parties.

Inconsistent and disconnected severity measures mean that either members of the general public may not clearly understand the degree of the emergency, or that members of emergency management systems may not have a clear understanding of the potential hazard. Therefore, there is a mandate for a new system that integrates both measurement systems: management and size.

Clearly defined existing terms are required to quantify disaster events. Integrating descriptive words into an emergency management system improves mutual understanding between both parties and is easier to manage with minimal confusion. For instance, the terms incidents, emergencies, disasters, catastrophes, calamities, and cataclysms have increasing levels of seriousness; therefore, these words should be used instead of the headings that merely state type 1, 2, 3, 4, 5 for incident management teams. This change will improve understanding at all levels and avoid confusion about whether type 1 or type 5 is the most critical. Naming the different categories, using plain language to describe the magnitude of a disaster, allows for easier management at all levels. However, selecting the appropriate term for different levels should be conducted with careful evaluation.

Knowing that disasters are large emergencies, and that catastrophes are large disasters, is not sufficient. Though these words imply increasing levels of severity, one observer's "disaster" might be another's "catastrophe," depending on one's personal feelings and experiences of the event. Even in the literature on disasters, there is controversy about whether the term "catastrophe" can be differentiated from disaster, or whether they are synonyms (Penuel et al. 2013). Therefore, these words require clear definitions to distinguish one meaning from the other and to clearly indicate the levels of seriousness. Consequently, these words will more accurately categorize events for emergency management processes and subsequent disaster impact.

As a solution to the aforementioned inconsistencies, a standard technique is required to describe the severity levels of natural disasters. However, emergencies, disasters, and catastrophes are not enough to clearly differentiate the sizes of the disasters. The Encyclopedia of Crisis Management's improved classification with four levels (see Table 1.2) are still insufficient for accurate categorization (see Section 1.2.1.1 for more explanation). Therefore, more levels are required to clearly differentiate the impact of natural disasters.

Accordingly, existing scales and the descriptive terms for disasters are not sufficient to clearly distinguish the severity levels of the disaster. In addition, comparing different events, and obtaining a sense of scale, are problematic due to the deficiencies that reduce the quality of the data set. Therefore, disaster managers may face inconsistencies in identifying a hazard potential, responding to the event properly, and allocating resources for mitigation measures (Gad-el-Hak 2008a). Also, disaster compensation and insurance policies may not include a clear basis in order to assess disasters in common way when there are deficiencies (Kelman 2008). These issues support the need to develop a consistent scale in order to understand the disaster continuum, and to develop a platform for a reliable and transparent data management process that facilitates comparisons between different disasters (Gad-el-Hak 2008a; Löw and Wirtz 2010).

Moreover, databases that compile disaster events at the national level face issues regarding disasters that have impacts on a regional or continental scale. The same disaster event can have very different impacts in each country (Löw and Wirtz 2010), and thus, the interpretation of scale for the same event can vary between countries (Wirasinghe et al. 2013). Furthermore, one disaster may lead to another disaster, which results in conjoint disaster records, and therefore, separating the impacts can be problematic. Thus, the nature of the disaster, whether it is primary or secondary, is one of the main issues in distinguishing one disaster from the other. Although historical records are typically the most important sources for understanding natural disasters, the historical inaccuracy of past records is unavoidable. Therefore, there is a need to avoid inaccuracies in the future. Hence, consistent interpretation, common terminology to identify the scale, a good understanding of each disaster, and an expanded recording system are required to accomplish this goal.

This chapter introduces terms that can be used to compare the severity levels. Clear definitions of these terms are proposed in order to make comparisons, and to rank natural disasters more accurately. These definitions are provided based on an analysis of their etymology and current English dictionary definitions. Having clear definitions with clear order of seriousness allows for easier recognition of an event occurrence, and provides an overall picture of the severity of disasters, in order to help emergency response management systems.

5.1.1 Significance of clearly defined terminologies

Clear definitions of the currently used terminologies are necessary to classify the severity of various types of disasters because the current data quality is insufficient for many purposes. Clearer terminology will improve the existing poor quality of the data in reporting databases. It may take many years to obtain sufficient quantities of quality reports in order to directly estimate event occurrences. However, even relatively short records can be used to develop relationships among variables records in databases (Brooks 2013), which improve the analysis, and research in order to have more understanding about disasters . Therefore, easily recognizing an event occurrence, and having a set of standard terms in a proposed scale, will allow database managers to improve information management and processing. A standardized database terminology can be developed, and the associated data can be managed in order to mitigate missing or inaccurate data. Using common terminology to clearly identify the scale of a disaster can be the standard used to record disasters. Then, the scale can be used to record global disasters and the sub-divisions of a continental, regional, or national records. Common terminology can also be used to record joint disaster records (i.e., combine impact of primary and secondary disasters), and the separation, and separate disasters can be recorded as a subdivision of the record, where possible (if the impact of primary and secondary disasters can be separate clearly). As a result, complications, misunderstandings, misclassifications, and missing records can be minimized as much as possible.

In addition, the warnings indicating the severity of a natural disaster can be communicated using the clearly defined terms. Consequently, meaningful communication regarding life-threatening situations are more likely to elicit an appropriate public response; people may then have the necessary time and information to get to a safe location prior to being affected by the disaster.

Furthermore, by having an overall picture of the severity of the disaster, emergency responders and disaster managers can quickly recognize the severity potential and appropriately allocate resources. The proposed terms should also be used as preparedness and mitigation methods; warnings, evacuation, public awareness, disaster education, and disaster drills may gain the public's attention and increase trust towards the techniques used by the emergency management system and emergency responders. Thus, response time to warnings can be decreased, and response rates can be increased by using the proposed terms. This is because a direct relationship between a disaster and the human impact will be more explicit. As Durage (2014) indicated, “The frequent occurrence and high intensity of natural disasters can impose irreversible negative effects on people. Taking mitigation actions well in advance can avoid or significantly reduce the impacts of disasters.” Although it is difficult to avoid property damage, due to the sudden onset of a natural disaster, if proper classifications and terminology are used in an emergency management system, fatalities and injuries could be minimized by taking appropriate actions such as issuing warnings on time and raising the public awareness.

Clear terminology is important for social aspects. The scale will also benefit many other groups such as insurance managers and estimators, the research community, and the media (see Section 1.7 for more details). Introducing a clearly defined terminology and application of common terms may save lives.

5.2 Descriptive terms

People often describe natural events in a myriad of subjective levels of severity: deaths, injuries, and property damage are identified as armageddon, apocalypse, calamities, cataclysms, catastrophes, disasters, and emergencies. However, the sense of the real magnitude of a disaster’s severity cannot be comprehended using this lexical system of language, because this basic method has several deficiencies. First, the vocabulary, context and interpretation of each term is not fixed (Kelman 2008), which is illustrated through the etymological analysis of these words. Second, there is no consistent method to distinguish one term from the other, which can be illustrated by English dictionary definitions. Third, the meanings of these terms change according to their application. These terms are often used as metaphors, and have different connotations. Fourth, although these terms imply increasing levels of severity, one observer's "disaster" might be another's "catastrophe" or even "calamity" depending on personal feelings and experience. The following subsections explain more about these discrepancies.

5.2.1 Etymological analysis

The linguistic method is the most commonly used and oldest method of describing natural disasters of various magnitudes, and has been applied since the beginning of civilised society. However, the meaning of the descriptive terms used to define the seriousness of disasters has changed over time. Etymological dictionary definitions of apocalypse, calamity, cataclysm, catastrophe, disaster, and emergency are given in Table 5.2. The current definitions of the same terms as documented in well-known dictionaries of English are given in Table 5.3. A comparison of Table 5.2 and Table 5.3 shows how the meaning of these terms has changed dramatically. For instance, the word disaster was added to the English vocabulary in the late 16th century and meant 'ill-starred event'; currently, it is defined in the Oxford Dictionary as 'a sudden accident or a natural catastrophe that causes great damage or loss of life.' The level of seriousness of these terms has also changed over time as the meaning of these terms change. This change is further explained in the 'order of seriousness of the terms' section (Section 1.2).

Table 5.2 Etymological Definitions

Disaster term	The Oxford Dictionary of Word Origins [1]	Oxford English Dictionary [2]	Online Etymology dictionary [3]
Apocalypse	-	< Latin apocalypsis, < Greek ἀποκάλυψις, noun of action < ἀποκαλύπτειν to uncover, disclose, < ἀπό off + καλύπτειν to cover	late 14c., "revelation, disclosure," from Church Latin apocalypsis "revelation," from Greek apokalyptein "uncover, disclose, reveal," from apo- "from" (seeapo-) + kalyptein "to cover, conceal" (see Calypso). The Christian end-of-the-world story is part of the revelation in John of Patmos' book "Apokalypsis"(a title rendered into English as "Apocalypse" c. 1230 and "Revelations" by Wyclif c. 1380). Its general sense in Middle English was "insight, vision; hallucination;" meaning "a cataclysmic event" is modern. As agent nouns, apocalypst (1829),apocalypt (1834), and apocalyptist (1835) have been tried.
Calamity	This is from Old French calamite, from Latin calamitas 'damage', 'disaster', 'adversity'. Latin writers thought this was from calamus 'straw, corn stalk' linked to damage done to crops by bad weather, but this is doubtful.	French calamité, < Latin calamitȧt-em (nominative calamitas), damage, disaster, adversity; by Latin writers associated with calamus straw, corn-stalk, etc., in the sense of damage to crops from hail, mildew, etc. But there is difficulty in reconciling this with the force of the suffix, which etymologically could give only some such sense as 'the quality of being a calamus, reed, or straw' (compare cīvitas, auctoritas, bonitas); hence some would refer it to a lost *calamis 'injured, damaged', whence incolumis 'uninjured, sound'. Bacon (Sylva §669) thus fancifully etymologized the word 'Another ill accident is drouth, at the spindling of the corn, which with us is rare, but in hotter countries common; insomuch as the word calamitas was first derived < calamus, when the corn could not get out of the stalke.'	Early 15c., from Middle French calamite (14c.), from Latin calamitatem (nominative calamitas) "damage, loss, failure; disaster, misfortune, adversity," origin obscure. Early etymologists associated it with calamus "straw" (see shawm); but it is perhaps from a lost root preserved in incolumis "uninjured," from PIE *klemo-, from base *kel- (1) "to strike, cut" (see holt).

Disaster term	The Oxford Dictionary of Word Origins [1]	Oxford English Dictionary [2]	Online Etymology dictionary [3]
Cataclysm	kata 'down' include cataclysm[E17th] from kluzein 'to wash'.	French cataclysme (16th cent. in Littré), < Greek κατακλυσμός deluge, < κατακλύζειν to deluge, < κατά down + κλύζειν to wash, dash as a wave	1630s, from French cataclysme (16c.), from Latin cataclysmos or directly from Greek kataklysmos "deluge, flood, inundation," from kataklyzein "to deluge," from kata "down" (see cata-) + klyzein "to wash," from PIE *kleue- "to wash, clean" (see cloaca).
Catastrophe	kata 'down' include catastrophe [M16th] from strophe 'turning'	Greek καταστροφή overturning, sudden turn, conclusion, < κατα-στρέφειν to overturn, etc., < κατά down + στρέφειν to turn	1530s, "reversal of what is expected" (especially a fatal turning point in a drama), from Latin catastropha, from Greek katastrophe "an overturning; a sudden end," from katastrephein "to overturn, turn down, trample on; to come to an end," from kata "down" (see cata-) + strephein "turn" (see strophe). Extension to "sudden disaster" is first recorded 1748.
Disaster	In a disaster the stars are against you, for this is from Italian disastro 'ill-starred event', from dis- (expressing negation) and astro 'star' from Latin astrum.	French désastre (1564 in Hatzfeld & Darmesteter) 'a disaster, misfortune, calamitie, misadventure, hard chance'; < des- , dis- prefix 1d + astre 'a starre, a Planet; also destinie, fate, fortune, hap' (Cotgrave), < Latin astrum, Greek ἄστρον star; after Italian disastro 'disastre, mischance, ill lucke' (Florio). Compare Provençaldezastre, Spanish desastre, Portuguese desastre, also Provençal benastre good fortune, malastre ill fortune, and English ill-starred.	1590s, from Middle French désastre (1560s), from Italian disastro "ill-starred," from dis-, here merely pejorative (see dis-) + astro "star, planet," from Latin astrum, from Greek astron (see star (n.)). The sense is astrological, of a calamity blamed on an unfavorable position of a planet.
Emergency	-	late Latin ēmergentia: see emergence n. and -ency suffix	"Unforeseen occurrence requiring immediate attention," 1630s, from Latin emergens, present participle of emergere "to rise out or up" (see emerge). Or from emerge + -ency. As an adjective by 1881.

Source: [1] (Cresswell 2009); [2] (Oxford University Press 2014); [3] (Harper 2001)

Table 5.3 Well-known dictionary definitions of English

Disaster term	Oxford Dictionary of English [1]	Merriam- Webster Thesaurus [2]	Dictionary.com [3]	Google Glossary [4]	The Free Dictionary [5]
Apocalypse	▪ The complete final destruction of the world, as described in the biblical book of Revelation ▪ An event involving destruction or damage on a **<u>catastrophic scale</u>**	▪ A great **<u>disaster</u>**: a sudden and very bad event that causes much fear, loss, or destruction	▪ Any universal or wide spread destruction or **<u>disaster</u>**	▪ The complete final destruction of the world, especially as described in the biblical book of Revelation. ▪ An event involving destruction or damage on an awesome or **<u>catastrophic scale</u>**	▪ Especially of the imminent destruction of the world and the salvation of the righteo us. ▪ The end of the world, espec ially as described in one of t hese texts. ▪ A great **<u>catastrophe</u>** that re sults in widespread destruct ion or the collapse of civiliz ation
Calamity	▪ An event causing great and often sudden damage or distress; a **<u>disaster</u>**	▪ A **<u>disastrous event</u>** marked by great loss and lasting distress and suffering	▪ great misfortune or **<u>disaster</u>**, as a flood or serious injury.	▪ An event causing great and often sudden damage or distress; a **<u>disaster</u>**. ▪ **<u>Disaster</u>** and distress	▪ An event that brings terrible loss, lasting distress, or severe affliction; a **<u>disaster</u>**
Cataclysm	▪ A large-scale and violent event in the natural world	▪ Flood, deluge ▪ **<u>Catastrophe</u>**	▪ Physical Geography. A sudden and violent physical action producing changes in the earth's surface. ▪ An extensive flood; deluge.	▪ A large-scale and violent event in the natural world.	▪ A violent upheaval that causes great destruction or brings about a fundamental change. ▪ A violent and sudden change in the earth's crust. ▪ A devastating flood.

Disaster term	**Oxford Dictionary of English** [1]	**Merriam- Webster Thesaurus** [2]	**Dictionary.com** [3]	**Google Glossary** [4]	**The Free Dictionary** [5]
Catastrophe	▪ An event causing great and usually sudden damage or suffering; a **<u>disaster</u>**	▪ A violent and sudden change in a feature of the earth ▪ A violent usually destructive natural event (as a supernova)	▪ A sudden and widespread **<u>disaster</u>** ▪ Geology. A sudden, violent disturbance, especially of a part of the surface of the earth; cataclysm.	▪ An event causing great and often sudden damage or suffering	▪ A great, often sudden **<u>calamity</u>** ▪ A sudden violent change in the earth's surface; a **<u>cataclysm</u>**
Disaster	▪ A sudden accident or a natural **<u>catastrophe</u>** that causes great damage or loss of life	▪ A sudden **<u>calamitous event</u>** bringing great damage, loss, or destruction	▪ A **<u>calamitous event</u>**, especially one occurring suddenly and causing great loss of life, damage, or hardship, as a flood, airplane crash, or business failure.	▪ A sudden event, such as an accident or a natural **<u>catastrophe</u>**, that causes great damage or loss of life.	▪ An occurrence causing widespread destruction and distress; a **<u>catastrophe</u>**
Emergency	▪ A serious, unexpected, and often dangerous situation requiring immediate action	▪ An urgent need for assistance or relief	▪ A state, especially of need for help or relief, created by some unexpected e vent	▪ A serious, unexpected, and often dangerous situation requiring immediate action.	▪ A serious situation or occurrence that happens unexpectedly and demands immediate action. ▪ A condition of urgent need for action or assistance

Source: [1] (Oxford University 2010); [2] (Merriam- Webster 2013); [3] (“Dictionary.com” 2013); [4] (“Google Glossary” 2014); [5] (Farlex 2013)

5.2.2 Current dictionary definitions analysis

Table 5.3 shows that almost all well- known dictionaries use these terms synonymously in their definition. For example, the Oxford Dictionary describes a disaster as a catastrophe, and then defines catastrophes and calamities as disasters. Merriam-Webster describes a disaster as a calamity, and a calamity and apocalypse as a disaster. Therefore, a clear sense of the real magnitude of the disaster cannot be understood by using these terms to describe an event.

5.2.3 Different meanings depending on their contexts

The terms, such as disasters, catastrophe, and calamity, often rely on metaphors and connotations. In addition, the meaning of the terms is different depending on the context in which they are used. For example, Shakespeare used the term “catastrophe” to express insult: “I’ll tickle your catastrophe” in Henry IV, Part 2 (Shakespeare 1600). However, a catastrophe in Geology is a sudden and violent change in the physical order of things, such as a sudden upheaval, depression, or convulsion affecting the Earth's surface and the living beings upon it. Some have supposed that a catastrophe occurs at the end of the successive geological periods (Oxford University Press 2014). Another example is as follows: “emergency” is generally used to indicate urgency, or pressing need, but in Botany, “when the cells of hairs are hardened by thickening of the cell-wall. They are called Prickles... By some these are not considered as hairs, but are termed emergencies (Edinburgh and Black 1889).

Even in the same field, the definition of the descriptive terms varies. For instance, the EM-Dat disaster database has defined a disaster as “a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering." An emergency management framework of Canada's definition of disaster extends to include geophysical, biological, and human caused events (such as terrorism, accidents, and technological failures, either malicious or unintentional), which cause serious harm to the safety, health, welfare, property of people, or to the environment (Ministers Responsible for Emergency Management 2011). The following sub-sections illustrate the application of the terms according to their meaning as mainly taken from the Oxford English Dictionary website, the definitive record of the English language (Oxford University Press 2014).

5.2.3.1 Apocalypse

The various definitions of the term "apocalypse" according to the Oxford Dictionary of English are as follows:

1. (With capital initial.) The 'revelation' of the future granted to St. John in the isle of Patmos. The book of the New Testament in which this is recorded.
    - Æfter þysum sy gecweden an ræding of apocalipsin gemyndelice butan bec (Rule of St. Benet, a1100–1450, (Tiber.) xii. 36)
    - Herof seid Seint Johan þe ewangeliste in apocalipsi [Lambeth homilies,81, c1175 (in O.E. homilies, I, E.E.T.S. 1868)]
    - Hit isan derne halewi seið sein Iohan þe godspeller in þe apocalipsi (E. J. Dobson, The English text of the Ancrene Riwle, c1225, EETS 267, 1972, 74, London: Oxford University Press,ISBN 0197222692

- That sallow horse of hewe, That in the Apocalips is shewed (Roman Rose, 1400, 7395, c1400)
- The Pocalyps of Ion (L. F. Casson, The romance of Sir Degrevant: a parallel-text edition from mss. Lincoln Cathedral A.5.2 and Cambridge University Ff.1.6, EETS 221, 1949, London: Published for the Early English Text Society by Geoffrey Cumberledge, Oxford University Press, LCCN 50003265, a1440,1437)
- The Laodicean Councill omitteth Lukes Gospel & the Apocalyps (J. Walker in A. Nowell et al. True Rep. Disput. E. Campion (1584) iv. sig. Z iiij b, 1581)
- That warning voice, which he who saw Th' Apocalyps, heard cry in Heaven aloud (J. Milton, Paradise lost: a poem in ten books · 1st edition, 1667, vol.1, iv.2)
- The long-controverted point whether Rome in the great Apocalypse was signified by Babylon (B. Disraeli, Lothair, new ed. xliv. 230, 1870)

2. By extension: Any revelation or disclosure.
    - He hath techinge, he hath apocalips, or reuelacioun, he hath tunge (Bible (The Wycliffite Bible (early version) · a1382) (Douce 369(2)) (1850) 1 Cor. xiv. 26 , c1384)
    - Interpret Apocalypses, & those hidden misteries to priuate persons (1621 R. Burton Anat. Melancholy iii. iv. i. iii. 756)
    - The Revelation, or rather, the Apocalyps of all State Arcana (1704 Swift Tale of Tub i. 48)

- The new Apocalypse of Nature unrolled to him (1834 T. Carlyle Sartor Resartus ii. v. 52/2)

3. Christian Church. The events described in the revelation of St John; the Second Coming of Christ and ultimate destruction of the world.
    - There are those who...think they already behold its fearful apocalypse terminating in darkness and in blood (1862 R.I. Schoolmaster (Rhode Island Commissioner Public Schools) 8 22/2)
    - The apocalypse will necessarily begin with a slaughter of tyrants, and Christ came, Blake says, to deliver those bound under the knave. (1947 N. Frye Fearful Symmetry (1990) iii. 67)
    - Eddy sends an e-mail to thousands of like-minded Christians announcing: ‘The End Days have arrived. TheApocalypse and the Rapture are at hand (2008 Washington Post (Electronic ed.) 28 Jan. c3)
4. More generally: a disaster resulting in drastic, irreversible damage to human society or the environment, esp. on a global scale; a cataclysm. Also in weakened use.
    - Comrades of Chicago...In these times there are...prophecies of approaching apocalypse...It will surely come (J. Swinton Striking for Life 357, 1894)
    - Washington is preoccupied with the threat of apocalypse across the Atlantic (Common Sense, 1940)

- Although most people are saddened by the enforced abandonment of some titles, no one is prepared to interpret it as the publishers' apocalypse (Bookseller 1980)
- While the poor are bewitched by dreams of peace and plenty, the rich are preparing for an apocalypse (Time, 1994)

5.2.3.2 Calamity

A person can apply different meanings, according to the situation, when he/she uses the term "calamity." To demonstrate further, the list below is a compilation of William Shakespeare's use of the word calamity with different meanings.

- as there is no true cuckold but calamity (Twelfth Night, TN 1.05. 51 P)
- I feel | the different plague of each calamity (King John, JN 3.04. 60)
- faithful loves, | sticking together in calamity (King John, JN 3.04. 67)
- is so arm'd | to bear the tidings of calamity (King Richard The Second, R2 3.02.105)
- and free my country from calamity (The First Part of King Henry The Sixth, 1H6 1.02. 81)
- why should calamity be full of words? (King Richard The Third, R3 4.04.126)
- you are transported by calamity | thither where (Coriolanus, COR 1.01. 75)
- we must find | an evident calamity (Coriolanus, COR 5.03.112)
- of thy parts, | and thou art wedded to calamity (Romeo and Juliet, ROM 3.03. 3)
- respect | that makes calamity of so long life: (Hamlet , HAM 3.01. 68)

The various definitions of the term "calamity" according to the Oxford Dictionary of English are as follows:

1. The state or condition of grievous affliction or adversity; deep distress, trouble, or misery, arising from some adverse circumstance or event.
    - He was restored..from anguisshe and calamyte in to right grete prosperite(Caxton, tr. The boke yf Eneydos, 1490)
    - I shalbe releuyd and in this my calamyte holpyn (Wolsey in H. Ellis Original letters illustrative of English history, 1529)
    - They fell from one calamitie into an other (R. Eden, tr. Peter Martyr of Angleria Decades of Newe Worlde, 1555)
    - Thou art wedded to Calamitie (Shakespeare, Romeo & Juliet, 1597)
    - So full is the world of calamity, that every source of pleasure is polluted (Johnson Rambler , 1752)
    - I am in calamity, my dear. I would love you if you were in calamity (S. Richardson, he history of Sir Charles Grandison, 1753)
    - Yet the compensations of calamity are made apparent to the understanding also, after long intervals of time (R. W. Emerson Compensation in Essays,1st Series (London ed.), 1841)
2. A grievous disaster, an event or circumstance causing loss or misery; a distressing misfortune.
    - Thair is na calamitie..yat may chance to man or woman (J. Hamilton, The catechisme, 1552)
    - A greefe of the head proceeding of a rewme, which is a common calamitie of students (T. Cogan, Hauen of Health, 1584)

- The bearing well of all calamities(Milton, Samson Agonistes, 1671)
- Because of any great Calamity that may have fallen on their Person (Bp. G. Burnet tr. T. More, Utopia, 1684)
- It was not his Custom to look out for distant Calamities (Johnson, An account of the life of Mr. Richard Savage, 1744)
- Voltaire saw his [sc. Newton's] death mourned as a public calamity (J. Morley, Voltaire, 1872)

5.2.3.3 Cataclysm

The various definitions of the term “cataclysm” according to the Oxford Dictionary of English are as follows:

1. A great and general flood of water, a deluge; esp. the Noachian deluge, the Flood.
    - In Geology resorted to by some as a hypothesis to account for various phenomena; hence used vaguely for a sudden convulsion or alteration of physical conditions.
    - More soules..then perisht in the first Vniversall Cataclisme (T. Heywood, A true Description of His Majesties Royall Ship, 1637)
    - Mankind sinned Malitiously, before God brought the general cataclysme upon them (R. Coke, Elements Power & Subjection 91 in Justice Vindicated, 1660)
    - For the proofs of these general cataclysms we have searched in vain (C. Lyell, Principles of geology, 1833)
    - The accumulated waters..will sweep through the ancient gap with the force of a cataclysm (H. M. Stanley, Through Dark Continent, 1878)

- The hypothesis usually called the Theory of Cataclysms or Catastrophes (Haeckel, Evolution of Man, 1879)

2. A political or social upheaval which sweeps away the old order of things.
    - Ready to pour down cataclysms of blood (True Trojans in W. C. Hazlitt A select collection of old English plays (1875), 1633)
    - Heaven rained on them great cataclismes of flames (T. Adams, A commentary or, exposition vpon the diuine second epistle generall, written by the blessed apostle St. Peter, 1633)
    - That the Indian army surgeons will be swept away in the general cataclysm (The Saturday Review (U.S.), 20 July 1861)
    - In the general upheaval of doctrine..during the Reformation cataclysm (J. H. Blunt, Reformation Church of England, 1882)

5.2.3.4 Catastrophe

There are several meanings of the word "catastrophe," which depend on context. To demonstrate further, the list below is a compilation of the different ways that William Shakespeare used the word "catastrophe."

- the catastrophe is a nuptial (Love's Labor's Lost, LLL 4.01 77P)
- began, | on the catastrophe and heel of pastime (All's Well That Ends Well, AWW 1.02. 57)
- I'll tickle your catastrophe (The Second Part of King Henry The Fourth, 2H4 2.01. 60 P)
- he comes like the catastrophe of the old comedy (King Lear, LR 1.02.134 P)

The various definitions of the term "catastrophe" according to the Oxford Dictionary of English are as follows:

1. The change or revolution which produces the conclusion or final event of a dramatic piece' (Johnson); the dénouement.
    - This tale is much like to that in Aesops fables, but the catastrophe and ende is farre different (E. K. in Spenser The shepheardes calender May Gloss, 1579)
    - A comicall catastrophe (R. Scot, Discouerie Witchcraft, 1584)
    - Sad is the plot, sad the Catastrophe (2nd Part Returne from Pernassus (Arb.), 1602)
    - Thou shalt be both the protasis & catastrophe of my epistle (R. C. Certaine Poems Ad Lectorem in Times' Whistle (1871), 1616)
    - That happy catastrophe and last scene which is to crown the work (T. Burnet, Theory of Earth, 1690)
    - They deny it to be Tragical, because its Catastrophe is a Wedding (J. Gay, What d'ye call It Pref. sig. Aiiv, 1715)
    - Such was the catastrophe of this long and anxious drama (J. H. Newman, Historical Sketches, 1876)
2. 'A final event; a conclusion generally unhappy' (Johnson); a disastrous end, finish-up, conclusion, upshot; overthrow, ruin, calamitous fate.
    - Thinking to deuower And worke my liues Catastrophy (R. Armin, The Italian Taylor, 1609)

- On the Catastrophe and heele of pastime When it was out (Shakespeare, All's Well that ends Well (1623), 1616)
- This was the obscure catastrophe of that great man (J. Mede Let. in H. Ellis Original letters, illustrative of English history (1824) 1st Series, 1628)
- The late war, and its horrid catastrophe (A. Marvell, Rehearsal Transpros'd, 1672)
- A Catastrophe or upshot of a business, catastrophe exitus (A. Littleton, Linguæ Latinæ Liber Dictionarius, 1678)
- This catastrophe had the brave Barbarossa and all his vast Designs (J. Morgan, A complete history of Algiers, 1728)
- The catastrophe of that siege is well known (Ld. Hailes Disquis. Antiq. Christian Church, 1783)
- This miserable catastrophe to a miserable career (W. Irving, Mahomet, 1850)

3. Humorously. The posteriors. (Obsolete)
    - Away you scullian..ile tickle your catastrophe (Shakespeare, Henry IV, Pt. 2, 1600)
4. An event producing a subversion of the order or system of things.
    - The Consternation and Confusion..upon such a sudden Catastrophy (Month. Mercury, 1696)
    - Her many Revolutions, Convulsions, and Catastrophes (D. Defoe, Memoirs of the Church of Scotland , 1717)

- God reveals His will not by sudden catastrophes and violent revolutions (F. W. Farrar, The witness of history to Christ, 1871)

5. Especially in Geology. A sudden and violent change in the physical order of things, such as a sudden upheaval, depression, or convulsion affecting the earth's surface, and the living beings upon it, by which some have supposed that the successive geological periods were suddenly brought to an end.
   - C. Lyell, Principles of geology (ed. 2), 1832
   - There are, in the palætiological sciences, two antagonist doctrines: catastrophes and uniformity (W. Whewell, Novum organon renovatum, 1858)
   - No geologist of repute now believes that mountain-ranges originated in catastrophes (Spectator, 7 May 1887)
6. A sudden disaster, wide-spread, very fatal, or signal. (In the application of exaggerated language to misfortunes, it is used very loosely.)
   - Thus were we all reduced to the utmost despair by this catastrophe (G. Anson, A Voyage round World (ed. 4), 1748)
   - The public catastrophe was actually completed by the actual recall of Lord F (E. Burke, Correspondence of … Edmund Burke (1844), 1795)
   - An inundation, more tremendous than any recorded in those annals so prolific in such catastrophes (J. L. Motley, Rise Dutch Republic, 1855)
   - This fishery is fearfully hazardous; scarcely a year passes without a catastrophe (E. K. Kane, Arctic explorations, 1856)

- Our hostess was immensely relieved that dinner had gone off without any catastrophe. My luggage has not arrived: what a catastrophe! (A new English dictionary on historical principles at Catastrophe, Mod., 1889)

7. Catastrophe theory in Mathematics the topological description of systems which display abrupt discontinuous change.
    - It is not too difficult a task to find all possible singularities V(x) of finite co-dimension not exceeding four. These singularities are important, because they may appear on our space–time in a structurally stable way. They give rise to what we call the ‘elementary catastrophes’, when we interpret them as describing dynamical fields on our space–time. (R. Thom, Topology, 1969)
    - Another interesting feature of catastrophe theory is called the divergence effect (The Times Literary Supplement, 10 Dec. 1971)
    - We can explicitly use catastrophe theory to explain and predict psychological phenomena (International Journal Neurosci, 1973)
    - Catastrophe theory is itself said to be in a catastrophic state (British Journal of Sociology, 1987)
    - Gravitational optics has an important connection with the branch of mathematics known as catastrophe theory (S. P. Maran, The Astronomy and Astrophysics Encyclopedia, 1st edition, 1992)

5.2.3.5 Disaster

A person can apply different meanings, according to the situation, when he/she uses the term "disaster." To demonstrate further, the list below is a compilation of William Shakespeare's use of the word calamity with different meanings.

- his faith, his sweet disaster (All's Well That Ends Well, AWW 1.01.173)
- it was a disaster of war that caesar himself (All's Well That Ends Well, AWW 3.03. 52P)
- this very instant disaster of his setting I' th' (All's Well That Ends Well, AWW 4.03.110)
- come, or sent it us | upon her great disaster (All's Well That Ends Well, AWW 5.03.112)
- should be, which pitifully disaster the cheeks (Antony and Cleopatra, ANT 2.07. 16 P)
- till the disaster that, one mortal/ night (Pericles, PER 5.01. 37)

The various definitions of the term "disaster" according to the Oxford Dictionary of English are as follows:

1. An unfavourable aspect of a star or planet; 'an obnoxious planet' (Obsolete)
    - Starres with traines of fier and dewes of blood Disasters in the sunne; and the moist starre, Vpon whose influence Neptunes Empier stands, Was sicke almost to doomesday with eclipse. (Shakespeare, Hamlet, 1604)
    - What dire disaster bred This change, that thus she veils her golden head? (F. Quarles, Emblemes, 1635)
2. Meaning: Anything that befalls of ruinous or distressing nature; a sudden or great misfortune, mishap, or misadventure; a calamity. Usually with a and plural, but also without a, as 'a record of disaster'

- ‘Disaster is etymologically a mishap due to a baleful stellar aspect’ (Whitney, Life Lang, 1875)
- Disastro, disastre, mischance, ill lucke (J. Florio, Worlde of Wordes, 1598)
- We make guiltie of our disasters, the Sunne, the Moone, and the Starres. (Shakespeare, King Lear, 1608)
- It was a disaster of warre that Cæsar him selfe could not haue preuented (Shakespeare, All's Well that ends Well, 1623)
- Let those soulls suffer that ar the occasioners of thy disaster and myne (J. Horsey, Relacion Trav. in E. A. Bond Russia at Close of 16th Cent. ,1856)
- Fate, it seems, would needs involve them in the same disasters (B. Harris tr. J. N. de Parival, The History of this Iron Age, 1656)
- Well had the boding tremblers learn'd to trace The day's disasters in his morning's face (O. Goldsmith, Deserted Village, 1770)
- Faithlessness was the chief cause of his disasters, and is the chief stain on his memory (T. B. Macaulay, History of England, 1849)
- Such a system must inevitably bring disaster (J. Morley, On Compromise, 1874)

3. A bodily affliction or disorder (Obsolete rare)
    - I am very ill of a disaster upon my stomach, yt I cannot ride (F. Rogers Let. in H. Slingsby Diary (1836), 1684)

5.2.3.6 Emergency

The various definitions of the term “emergency” according to the Oxford Dictionary of English are as follows:

1. The rising of a submerged body above the surface of water (Now rare)
    - A Tyrant..to prevent the emergencie of murdered bodies did use to cut off their lungs (Sir T. Browne, Pseudodoxia Epidemica, 1646)
    - They [sc. the Goodwin Sands] may be of late Emergency (Philosophical transactions (Royal Soc.), 1693)
    - Repeated submergencies and emergencies of the land (A. R. Wallace, Island Life, 1880)
2. The process of issuing from concealment, confinement, etc. (Obsolete)
    - Congratulate his...emergency from that course he was plunged in (J. Howell, A New Volume of Letters, 1647)
    - The..immediate emergency of Vitality from Spirit (H. More Antidote Atheism (1712) Pref. Gen., 1656)
    - The emergency, Pyrophilus, of Colours upon Coalition of the Particles of such Bodies...is very well worth our attentive Observation (R. Boyle, Experiments and considerations touching colours, 1664)
3. Emergency in Astronomy (Obsolete rare).
    - I had compared it with the fixed stars, and the Moon, after emergency from the aforementioned clouds (S. Dunn, Philosophical transactions of the Royal Society of London, 1763)

4. The arising, sudden or unexpected occurrence (of a state of things, an event, etc.). (Obsolete)
    - Most of our Rarities have been found out by casual emergency (J. Glanvill, Vanity of Dogmatizing, 1661)
    - The Emergency of an unexpected Case (N. Magens, An essay on insurances, 1755)
    - The emergency of war very frequently required their presence on the frontiers (Gibbon, The history of the decline and fall of the Roman Empire, 1776)
5. Concrete. A juncture that arises or ‘turns up’; esp. a state of things unexpectedly arising, and urgently demanding immediate action (The ordinary mod. use.)
    - The Psalmes minister Instruction..to every man, in every emergency and occasion (J. Donne, The sermons,1954)
    - Relief on sudden emergencies (R. Burn, The history of the poor laws, 1764)
    - On great emergencies, The law must be remodell'd or amended (Byron, Marino Faliero, Doge of Venice · 1st edition, 2nd issue, 1821)
    - The bishop, beautifully equal to the emergency, arose (A. Froude, History of England,1858)
    - On an emergency he would even undertake to measure land (S. Smiles, Huguenots in England, 1867)
6. Sometimes used for: Urgency, pressing need. ‘A sense not proper’ (Johnson).
    - In any Case of Emergency, [he] could employ the whole Wealth of his Empire (J. Addison, Free-Holde, 1716)

- It is a case of great emergency (A new English dictionary on historical principles at Emergency, Mod., 1891)

7. Casual or contingent profits (Obsolete)
    - Rents, Profits and Emergencies belonging to a Bishop of Bath and Wells (P. Heylyn, Cyprianus Anglicus, 1662)
8. Cricket, etc. An emergency man, a substitute. (No longer current.)
    - Emergency Williams, Esq., b. Goodrich. (Nottingham Review 5, 3-4 September 1851)
    - With this ball (presented by M.C.C. to E. M. Grace), he got every wicket in 2nd innings, in the match played at Canterbury, August 14, 15, 1862, Gentlemen of Kent v. M.C.C. for whom he played as an emergency, and in which, going in first, he scored 192 not out. (1862 in W. G. Grace Cricketing reminiscences (1899) i. 12)
    - George Alexander…only played as an emergency. (J. Lillywhite Cricketers' Companion 59, 1885)
9. Specifically, as a political term, to describe a condition approximating to that of war; occas. as a synonym or euphemism for war; also state of emergency, wherein the normal constitution is suspended.
    - He has declared a state of emergency to suppress a strike of African railway workers (The Spectator, 17 Jan. 1958)
    - The unmentionable word 'war' decently euphemised as 'emergency' (Oxford magazine, 13 Mar. 1958)

10. Emergency in Botany

- When the cells of hairs are hardened by thickening of the cell-wall…they are called Prickles... By some these are not considered as hairs, but are termed emergencies (Encyclopædia Britannica, 1876)

11. Emergency room in chiefly North America a hospital ward or department providing immediate treatment for urgent cases of illness and injury; a casualty department.

- The question has been.raised whether hospital authorities can be held responsible for the safety of persons who having attempted suicide, are successfully treated...in an emergency room (1886 Lancet 20 Nov. 985/2)
- Doctors and nurses on duty in emergency rooms never know what will be next...an explosion or fire victim or a brawl casualty (1948 Portsmouth (Ohio) Times 31 July 7/2)
- One man was admitted to a hospital emergency room with severe anemia (1997 Financial Post (Canada) 15 Mar. 31/5)
- I was a medical resident triaging patients in the emergency room of Mass General (2010 S. Mukherjee Emperor of all Maladies (2011) 437)

5.3 Order of seriousness of the terms

5.3.1 Etymological dictionary ranking

By summarizing Table 5.2, Figure 5.1 to Figure 5.6 illustrate how the words evolve. Table 5.4 gives a historical perspective of the order of seriousness of the words and their origin. “Emergency” and “apocalypse,” meaning to “rise up” and “disclose,” respectively, constitute lower levels of seriousness because they do not refer to physical impact. Using "emergency" and "apocalypse" to contextualize an event means these events are noteworthy and should attract the public's attention. However, the size of the impact described by these terms is assumed to be lower than an event described by other terms. "Calamity" can be considered as the next level because it's definition mentions damage, loss or failure of a system considered in an event. The next level, "cataclysm," mostly refers to water-related disasters, such as floods, which means an inundation of an area and property. A "catastrophe," meaning a "sudden turn," is the second highest level of seriousness as it implies the sudden end of a system because of an event. "disaster" describes the highest level of seriousness of an event. "Disaster" means an "ill-starred event," which implies the impact of a star or a planet with an event (i.e., the event caused to the planed to be ill state or destroyed). Therefore, according to the word origins, the order of seriousness of the terms from least serious to most serious are as follows: emergency, apocalypse, calamity, cataclysm, catastrophe, and disaster.

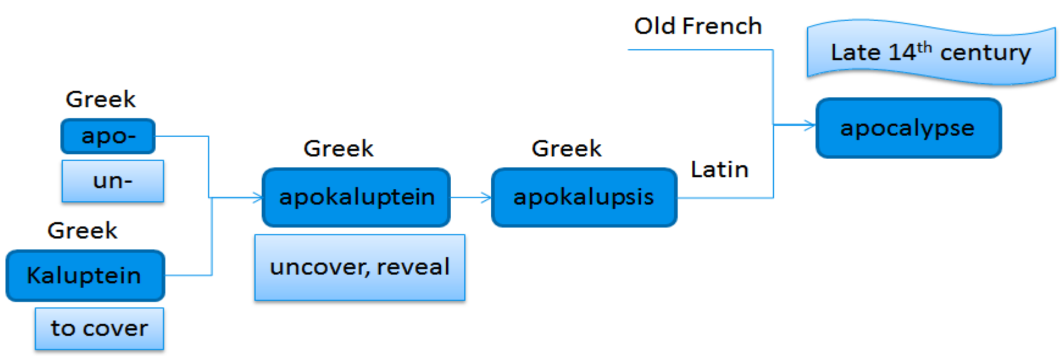


Figure 5.1 Etymological Definitions of the term "apocalypse" ("Google Glossary" 2014)

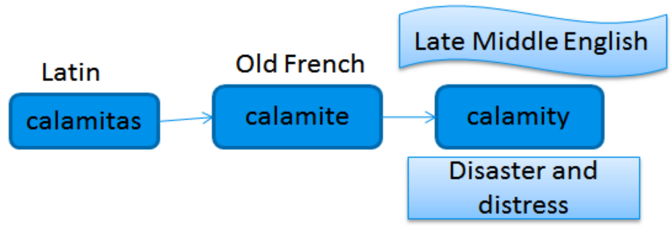


Figure 5.2 Etymological Definitions of the term "calamity" ("Google Glossary" 2014)

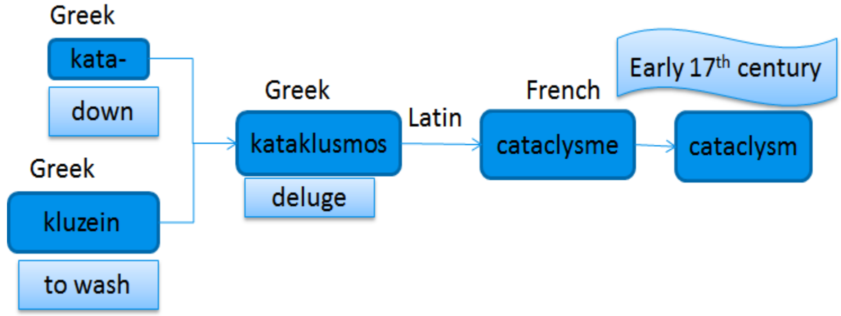


Figure 5.3 Etymological Definitions of the term "cataclysm" ("Google Glossary" 2014)

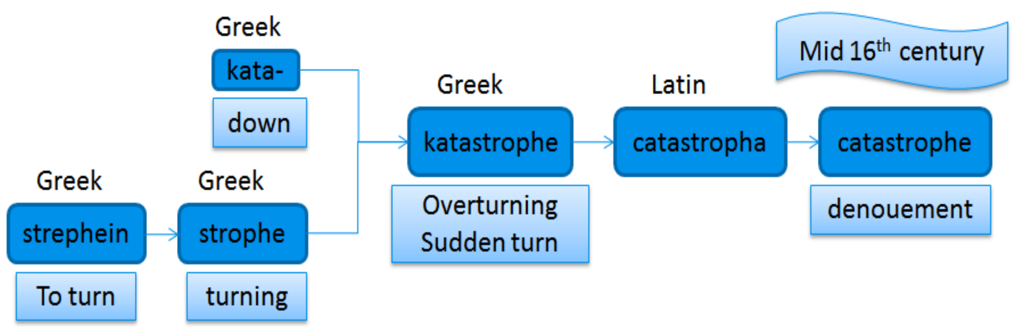


Figure 5.4 Etymological Definitions of the term "catastrophe" ("Google Glossary" 2014)

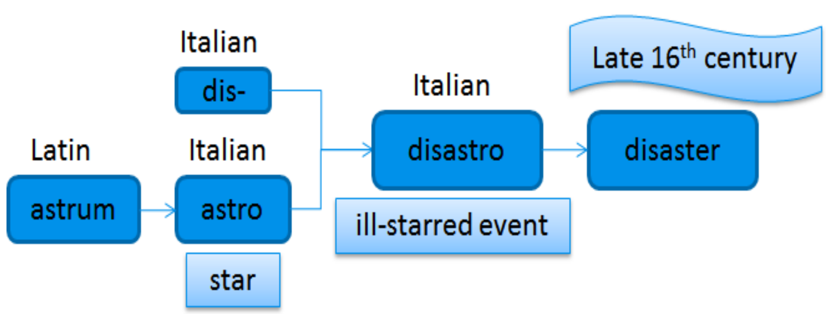


Figure 5.5 Etymological Definitions of the term "disaster" ("Google Glossary" 2014)

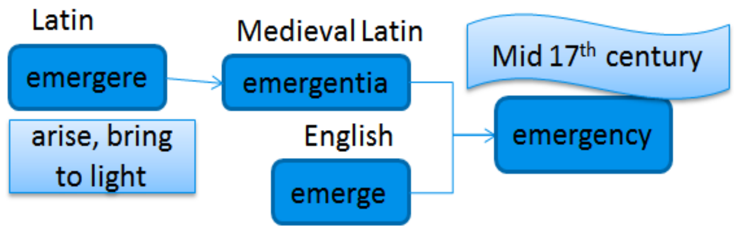


Figure 5.6 Etymological Definitions of the word "emergency" ("Google Glossary" 2014)

Table 5.4 Order of seriousness according to etymological definitions

Term	**Meaning**	**Time of the word origin**
Emergency	To rise out or up (unforeseen occurrence requiring immediate attention)	Mid-17th century (the 1630s)
Apocalypse	Uncover, disclose, reveal	Late 14th century
Calamity	Damage, loss, failure, misfortune, adversity	Late Middle English (Early 15c.)
Cataclysm	To wash down (deluge, flood, inundation)	Early17th century (the 1630s)
Catastrophe	Overturning, sudden turn (a sudden end)	Mid-16th century (the 1530s)
Disaster	Ill-started event (the stars are against you)	Late 16th century (the 1560s)

5.3.2 Current dictionary ranking

Table 5.5 shows the order of seriousness of the terms according to current English dictionary definitions and their summary definitions. An emergency accounts for the lowest level of seriousness of the considered terms. It describes an unexpected, serious condition that demands immediate action. However, damage or loss is not mentioned in the term's definitions. Therefore, damage can be considered minimal or none in this event. Disaster signifies the next level because it means a great deal of damage or loss of life. Calamity is considered as the third level of seriousness among the considered terms because it refers to terrible losses and lasting distress to people. Cataclysm constitutes the fourth level because it describes a sudden or violent change in the Earth's crust. Catastrophe can be considered as the fifth level of seriousness because it describes a sudden change in the Earth’s surface. Apocalypse is the final level of seriousness; it describes the collapse of civilisation and the end of the world.

Table 5.5 Order of seriousness according to current English dictionary definitions

Term	Meaning
Emergency	· A serious situation or occurrence that happens unexpectedly and demands immediate action · A condition of urgent need for action or assistance
Disaster	· A sudden accident or a natural catastrophe that causes great damage or loss of life
Calamity	· An event that brings terrible loss, lasting distress, or severe affliction; a disaster (causing great and often sudden damage or distress)
Cataclysm	· A violent upheaval that causes great destruction or brings about a fundamental change · A violent and sudden change in the Earth's crust · A devastating flood
Catastrophe	· A great, often sudden, calamity · A sudden violent change in the Earth's surface; a cataclysm (as a supernova)
Apocalypse	· The imminent destruction of the world and the salvation of the righteous · Any universal or widespread destruction or collapse of civilization · A sudden and very bad event that causes much fear, loss, or destruction · The end of the world; the complete final destruction of the world

5.3.3 Perceived ordering

“Emergency,” “disaster,” and “catastrophe” are commonly used words to describe disasters. The terms “emergency” and “disaster” are often used in government spheres, and the term “catastrophe” is often used in insurance spheres. Therefore, most people were familiar with the terms “emergency,” “disaster,” and “catastrophe.” However, the terms “calamity” and “cataclysm” are typically colloquial; “calamity” refers more to emotional reactions, and “cataclysm” refers to flood-related disasters. Similarly, the term “apocalypse” is biased towards some religions, though it refers to the destruction or end of the world. The majority opinion is that a “disaster” refers to a large-scale emergency, and “catastrophe” refers to a large-scale disaster (Penuel et al. 2013). An increasing level of seriousness of an event can be shown using terms from “emergency” to “disaster” to “catastrophe.” However, three levels are not enough to clearly differentiate the impacts of disasters. Further, “calamity” and ‘cataclysm’ are not heavily used to describe disasters; hence, it is conjectured that people may randomly guess the level of seriousness of these words. Therefore, clear definitions are required and beneficial in order to encourage a change in peoples’ response to disasters, and how they think about the severity of a disaster.

Further, the terms are more subjective than objective regarding disaster severity depending on user’s personal feelings, knowledge, and experience towards the event. Moreover, the level of seriousness of each term is not fixed. For example, the term “emergency,” describes different levels of severity, which is confusing to the user. Governments issue a state of emergency when there is an uncontrollable situation, which is very serious. Therefore, emergency can be any level because the seriousness of the term “emergency” can describe situations as small as a car accident or as large as a major disaster. In addition, the levels of seriousness of the descriptive terms change over time because the meaning of the terms are not fixed; the respective orders of seriousness have changed from emergency, apocalypse, calamity, cataclysm, catastrophe, and disaster to emergency, disaster, calamity, cataclysm, catastrophe, and apocalypse. Therefore, clear standard definitions with an order of seriousness are required to describe the seriousness of disasters, and to integrate the terms into an emergency management system. The meaning should be fixed, but can be improved as the terms pass from generation to generation.

5.4 Proposed order and definitions of terminology for natural events

By presenting the *Deliverable V (i.e., the order of seriousness and clear definitions of existing disaster terminologies)* in this section, the *Objective 2* of this research is achieved. *The research sub-question b(i) Is there a substitute qualitative technique to categorize the severity of natural disasters?*

According to etymology, the level of seriousness of the terms from lowest to highest is emergency, apocalypse, calamity, cataclysm, catastrophe, and disaster; in contrast, the order is emergency, disaster, calamity, cataclysm, catastrophe, and apocalypse according to current English dictionary definitions. The summary is shown in Table 5.6. We can see the seriousness of disaster change drastically, and emergency remains in the same level throughout.

Table 5.6 The level of seriousness of the five terms according to etymology, and dictionary definition

Seriousness	Etymology	Dictionary
Level 1	Emergency	Emergency
Level 2	Apocalypse	Disaster
Level 3	Calamity	Calamity
Level 4	Cataclysm	Cataclysm
Level 5	Catastrophe	Catastrophe
Level 6	Disaster	Apocalypse

Figure 5.7 shows the proposed ranks for selected terms; the terms are arranged from left to right in increasing order of severity by considering the commonly accepted understanding of the terms together with their dictionary definitions. The colours were assigned to Figure 5.7 according to the strategy explained in Section 4.2 and Table 5.7 gives the proposed definitions for the existing terms on the basis of dictionary definitions and commonly accepted understandings. However, using any combination of the six terms

to describe another is carefully avoided when redefining these words. The ordering from lowest to highest in Figure 5.7 is taken into consideration rather than relying on the five words to describe each other.

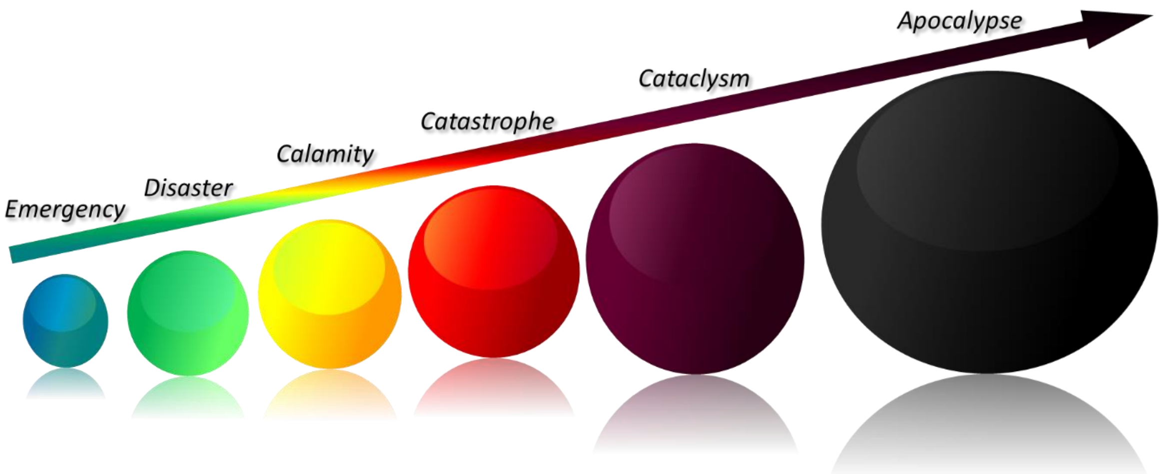


Figure 5.7 Proposed order of seriousness

The increasing level of seriousness is indicated in the terms' definitions, using the following methods of designation. Note that these terms are listed from lowest to highest order of impact; to describe circumstance (see blue colour in Table 5.7), we use "event," "disturbance," and "upheaval," which are modified by the adjectival forms "sudden," "major," "large-scale," "very large-scale," "extremely large-scale," and "world-scale." To describe the impact (see purple colour in Table 5.7), we use "damage," "destruction," and "devastation," which are modified by the adjectival forms "significant," "severe," "widespread continental," "global," and "universal." To describe the injuries (see green colour in Table 5.7), we use "many serious," "major," "massive," and "uncountable." To describe the fatalities (see red colour in Table 5.7), we use "some," "many," "great," "extensive," "unimaginable," and "partial or full extinction."

Table 5.7 Proposed definitions

Seriousness	Proposed order	Definition
Level 1	**Emergency**	**A** *sudden* **natural** event that causes damage**,** injuries, and *some* fatalities
Level 2	**Disaster**	**A** *major* **natural** event that causes *significant* damage**,** *many serious* injuries, and *many* fatalities
Level 3	**Calamity**	**A** *large-scale* **natural** disturbance that causes *severe* destruction, a *major number of* injuries, and *great number of* fatalities
Level 4	**Catastrophe**	**A** *very large-scale* **natural** disturbance that causes *widespread continental* destruction**,** *a massive number of* injuries, and *an extensive* loss of life
Level 5	**Cataclysm**	**An** *extremely large-scale* **natural** upheaval that causes *global* devastation**,** an *uncountable number of* injuries, and *unimaginable* loss of life
Level 6	**Apocalypse**	**A** *world-scale* **natural** upheaval that causes *universal* devastation, *partial or full extinction of humans*

5.5 Initial Qualitative Measure of Universal Disaster Severity Classification

Research sub-question c(i) How does this substitute qualitative technique adequately compare the severity level of natural disasters?

Possible solutions to differentiate the various levels of impact of an event are discussed below. Determining the number of levels for all disasters for all applications is not feasible. The terms “emergency,” “disaster,” “calamity,” “catastrophe,” “cataclysm,” and “apocalypse” are clearly defined in Table 5.7 according to their level of seriousness. However, there is a question about whether these six categories are sufficient to clearly distinguish different levels of disasters. If not, two questions that can be raised are: 1) how many levels of seriousness are needed? and 2) how should they be classified? There are no right or wrong answers to these questions because the number of levels needed can vary depending on how a situation is categorized. Therefore, several options are introduced and discussed in Section 5.5.2.

Nevertheless, 10 levels are proposed in Section 4.2 as a standard number of levels to represent impacts of both human and material damage and to design a UDSC combining both qualitative and quantitative measure. Step 3A of the methodology (in Section 1.5), combines qualitative measure and the foundation of the UDSC and is discussed in Section 5.5.1.

There are six different words are clearly defined to represent the seriousness of a disaster and the order of seriousness are also discussed; however, there are 10 levels in the base of UDSC that should be represented using these six words. Therefore, a solution is needed to combine the proposed qualitative measure with 6 words and the UDSC with 10 levels. The same concept then can be used to compress the UDSC to represent the 6 words (see Section 5.5.2.1).

5.5.1 Step 3A: Combined qualitative measure and the UDSC

The two possible solutions to combine the foundation of the UDSC (with 10 severity levels) and qualitative technique are discussed below.

5.5.1.1 Solution 1

As a qualitative technique, each level, or category, is labeled using the proposed order of the words for disasters, from ‘Emergency’ to ‘Cataclysm’. In this solution, the boundary levels of UDSC (i.e., UDSC 1 and 10), are defined using the words with lowest and highest level of seriousness as depicted in Figure 5.7. That is, the first level of the UDSC is “Emergency” to indicate the impact of the disturbance on inhabited areas. In this case, although “apocalypse” refers to the destruction or end of the world; however, this term is religiously biased and some individuals do not use this word because of the religious connotation. Hence, the term "apocalypse" was replaced by the term "Partial or Full extinction". The term "Partial or Full extinction" is taken to represent the last level of the UDSC and indicates the total or partial destruction of the earth or the world's end without any religious bias. Subsequently, in between 8 severity levels of the UDSC (i.e., UDSC 2 to 9) are equally distributed among other four words, each of the term have been sub-divided into Types 1 and 2 of "Disaster", "Calamity", "Catastrophe", and "Cataclysm."

Table 5.8 is an example of UDSC combines the previously mentioned proposed definitions of the terms (i.e., quantitative technique) to create a bridge of UDSC with ten levels. It also lists the proposed definitions for each given term by integrating Table 4.3, Table 5.7. Moreover, Table 5.8 outlines a description of each type of event, categorized according to colour. Although, this table is produced with English words (column 2 in Table 5.8), it could be translated into any other language.

Table 5.8 Initial Qualitative Universal Disaster Severity Classification

Seriousness	Proposed word and order	Definition
UDSC 1	**Emergency**	**A** *sudden* **natural** event that causes damage, injuries, and *some* fatalities
UDSC 2	**Disaster Type 1**	**A** *major* **natural** event that causes *significant* damage, *many serious* injuries, and *many* fatalities
UDSC 3	**Disaster Type 2**	
UDSC 4	**Calamity Type 1**	**A** *large-scale* **natural** disturbance that causes *severe* destruction, a *major number of* injuries, and *great number of* fatalities
UDSC 5	**Calamity Type 2**	
UDSC 6	**Catastrophe Type 1**	**A** *very large-scale* **natural** disturbance that causes *widespread continental* destruction, *a massive number of* injuries, and *an extensive* loss of life
UDSC 7	**Catastrophe Type 2**	
UDSC 8	**Cataclysm Type 1**	**An** *extremely large-scale* **natural** upheaval that causes *global* devastation, an *uncountable number of* injuries, and *unimaginable* loss of life
UDSC 9	**Cataclysm Type 2**	
UDSC 10	**Partial or Full Extinction**	**A** *world-scale* **natural** upheaval that causes *universal* devastation, *partial or full extinction of humans*

5.5.1.2 Solution 2

The terms “emergency” and “disaster” are often used in governmental spheres, whereas the term “catastrophe” is often used in insurance spheres, and the term “apocalypse” comes from religion and generally means “the end of the world.” In insurance, the term “catastrophe” is applied to different large-scale severity levels, however, all these levels are within the most severe range of the proposed UDSC. Therefore, the term “catastrophe” can be adopted to the scale without confusion. In contrast, although there are clear definitions of the terms “emergency” and “disaster” in the proposed UDSC, confusion can still occur. This confusion (i.e., which severity level these terms refer to) is because, governmental agencies use the term “emergency” to declare a state of emergency, and the term “disaster” is a general term people use to represent any event that negatively impacts people and/ or communities.

Because one term cannot differentiate different levels, in the UDSC, the terms “emergency” and “disaster” were replaced by the terms “incident” and “tragedy,” respectively. The term “incident” is used in the Encyclopedia of Crisis Management to represent the smallest level of severity, and the term “tragedy” replaces “disaster”. In this case, without any religious bias, the term “apocalypse” is also taken to represent the last level of the UDSC. Considering this, Table 5.8 was revised, which resulted in Table 5.9.

Table 5.9 Revised Qualitative Universal Disaster Severity Classification

Seriousness	Proposed word and order	Definition
UDSC 1	**Incident**	**A** *sudden* **natural** event that causes damage**,** injuries, and *some* fatalities
UDSC 2	**Tragedy Type 1**	**A** *major* **natural** event that causes *significant* damage**,** *many serious* injuries, and *many* fatalities
UDSC 3	**Tragedy Type 2**	
UDSC 4	**Calamity Type 1**	**A** *large-scale* **natural** disturbance that causes *severe* destruction, a *major number of* injuries, and *great number of* fatalities
UDSC 5	**Calamity Type 2**	
UDSC 6	**Catastrophe Type 1**	**A** *very large-scale* **natural** disturbance that causes *widespread continental* destruction, *a massive number of* injuries, and *an extensive* loss of life
UDSC 7	**Catastrophe Type 2**	
UDSC 8	**Cataclysm Type 1**	**An** *extremely large-scale* **natural** upheaval that causes *global* devastation, an *uncountable number of* injuries, and *unimaginable* loss of life
UDSC 9	**Cataclysm Type 2**	
UDSC 10	**Apocalypse**	**A** *world-scale* **natural** upheaval that causes *universal* devastation, *partial or full extinction of humans*

5.5.2 Different strategies to implement qualitative scale depending on the application

Determining the standard number of levels (i.e., 10 in the UDSC) for all types of applications is unfeasible because the number of required levels can differ depending on the application or context. Different options can be implemented to differentiate between each level of impact using the UDSC *without interfering with the originality of UDSC*, as discussed in Section 5.5.1. Although the standard UDSC has been constrained to 10 levels, depending on the application of disaster mitigation, the number of levels can be either compressed (see Section 5.5.2.1) or expanded (see Section 5.5.2.2) according to the concepts introduced in the following sub-sections using Solution 1**.**

Solution 1 is selected among two solutions as an integrated quantitative technique to clearly differentiate the levels of seriousness of disasters, because the terms used in Solution 1 are more familiar and clearly defined.

5.5.2.1 Strategy to compress the scale

In order to avoid the language barrier and further clarify the order of seriousness of the six words proposed in this chapter, a colour coding can be assigned to each word. Therefore, the six words are further classified using the compressed version of UDSC. Similar to above solutions, the boundary levels of UDSC are not compressed and "Emergency" and "Apocalypse" represent the UDSC 1 and 10, respectively. Each set of two levels between UDSC 2 and 9 is then grouped together as one level to represent four words: "Disaster," "Calamity," "Catastrophe," and "Cataclysm." Table 5.10 outlines a description of each word with compressed UDSC, categorized according to colour. In addition, Table 5.10 explains how the colour coding is assigned to each word when the order of seriousness was previously represented in Figure 5.7.

Table 5.10 Compressed version of Initial Qualitative Universal Disaster Severity Classification using proposed six terms

Seriousness	Proposed word and order with colour code	Definition
UDSC 1	Emergency	A ***sudden*** natural **event** that causes **damage**, **injuries,** and ***some*** **fatalities**
UDSC 2 UDSC 3	Disaster	A ***major*** natural **event** that causes ***significant*** **damage**, ***many serious*** **injuries,** and ***many*** **fatalities**
UDSC 4 UDSC 5	Calamity	A ***large-scale*** natural **disturbance** that causes ***severe*** **destruction**, a ***major number of*** **injuries,** and ***great number of*** **fatalities**
UDSC 6 UDSC 7	Catastrophe	A ***very large-scale*** natural **disturbance** that causes ***widespread continental*** **destruction**, *a* ***massive number of*** **injuries**, and ***an extensive*** **loss of life**
UDSC 8 UDSC 9	Cataclysm	An ***extremely large-scale*** natural **upheaval** that causes ***global*** **devastation**, an ***uncountable number of*** **injuries,** and ***unimaginable*** **loss of life**
UDSC 10	Apocalypse	A ***world-scale*** natural **upheaval** that causes ***universal*** **devastation,** ***partial or full extinction of humans***

Different solutions can be implemented based on application. For example, an application that measures the severity of the most extreme natural disasters, such as super volcanic eruptions and meteor strikes, requires eight levels of classification. However, more attention is needed for the most extreme cases. Therefore, in a compressed version of the UDSC scale, the lower severity levels can be combined as follows (using solution 1): Emergency, Disaster, Calamity, Catastrophe Type 1 and 2, Cataclysm Type 1 and 2, and Partial or Full Extinction (see Table 5.11).

Table 5.11 Compressed version of Initial Qualitative Universal Disaster Severity Classification using eight terms

Seriousness	**New Levels**	**Proposed word and order**	**Definition**
UDSC 1	1	Emergency	A ***sudden*** natural **event** that causes **damage**, **injuries,** and ***some*** **fatalities**
UDSC 2	2-3	Disaster	A ***major*** natural **event** that causes ***significant*** **damage**, ***many serious*** **injuries,** and ***many*** **fatalities**
UDSC 3			
UDSC 4	4-5	Calamity	A ***large-scale*** natural **disturbance** that causes ***severe*** **destruction**, a ***major number of*** **injuries,** and ***great number of*** **fatalities**
UDSC 5			
UDSC 6	6	Catastrophe Type 1	A ***very large-scale*** natural **disturbance** that causes ***widespread continental*** **destruction**, *a* ***massive number of*** **injuries**, and ***an extensive*** **loss of life**
UDSC 7	7	Catastrophe Type 2	
UDSC 8	8	Cataclysm Type 1	An ***extremely large-scale*** natural **upheaval** that causes ***global*** **devastation**, an ***uncountable number of*** **injuries,** and ***unimaginable*** **loss of life**
UDSC 9	9	Cataclysm Type 2	
UDSC 10	10	Partial or Full Extinction	A ***world-scale*** natural **upheaval** that causes ***universal*** **devastation,** ***partial or full extinction of humans***

Table 5.11 links the colour coding, new level numbering and different definitions to create a compressed UDSC with eight levels *without altering the originality of UDSC* discussed in Section 5.5.1.1. Therefore, group-numbering and group-colour coding techniques are used to assign the level numbers and colours of new levels of compressed

versions of the UDSC as shown in Column 2 for “Disaster” and “Calamity” levels in Table 5.11.

5.5.2.2 Strategy to Expand the scale

Another example is of an application to evaluate the full range of events that can affect a city with 12 different levels required to measure the severity. In this case, the focus is on local events, such as lightning strikes and tornadoes; however, depending on location, the city can be affected by more extreme disasters. Therefore, Table 5.8 (i.e., Solution 1) can be further expanded from ten quantitative terms to twelve using adjectives such as “minor,” “major,” and “severe” to distinguish each UDSC level, as shown in Table 5.12. Moreover, Table 5.12 expands the colour coding, new level numbering and different definitions to create an expanded version of UDSC with twelve levels *without interfering the originality of UDSC.* Therefore, sub-numbering and sub-colour coding techniques are used to assign the level numbers and colours of new levels of the expanded UDSC, as shown in Column 2 for “Minor Emergency,” “Emergency,” and “Major Emergency” levels in Table 5.12.

Adjectives can be removed and the levels combined to reduce the number of levels. In contrast, adjectives can be added and the levels expanded to increase the number of levels. Therefore, removing or adding adjectives can be done to compress or expand the UDSC according to necessary requirements as shown in these examples. However, numbering and colour coding (see Table 5.11 and Table 5.12) of the new levels of compressed and expanded versions of the UDSC must be assigned with care. Group-numbering/-colour coding techniques are used in compressed versions; and sub-numbering/-colour coding techniques are used in expanded versions to maintain the standard of UDSC

Table 5.12 Expanded version of Initial Qualitative Universal Disaster Severity Classification using thirteen terms

Seriousness	**New Levels**	**Proposed word and order**	**Definition**
		Hazard	A sudden natural **event** that causes **no damage**
UDSC 1	1.1	Minor Emergency	A sudden natural **event** that causes **damage**
	1.2	Emergency	A sudden natural **event** that causes **damage** and/or **injuries**
	1.3	Major Emergency	A ***sudden*** natural **event** that causes **damage**, **injuries,** and ***some*** **fatalities**
UDSC 2	2	Disaster Type 1	A ***major*** natural **event** that causes ***significant*** **damage**, ***many serious*** **injuries,** and ***many*** **fatalities**
UDSC 3	3	Disaster Type 2	
UDSC 4	4	Calamity Type 1	A ***large-scale*** natural **disturbance** that causes ***severe*** **destruction, a *major number of* injuries,** and ***great number of*** **fatalities**
UDSC 5	5	Calamity Type 2	
UDSC 6	6	Catastrophe Type 1	A ***very large-scale*** natural **disturbance** that causes ***widespread continental*** **destruction**, ***a massive number of*** **injuries**, and ***an extensive*** **loss of life**
UDSC 7	7	Catastrophe Type 2	
UDSC 8	8	Cataclysm Type 1	An ***extremely large-scale*** natural **upheaval** that causes ***global*** **devastation**, an ***uncountable number of*** **injuries,** and ***unimaginable*** **loss of life**
UDSC 9	9	Cataclysm Type 2	
UDSC 10	10	Partial or Full Extinction	A ***world-scale*** natural **upheaval** that causes ***universal*** **devastation, *partial or full extinction of humans***

5.6 Discussion

Unlike the existing definitions of the descriptive terms, the proposed definitions provide a consistent method of differentiating between the descriptive terms as these definitions clearly articulate the real magnitude of different severity levels. The proposed definitions were improved in the following ways: (1) by clearly re-defining the existing terms without using one term to define another; (2) by mentioning different factors (i.e., circumstance, impact, injuries, and fatalities) that are normally considered to show the impact of a disaster, and (3) by using more descriptive words and adjectives to reflect the increasing levels of seriousness of these factors. Therefore, these descriptive words can clearly be differentiated from one another.

Nevertheless, the order of seriousness introduced in this chapter would not be same as the commonly accepted understanding of some of the English-speaking population. Different individuals will attribute varying levels of seriousness to the different words because the current definitions are not clear and change over time.

Moreover, there are slowly developing disasters, such as drought, famine, and pollution, and there are rapidly developing disasters, such as earthquakes, tornadoes, and tsunamis. For an example, the pollution of air and water progress slowly, and are measured in years or decades, whereas earthquakes occur over extremely short time periods, measured in seconds. Although disasters move rapidly or slowly, the severity cannot be measured as quickly as they strike. For example, an earthquake, which occurs in seconds, can be categorized as a "disaster" in terms of severity *within the first few hours* after the earthquakes hits according to the reported impacts and causalities. However, the impact and causalities can increase days or weeks after the event. Accordingly, the severity of the earthquake, first classified as a "disaster," can be reclassified as "calamity" *within a day or two* after the event; it could potentially be considered a catastrophic event *within weeks*. Therefore, the classification of the severity of the event may change as reports on the number of injuries and fatalities are updated. Therefore, the degree of severity changes with time and with frequent updated reporting about the disaster.

Although the accuracy of the severity can change with frequent updates of the impact, it is vital to estimate the severity shortly after the event strikes to provide information to first-responders and for public reporting and planning.

The severity of a disaster can be predicted in advance with a certain degree of accuracy, which is beneficial because the size of a first-responder contingency depends on the magnitude of the disaster impact. The initial assessment of the disaster is based on the estimates shortly after the event strikes and it is frequently updated. For example, first evaluations are used for planning such as, whether to call a state of emergency, evacuate, request international assistance, or involve military forces. Other decisions regarding planning include the following: the resources, such as food, water, medicine, and clothes, that should be stored and delivered to the stricken area; the hospitals that should be assembled and to what extent; and the shelters to mobilize, where to set up temporary housing, and for how long. Therefore, predicting the severity can accelerate the recovery process.

5.7 Conclusions

This chapter described the Steps 2A and 3A (see Section 5.4 and 0) of developing a Universal Disaster Severity Classification (UDSC). The UDSC with colour coding is introduced, as shown in Table 5.8, to distinguish the different levels of a disaster's impact. By using the descriptive terms, "emergency," "disaster," "calamity," "catastrophe," "cataclysm," and "partial or full extinction," 10 different levels of severity of UDSC are clearly described in plain language. Even though these tables are produced with English words, they can be translated into any language.

Although the terms “emergency” and “disaster” are clearly defined in order to categorize the severity of an event, these words are also used in other applications. As a result, confusion may still occur. Therefore, a revised version of the UDSC scale is proposed, as shown in Table 5.9. However, Solution 1 is recommended as an integrated quantitative technique to clearly differentiate the levels of seriousness of disasters, because the terms used in Solution 1 are more familiar and clearly defined. Therefore, Solution 1 can be implemented as standard definitions.

In addition, depending on the application, the 10 levels can be either expanded or compressed by including or excluding the adjectives “minor,” “severe,” and “major” or including extra terms, such as “incident,” “tragedy,” and “apocalypse.” However, as a standard 10 levels is preferable because ten levels make it easy to combine the qualitative measure and the foundation of the UDSC discussed in Section 4.2. Subsequently, it is easy to integrate the combine foundation of the UDSC and the qualitative measure with quantitative techniques because even very large ranges of almost all socio-economic factors (e.g., human and material damage factors) can be concentrated to 10 different levels using the log scale as explained in Section 4.2. In addition, the confusions can be minimized when there is a consistent number of level. Moreover, this scale is easy to remember as the levels increase by a power of 10 between levels. Furthermore, people are most comfortable with a 10 level representation rather than some random number of levels such as 8, 9, 11, or 12. Therefore, combined qualitative measure with foundation of the UDSC introduced in Table 5.8 is the most suitable index.

Chapter Six: UNIVERSAL DISASTER SEVERITY CLASSIFICATION AND INITIAL QUANTITATIVE MEASURE

In this chapter, a suitable method of describing disaster using statistics is discussed, in order to compare natural disasters. Also, the quantitative part of *Research Question B (i.e., how are these levels used to clearly distinguish the various degrees of natural disasters?)*, and the *research sub-question c(ii) (i.e., how does this substitute quantitative technique adequately compare the severity level of natural disasters?)*, are answered in Sections 6.2.1 and 6.2.3. *Research Objective 3 (i.e., develop an initial disaster severity scale, based on most influencing factor(s), to describe the range of severity levels of natural disasters worldwide)* including *Deliverables VI* through *IX* inclusive, are achieved in this chapter.

6.1 Methodology

The process of developing Universal Disaster Severity Classification (UDSC) is discussed in this section. As explained previously in Chapter 1, there are seven main steps in order to develop a UDSC for all types of natural disaster (see Figure 1.2). Key steps that are used to define an initial quantitative disaster severity scale (i.e, Steps 1, 2C and 3B) are discussed in the following sub-sections.

6.1.1 Step 1: Identify the Most Influential Factor(s) and their relationship to severity

The severity of the impact of natural disasters increases with an increase in intensity of an event for a given population density, and with an increase in the impact to humans and their possessions. In contrast, the severity level decreases with preparedness for a given disaster (Caldera, Wirasinghe, and Zanzotto 2016). However, no matter how prepared for the hazard or how powerful/intense the hazard is, if the hazard occurs in a desert without affecting any human or their habitat, then this hazard will not be a disaster according to definition. In addition, if people lose all their belongings or loved ones in a natural disaster, their mental health will not be improved knowing that they prepared for the disaster. Nor will it depend on the intensity/power of the natural disaster. Therefore, the severity of an event can be evaluated by measuring the negative impact of a disaster on people and infrastructure. Hence, severity of a disaster directly relates to human impact, and indirectly relates to preparedness and intensity of the disaster. Consequently, a multi-dimensional severity scale should be based on a cross section of data that takes into account socio-economic factors, such as fatalities, injuries, cost of damage, affected population, missing persons, evacuees, homeless, population density, impacted region, number of houses damaged, and GDP per capita. Although, there are many aspects that need to be considered, a scale representing all these factors is complex. A lack of data in current databases prevent in depth analysis.

Due to the lack of a recording system, the socio-economic factors considered in this analysis are: fatalities, injuries, missing persons, houses damaged, houses destroyed and cost of damage in USD, in the NOAA database; and fatalities, injuries, homeless and cost of damage in the EM-Dat database. Therefore, the common impact factors including fatalities, injuries, and cost of damage can be considered for a multi-dimensional scale. The relationship between these human impact factors is previously described in detail in Chapter 3. According to the analysis, these impact factors are correlated ($\rho \geq 0.5$) with each other. That is, one factor encapsulates many effects on humans because they are correlated with each other. Therefore, to measure the severity using these correlated factors, two approaches can be applied:

- measure the severity using one of these factors, or
- develop a complex disutility function that includes several factors.

As the scope of this research is to develop the initial disaster severity scale, the simplest approach is selected to measure the severity and leave the complex disutility function approach for future research. Therefore, one out of the four factors (i.e., fatalities, injuries, and damage or houses damaged) is selected as an initial scale to measure the disasters. Out of these available factors:

- houses damaged closely relate to the location, time, material, size and so on;
- in general, cost of damage tends to increase with time because of inflation, recession or depression, and wealth of people;
- injuries are ambiguously defined because they can range from ‘small’ to ‘moderate’ to ‘severe’; and
- fatalities are easy to define because they are the finality of death.

In addition, populations are most sensitive to disastrous events with high fatalities, and many people consider fatality a good measure of severity. Therefore, fatalities are selected as the most significant factor representing the severity, to develop the initial severity scale.

6.1.2 Step 2C: Analyze the extreme events and find the Extreme Probability Distribution of severity based on the most influencing factor(s)

After finding the most influencing factor (i.e., fatalities) relates to severity of natural disasters, extreme events based on the most influencing factor are further analyzed using extreme value theory. The extreme value analysis determines the probabilities of extreme events.

Extreme value theory is used to study the behaviour and the destructive capacity of strong, violent, infrequent, uncontrollable disasters. Extremes are low probability events, which are located on the tail of the parent probability density function (PDF). In this case, the right tail of the parent PDF because the considered extremes are largest or maxima of severe events (see left side of Figure 6.1). These extreme events are selected to fit the extreme value probability distribution function (EPDF). EPDFs are limiting distributions and essential to evaluate the probability of extreme disasters. There are three models, which are block Maxima, R^{th} order statistic, and peak over threshold, to identify the extreme events. According to extreme value theory different types of EPDF are fitted according to the method selected to extract the extreme values. More details about the extreme value selection and best-fitted EPDF selection procedure are discussed in the Section 6.1.4 and 6.1.5 respectively.

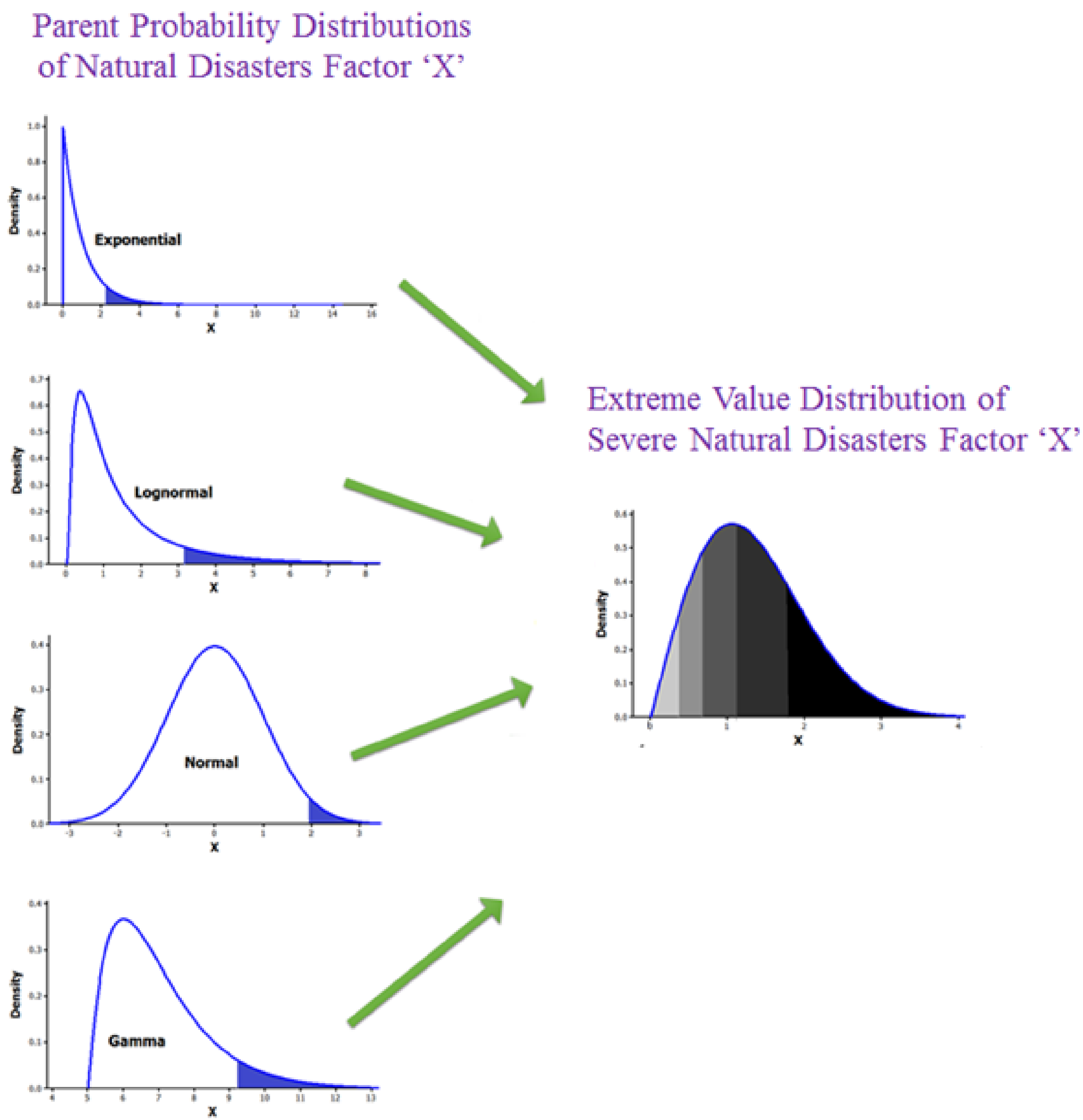


Figure 6.1 Extreme Value Distribution

6.1.3 Step 3B: Combined quantitative measure and the UDSC

The EPDF of extreme and the log-scale system are used, in order to define the ranges of severity levels as shown in Figure 6.2. Using the Universal Disaster Severity Classification, a set of English words are clearly defined and combined in the initial disaster severity scale, according to the four steps discussed in Section 1.5, resulting the development of the Universal Disaster Severity Scale.

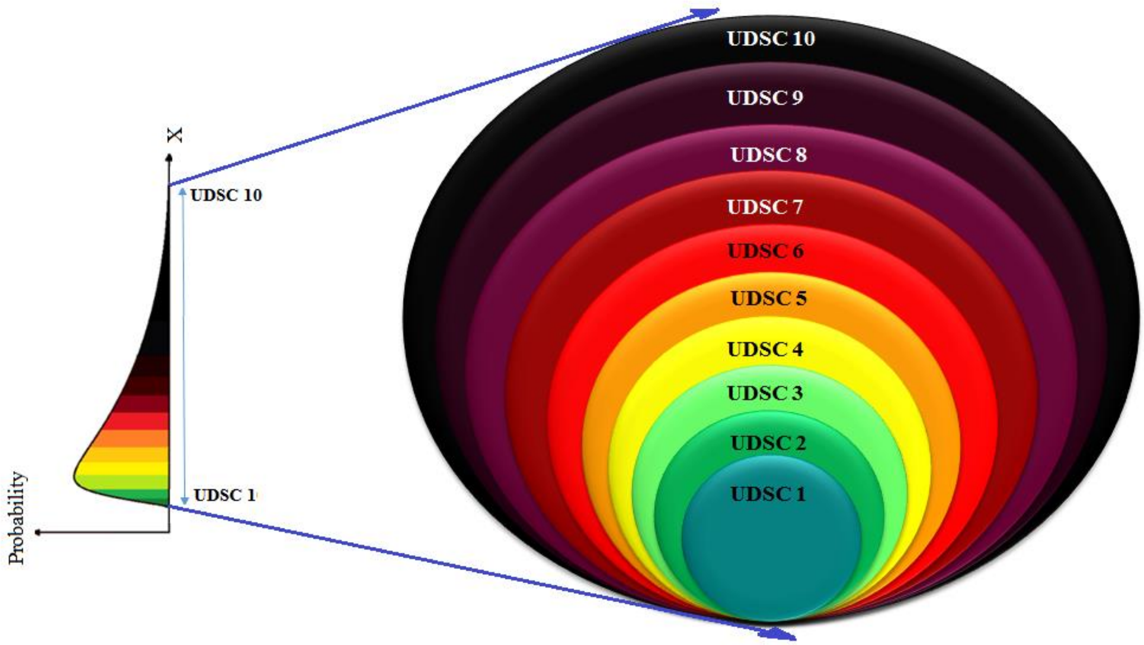


Figure 6.2 Probability Distribution and severity levels

6.1.4 Extreme value selection

As explained previously, three different methods: block maxima, R^{th} order statistics, and peak over threshold, were identified to determine the extreme values from a given data set. Artificial blocks need to be considered in the block maxima or the R^{th} order statistical models. The maximum value of each block was selected as the extreme value for a block maxima model. Figure 6.3 shows five blocks and the selected extreme x_i values (i.e., 15, 12, 9, 7, and 19) according to a selected data set. Annual maxima are the most commonly used values in the block maxima method, where blocks are defined as a particular year. However, blocks can vary according to the nature of a specific data set. In some situations, considering only the maximum in a block yields too few data points to make meaningful inferences; therefore, the Rth order statistical model can be used to select more data points in the extreme data set. For example, as shown in Figure 6.4, a 2nd order statistical model provides twice as many data points as block maxima because the two largest data points (i.e., 15, 8, 12, 11, 8, 9, 7, 4, 19, and 16) are selected in each block. However, selecting the order is a tedious task in this method, in addition to selecting proper blocks. Extremes are distributed as a Unified/Generalized extreme value distribution (GEVD) in block maxima or Rth order statistical models. GEV) can be further explained by either Gumbel (EV0), Frechet (EV1), or Weibull (EV2) distributions. These distributions are further explained in Section 6.1.5.

Extremes that exceed a threshold value are considered in the peak over threshold model. Selecting a threshold value is difficult. Figure 6.5 shows that the selected extreme x_i values (i.e., 15, 12, 11, 19, 14, and 16) exceed the threshold value, u, (i.e., 10) according to the previously considered set. The extremes in the peak over threshold model are distributed as a Generalized Pareto distribution (GPD), which can be further illustrated as Exponential (GP0), Pareto (GP1) or Beta (GP2) distribution.

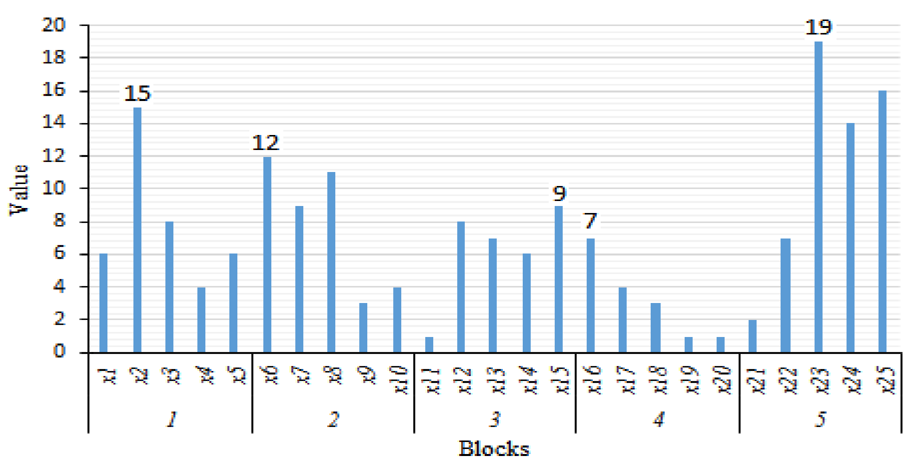


Figure 6.3 Extreme values of the block maxima model

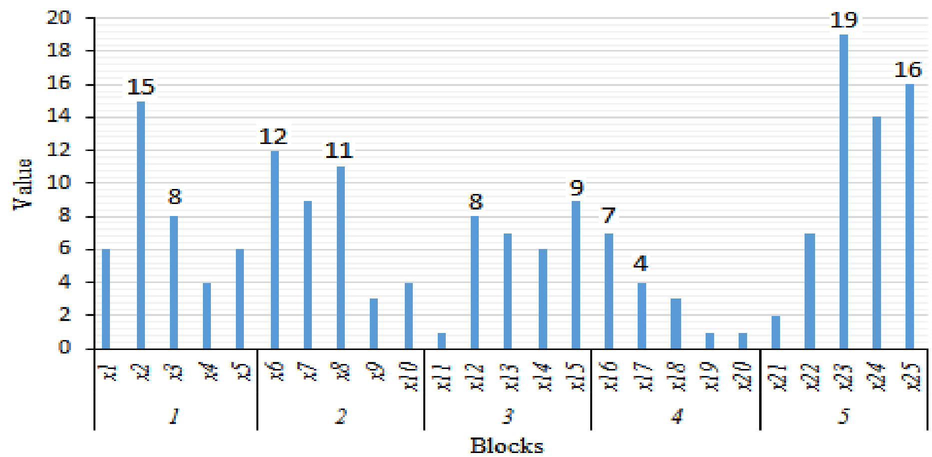


Figure 6.4 Extreme values of the Rth order statistic mode

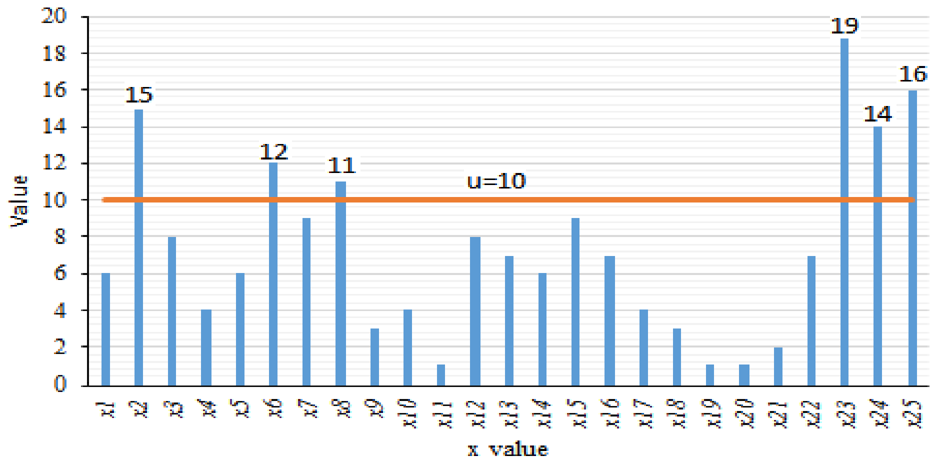


Figure 6.5 Extreme values of the peak over threshold model

Three different data sets are selected as extremes (see Table 6.1) according to different methods, as demonstrated by comparing Figure 6.3, Figure 6.4, and Figure 6.5; hence, the results varied. Each method has its own advantages and disadvantages. In the peak over threshold model, all extreme values are included, and they do not need any artificial blocking. In contrast, the peak over threshold model is bounded below because the minimum extreme is higher than the threshold selected; consequently, it is only concerned with high extreme values. In the block maxima and Rth order statistical models, a variation of extremes is included; therefore, extreme values, which are not necessarily bounded, can consist of extremes with a full range of data and do not need a minimum threshold value. In contrast, some extremes are neglected in these two methods.

Table 6.1 Selected extreme dataset according to different methods

Model	**Selected extreme dataset**									
Black maxima	7	9	12	15	19					
R^{th} order statistic (R=2)	4	7	8	8	9	11	12	15	16	19
Peak over threshold	11	12	14	15	16	19				

6.1.5 Best Extreme Value Distribution Fit

An extreme value distribution (EVD) is essential to evaluate the probability of extreme disasters. Parameter estimation for the EVD or GPD was conducted using the Xtremes 4.1 (Academic Version) software. To estimate the parameters, the Maximum Likelihood Estimation method was used. However, the feasibility of the other estimators such as Least Square Estimator and Methods of Moments Estimators were also considered.

After estimating the parameters (μ, σ and γ), both parametric and non-parametric methods were employed to determine the model appropriateness. As Reiss and Thomas (2007) have noted:

> For larger sample sizes n, visual diagnostic tools can be preferable to goodness–of–fit tests. A parametric hypothesis will be rejected for larger n, even if the deviation of this hypothesis is negligible (from a practical viewpoint) due to the high power of test procedures. (p. 61)

Therefore, non-parametric methods such as a visual comparison between the PP plot (see Section 6.1.5.1), the QQ plot (see Section 6.1.5.2), the histogram with probability density function (see Section 6.1.5.3), return level plot (see Section 6.1.5.5), and goodness of fit tests (see Section 6.1.5.6), were used to determine the best extreme value distribution fit for the data using the estimated parameters of the distribution. However, sometimes it is complex to determine the best distribution fit using only visual comparison, therefore, a residual analysis is conducted (see Section 6.1.5.4) for a more precise comparison.

6.1.5.1 Probability – Probability (PP) plot

The following procedures were undertaken to compare the PP plots.

Step1: Calculated the Sample Quantile Function q_i as shown in Equation 6.1 (Reiss & Thomas, 2007, p. 42; Kotz & Nadarajah, 2000, p. 18; Coles, 2001, p. 36) after arranging data in increasing order where $x_1 \leq x_2 \leq .... \leq x_n$ for n data points.

- Sample Quantile (also known as sample distribution function):

$$q_i = \frac{i}{n+1}\ for\ 1 \leq i \leq n$$

Equation 6.1

Step 2: Calculated the Cumulative Distribution Functions: $F(x_i)$. The mathematical equations of Gumbel, Frechet, Weibull, and Generalized EVD are shown in Equation 6.2 to Equation 6.5 below (Kotz & Nadarajah, 2000, p. 3), and the Exponential, Pareto, Beta, and Generalized Pareto, are shown in Equation 6.6 to Equation 6.9 (Reiss and Thomas 2007, p. 24-25).

- For block maxima or R^{th} order

Gumbel Distribution: $\mathrm{F}(\mathrm{x_i}) = e^{-\mathrm{e}^{-\left(\frac{\mathrm{x_i}-\mu}{\sigma}\right)}}$ for $-\infty < \mathrm{x_i} < \infty,\ \sigma > 0$

Equation 6.2

Frechet Distribution: $F(x_i) = \begin{cases} 0 & \text{for } x_i < \mu \\ e^{-\left(\frac{x_i-\mu}{\sigma}\right)^{-\alpha}} & \text{for } x_i \geq \mu \end{cases}$ and $\alpha, \sigma > 0$

Equation 6.3

Weibull Distribution: $F(x_i) = \begin{cases} e^{-\left(-\frac{x_i-\mu}{\sigma}\right)^{-\alpha}} & \text{for } x \leq \mu \\ 1 & \text{for } x > \mu \end{cases}$ and $\alpha < 0, \sigma > 0$

Equation 6.4

Generalized Extreme Value Distribution:

$$F(x_i) = \begin{cases} e^{-e^{-\left(\frac{x_i-\mu}{\sigma}\right)}} & \text{for } -\infty < x_i < \infty \textit{ and } \gamma = 0 \\ e^{-\left[1+\gamma\left(\frac{x_i-\mu}{\sigma}\right)\right]^{\frac{-1}{\gamma}}} & \text{for } \begin{matrix} -\infty < x_i < \mu - \frac{\sigma}{\gamma} \text{ for } \gamma < 0 \\ \mu - \frac{\sigma}{\gamma} < x_i < \infty \textit{ for } \gamma > 0 \end{matrix} \end{cases}$$; (Kotz & Nadarajah, 2000, p.61)

Equation 6.5

- For peak over threshold

Exponential Distribution: $F(x_i) = 1 - e^{-\left(\frac{x_i-\mu}{\sigma}\right)}$; $x_i \geq \mu$

Equation 6.6

Pareto Distribution: $F(x_i) = 1 - \left(\frac{x_i-\mu}{\sigma}\right)^{-\alpha}, \alpha > 0\, ; x_i \geq \sigma(1+\mu)$

Equation 6.7

Beta Distribution: $F(x_i) = 1 - \left[-\left(\frac{x_i-\mu}{\sigma}\right)\right]^{-\alpha}, \alpha < 0;\ \sigma(\mu - 1) \leq x_i < \mu$

Equation 6.8

General Pareto Distribution:

$$\mathrm{F}(\mathrm{x_i}) = \begin{cases} 1 - e^{-\left(\frac{x_i - \mu}{\sigma}\right)} & \text{for } x_i \geq \mu \; if \; \gamma = 0 \\ 1 - (1+\gamma x)^{-\frac{1}{\gamma}} \; for & \begin{cases} 0 < x & if \; \gamma > 0 \\ 0 < x < \dfrac{1}{|\gamma|} & if \; \gamma < 0 \end{cases} \end{cases}$$

Equation 6.9

<u>Step 3:</u> Drew the PP plot, which is {q_i, $F(x_i)$}, for i=1,...,n

The PP plot should be close to the unit diagonal because $q_i \approx F(x_i)$ (Reiss & Thomas, 2007, p. 40), and a strong deviation of the PP plot from the main diagonal indicates that the given model is incorrect (or the estimates of the location and scale parameters are incorrect), or considerable deviation from linearity is evidence of a failure in the estimated model for a given data (Coles, 2001, p. 37; Kotz & Nadarajah, 2000, p. 17).

6.1.5.2 Quantile – Quantile (QQ) plot

The following procedures were undertaken to compare QQ plots.

<u>Step 1:</u> Calculated the Inverse Distribution Function (also known as empirical distribution): $F^{-1}(q_i)$. The mathematical equations of Inverse Gumbel, Frechet, Weibull, Generalized EVD, Exponential, Pareto, Beta, and Generalized Pareto are shown in Equation 6.10 to Equation 6.17 (below) (Reiss and Thomas 2007, p. 36-37).

- For block maxima or R^{th} order

Inverse Gumbel: $F^{-1}(q_i) = -\mathrm{Ln}[-\mathrm{Ln}(q_i)]$ for $\sigma > 0$

Equation 6.10

Inverse Frechet: $F^{-1}(q_i) = [-\mathrm{Ln}(q_i)]^{\frac{-1}{\alpha}}$ for $\alpha, \sigma > 0$

Equation 6.11

Inverse Weibull: $F^{-1}(q_i) = -[-\mathrm{Ln}(q_i)]^{\frac{-1}{\alpha}}$ for $\alpha < 0, \sigma > 0$

Equation 6.12

Inverse Generalized Extreme Value: $F^{-1}(q_i) = \begin{cases} \{-\mathrm{Ln}[-\mathrm{Ln}(q_i)]\} & \text{for } \gamma = 0 \\ \frac{1}{\gamma}\{[-\mathrm{Ln}(q_i)]^{-\gamma} - 1\} & \text{for } \gamma \neq 0 \end{cases};$

(Coles, 2001, p.58)

Equation 6.13

- For peak over threshold

Inverse Exponential distribution: $F^{-1}(q_i) = -\mathrm{Ln}(1 - q_i)$

Equation 6.14

Inverse Pareto: $F^{-1}(q_i) = (1 - q_i)^{-\frac{1}{\alpha}}, \alpha > 0$

Equation 6.15

Inverse Beta: $F^{-1}(q_i) = -(1 - q_i)^{-\frac{1}{\alpha}}, \alpha < 0$

Equation 6.16

Inverse General Pareto : $F^{-1}(q_i) = \begin{cases} -\mathrm{Ln}(1 - q_i) \text{ for } \gamma = 0 \\ \frac{1}{\gamma}[(1 - q_i)^{-\gamma} - 1] \quad \gamma \neq 0 \end{cases};$

(Reiss & Thomas, 2007, p.37)

Equation 6.17

Step 2: Drew the QQ plot, which is $\{F^{-1}(q_i), x_i\}$, for i=1,......,n

The QQ plot is close to the unit diagonal if the estimated parameters are reasonable (Coles, 2001, p. 37) because $x_i \approx F^{-1}(q_i)$ (Reiss & Thomas, 2007, p. 42). The estimated location/ scale parameter family is impossible if vigorous deviation is observed from the straight line in the QQ plot (Reiss & Thomas, 2007, p. 62). The PP plot and QQ plot include the same information expressed in a different scale. Nevertheless, it is important to examine both because what looks reasonable on one scale, may look different on the other scale (Coles, 2001, p. 37).

6.1.5.3 Histogram and the probability density function

Following are the procedures undertaken to compare histograms with probability density functions (PDF). Calculated PDF: $f(x_i)$. The mathematical equations of PDF of Gumbel, Frechet, Weibull and Generalized EVD are shown in Equation 6.18 to Equation 6.21 (Reiss & Thomas 2007, p. 15-17), and Exponential, Pareto, Beta, Generalized Pareto, are shown in Equation 6.22 to Equation 6.25 (Reiss & Thomas 2007, p. 24-25)

- For block maxima or R^{th} order

Gumbel Density:

$$f(x_i) = \frac{1}{\sigma}\left\{e^{-\left(\frac{x_i-\mu}{\sigma}\right)} e^{-e^{-\left(\frac{x_i-\mu}{\sigma}\right)}}\right\} \text{ for } -\infty < x_i < \infty$$

Equation 6.18

Frechet Density:

$$f(x_i) = \frac{\alpha}{\sigma}\left\{\left(\frac{x_i-\mu}{\sigma}\right)^{-(\alpha+1)} e^{-\left(\frac{x_i-\mu}{\sigma}\right)^{-\alpha}}\right\} \text{ for } \alpha, \sigma > 0 \text{ and } \mu \le x < \infty$$

Equation 6.19

Weibull Density:

$$f(x_i) = \frac{|\alpha|}{\sigma}\left\{\left(-\frac{x_i - \mu}{\sigma}\right)^{-(\alpha+1)} e^{-\left(-\frac{x_i-\mu}{\sigma}\right)^{-\alpha}}\right\} \text{for } \alpha < 0, \sigma > 0 \ and$$

$$\mu \leq x < \infty$$

Equation 6.20

Generalized Extreme Value Density:

$$f(x_i) = \begin{cases} \frac{1}{\sigma} e^{-e^{-\left(\frac{x_i-\mu}{\sigma}\right)}} \ e^{-\left(\frac{x_i-\mu}{\sigma}\right)} & ; -\infty < \ x_i < \ \infty \ for \ \gamma = 0 \\ \frac{1}{\sigma}\left\{\left[1 + \gamma\left(\frac{x_i-\mu}{\sigma}\right)\right]^{-\left(1+\frac{1}{\gamma}\right)}\right\} e^{-\left[1+\gamma\left(\frac{x_i-\mu}{\sigma}\right)\right]^{\frac{-1}{\gamma}}} & ; \begin{matrix} -\infty < x_i < \mu - \frac{\sigma}{\gamma} \text{ for } \gamma < 0 \\ \mu - \frac{\sigma}{\gamma} < x_i < \infty \ for \ \gamma > 0 \end{matrix} \end{cases};$$

(Kotz & Nadarajah, 2000, p.61)

Equation 6.21

- For peak over threshold

Exponential Density: $f(x_i) = e^{-\left(\frac{x_i-\mu}{\sigma}\right)}; \ x_i \geq \mu$

Equation 6.22

Pareto Density: $f(x_i) = \alpha\left(\frac{x_i-\mu}{\sigma}\right)^{-(1+\alpha)}, \alpha > 0 \, ; x_i \geq \sigma(1 + \mu)$

Equation 6.23

Beta Density: $f(x_i) = |\alpha|\left[-\left(\frac{x_i-\mu}{\sigma}\right)\right]^{-(1+\alpha)}, \alpha < 0; \ \sigma(\mu - 1) \leq \ x_i < \mu$

Equation 6.24

$$\text{General Pareto Density: } f(x_i) = \begin{cases} e^{-\left(\frac{x_i-\mu}{\sigma}\right)} & \text{for } x_i \geq \mu \text{ if } \gamma = 0 \\ (1+\gamma x)^{-\left(1+\frac{1}{\gamma}\right)} \; for \begin{cases} 0 \leq x & if\, \gamma > 0 \\ 0 \leq x < \frac{1}{|\gamma|} & if\, \gamma < 0 \end{cases} \end{cases}$$

Equation 6.25

A histogram of the data is an approximate estimate of the probability density function of a fitted model (Reiss & Thomas, 2007, p. 44), however, it is less informative than the previous plots as the histogram can vary considerably with the block selection (Coles, 2001, p. 59).

6.1.5.4 Residual analysis

For more precise comparison, the Mean Absolute Error (MAE) and Mean Square Error (MSE) of each extreme value distribution with regards to the empirical values can be calculated. The distribution with the minimum MSE (or MAE) then was chosen as the best distribution fit.

6.1.5.4.1 Mean Absolute Error (MAE)

The MSE is a quantity used to measure how close estimates or predictions are to the actual results, and it is an average of the absolute errors (Equation 6.26).

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|e_i| = \frac{1}{n}\sum_{i=1}^{n}|y_i - y_i'|$$

Equation 6.26

where y_i is the actual value, y_i' is the predicted value, error e_i equals to $y_i - y_i'$, and n is the number of extreme values.

6.1.5.4.2 Mean Square Error (MSE)

The MSE is an average of the squares of the errors or deviations (Equation 6.27).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(e_i)^2 = \frac{1}{n}\sum_{i=1}^{n}(y_i - y_i')^2$$

Equation 6.27

where y_i is the actual value, y_i' is the predicted value, error e_i equals to $y_i - y_i'$, and n is the number of extreme values.

6.1.5.5 Return level plot

If the blocks are chosen to correspond to a time period of length one year, in which case n is the number of observations in a year and the block maxima are annual maxima. Then z_p (see Equation 6.29 to Equation 6.32) is the return level associated with the return period 1/p, and the level z_p is expected to exceed by the annual maximum in any particular year with probability p. If z_p is plotted against y_p (see Equation 6.28) on a logarithmic scale [i.e., (z_p, ln y_p)], the graph, which is a return level plot, is linear for γ equals to zero. If γ less than zero, then the graph is convex with asymptotic limit as p goes to zero at μ-σ/γ; and if γ grater than zero, the graph is concave and has no finite bound (Coles, 2001, p.49). Therefore, following procedures were undertaken to observe the return level plot.

- $y_p = -Ln(1 - p_i)$ where $F(z_p) = 1 - p_i$

Equation 6.28

- Return level: z_p as follows,

Gumbel Distribution: $z_p = \mu - \sigma \mathrm{Ln}(y_p)$ for $\sigma > 0$

Equation 6.29

Frechet Distribution: $z_p = \mu + \sigma(y_p)^{\frac{-1}{\alpha}}$ for $\alpha, \sigma > 0$

Equation 6.30

Weibull Distribution: $z_p = \mu + \sigma(y_p)^{\frac{1}{\alpha}}$ for $\alpha, \sigma > 0$

Equation 6.31

Generalized Extreme Value Distribution:

$$z_p = \begin{cases} \mu - \frac{\sigma}{\gamma}\{1 - (y_p)^{-\gamma}\} & \text{for } \gamma \neq 0 \\ \mu - \sigma \mathrm{Ln}(y_p) & \text{for } \gamma = 0 \end{cases} \text{(Coles, 2001, p.49)}$$

Equation 6.32

- Return level plot:

$$(\mathrm{Ln}(y_p), z_p) \begin{cases} \text{is linear if Gumbel distribution or } \gamma = 0 \text{ in GEV} \\ \text{is convex if Frechet distribution or } \gamma < 0 \text{ in GEV} \\ \text{is concave if Weibull distribution or } \gamma > 0 \text{ in GEV} \end{cases}$$

6.1.5.6 Goodness of Fit Tests

In order to evaluate how well the data follows a certain distribution, there are different type of tests available. Among those tests three different test were used in this analysis. They are Kolmogorov-Smirnov (K-S), Anderson-Darling (A-D), and Chi-Squared (C-S). Each of these test examine following hypothesis;

Hypothesis test: H_0: The data follow a specified distribution

H_1: The data do not follow the specified distribution

6.1.5.6.1 Kolmogorov-Smirnov (K-S)

Test Statistic: $D = \max_{0 \le i \le n} \left\{ \left[F(x_i) - \frac{i-1}{n} \right], \left[\frac{i}{n} - F(x_i) \right] \right\}$

Equation 6.33

Decision Criteria: Reject H_0 if D > critical value obtained from a table

Advantages:

- the distribution of the K-S test statistic independent on the underlying cumulative distribution function being tested
- it is an exact test (the chi-square goodness-of-fit test depends on an adequate sample size for the approximations to be valid)

Limitations:

- it only applies to continuous distributions
- it tends to be more sensitive near the center of the distribution than at the tails
- the distribution must be fully specified (i.e., location, scale, and shape parameters cannot be estimated from the data- typically must be determined by simulation)

6.1.5.6.2 Anderson-Darling (A-D)

Test Statistic:

$$A^2 = -n - S \text{ where } S = \sum_{i=1}^{n} \frac{(2i-1)}{n} \{Ln\, F(x_i) + Ln[1 - F(x_{n+1-i})]\}$$

Equation 6.34

Decision Criteria: Reject H_0 if A^2 > critical value and the critical values for the test depend on the specific distribution that is being tested.

The Anderson-Darling test is an alternative to the Kolmogorov-Smirnov (K-S), and Chi-Squared (C-S) goodness-of-fit tests, and this test is a one-sided test.

Advantages:

- distribution free in the sense that the critical values independent on the specific distribution being tested (note that this is true only for a fully specified distribution, i.e. the parameters are known)
- is a modification of the Kolmogorov-Smirnov test, and gives more weight to the tails than does the K-S test

Limitations:

- only applies to continuous distributions
- makes use of the specific distribution in calculating critical values

6.1.5.6.3 Chi-Squared (C-S)

Test Statistic: $\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$

Equation 6.35

Where k is the number of blocks; Oi is the observed frequency for block i, E_i is the expected frequency for block i , that is, $E_i=n\,[\,F(X_u)-F(X_l)]$, X_u is the upper limit for class i, X_l is the lower limit for class i, and n is the sample size.

Decision Criteria: Reject H0 if $\chi2 > \chi2;1-\alpha$, k-c where $\chi2;1-\alpha$, k-c is chi-square critical value with k-c degree of freedom and significant level α where c is the number of estimated parameters.

Advantages:

- can be applied to any univariate distribution for which you can calculate the cumulative distribution function

- is applied to blocked data (i.e., data put into classes). This is actually not a restriction since for non-blocked data you can simply calculate a histogram or frequency table before generating the chi-square test.
- can be applied to discrete distributions such as the binomial and the Poisson. The Kolmogorov-Smirnov and Anderson-Darling tests are restricted to continuous distributions.

Limitations:

- the value of the chi-square test statistic is dependent on how the data is blocked
- requires a sufficient sample size in order for the chi-square approximation to be valid

Because the A-D test has more emphasis on the tail of the distribution than K-S test, and because the analysis is of extreme values the A-D test is more appropriate than K-S test. However, the distributions are fitted using the R^{th} order statistics, which consider the different disaster category as each block. Therefore, C-S test is more appropriate for the analysis because it considers the blocks in the test procedure. The analysis is further described in Section 7.1.1.

6.2 Disaster Severity Classification

The research sub-question c(ii) How does this substitute quantitative technique adequately compare the severity level of natural disasters?

The impact of disasters on people, facilities, and the economy should be studied in detail to understand the severity of a natural disaster. Factors, such as the number of fatalities, injuries, homeless, affected population, affected area, and cost of damage can be considered for a multi-dimensional scale, which may provide a technique to compare and contrast the impacts of different types of disasters. As an initial step to develop qualitative measure, a one-dimensional scale based on fatalities was introduced as follows.

6.2.1 Preliminary Analysis

In this section, the Step 2C of the methodology [i.e., analyze the extreme events and find the Extreme Probability Distribution of severity based on the most influencing factor (fatalities)] is addressed. To understand the disaster continuum, a global level dataset with different types of natural events must be considered. Therefore, ten different type of disasters, that is, large-scale global disasters such as earthquakes, tsunamis, and volcanoes; regional scale disasters such as floods, cyclones, and tornadoes; and local scale disasters such as flash floods, forest fires, landslides and lightning, are included in the preliminary analysis.

To select the extreme fatalities using the block maxima or R^{th} order method for all types of natural disasters, each block should represent each type of disaster; otherwise, the method will be biased to large scale disasters and will not select fatalities from small scale disasters when small scale to large scale disasters are grouped together. The R^{th} order method is selected to define extreme events with high fatalities for this analysis because this method selects a considerable number of extremes for each type of disaster and covers the full range of severity (i.e., fatalities) ranging from a small scale to a large-scale disaster. A block maxima method is unsuitable because it does not provide enough data for the analysis when each block is considered a different type of disaster (i.e., only 10 extreme data points for block maxima). The peak over threshold method is not suitable because it includes only the extremes that are associated to large-scale disasters but not those included in small-scale disasters (i.e., extremes in large-scale disasters always exceed the selected threshold, but extremes of local-scale disasters, such as lightning, always fall below the threshold value). Therefore, the extreme fatalities of R^{th} order statistic was used for the extreme value analysis to understand the severity because this method selected a considerable number of extremes for each type of disaster and covered the full range of severity (extreme fatalities from small-scale disasters to large-scale disasters).

In order to represent a considerable number of extremes for each type of disaster, records of fatalities in the top-ten extreme cases (i.e., 10^{th} order statistic) for each disaster type were taken as one dataset for the preliminary analysis (see Section 6.1.4 for extreme value selection). The data set used for this preliminary analysis is shown in Table 6.2 and was taken from several web-sites.

Table 6.2 10^{th} order statistic data set for preliminary analysis

Disaster Type	Top 10 Fatalities									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Flood [1]	2,500,000	900,000	500,000	231,000	145,000	100,000	100,000	100,000	50,000	60,000
Earthquake[2]	830,000	316,000	273,400	260,000	250,000	242,769	230,273	230,000	200,000	200,000
Cyclone/ Hurricane/ Typhoons [2]	500,000	300,000	300,000	210,000	200,000	138,866	138,366	100,000	60,000	60,000
Tsunami [2]	230,273	123,000	100,000	40,000	36,417	31,000	30,000	27,122	25,674	23,024
Land slide [3]	100,000	30,000	23,000	22,000	7,200	5110	4000	4000	3100	2000
Volcano [2]	92,000	36,000	33,000	29,000	23,000	15,000	10,000	9,350	6,000	5,115
Lightning [4,5]	4000	3000	1523	469	91	81	30	-	-	-
Flash Flood [6]	2,200	1,400	464	350	270	247	238	180	172	143
Tornado [2]	1,300	923	695	681	600	500	500	500	440	400
Forest fire (Wild fire, Bush fire) [2]	1,200	1,200	453	418	282	273	240	230	213	173

Sources: [1] ("List of deadliest floods" 2013); [2] ("List of natural disasters by death toll" 2013); [3] ("List of landslides" 2013); [4] (WordPress.com 2013); [5] ("Lightning strike" 2013); [6] ("List of flash floods" 2013)

To develop a fatality-based scale by reflecting the reasonable amount of data from each type of disaster, the 10th order statistic was selected; however, only the most extreme seven lightning fatalities were considered because the dataset consists of natural events that cause at least one fatality. The mean and the standard deviation of the 97 disaster data for fatalities are 112,135 and 290,807 respectively. Figure 6.6 shows the CDF of fatalities and the best-fitted Weibull distribution (Equation 6.36) plotted in the same graph.

$$F(x) = 1 - e^{-\left(\frac{x}{37496}\right)^{0.4095}} ; x \geq 0$$

Equation 6.36

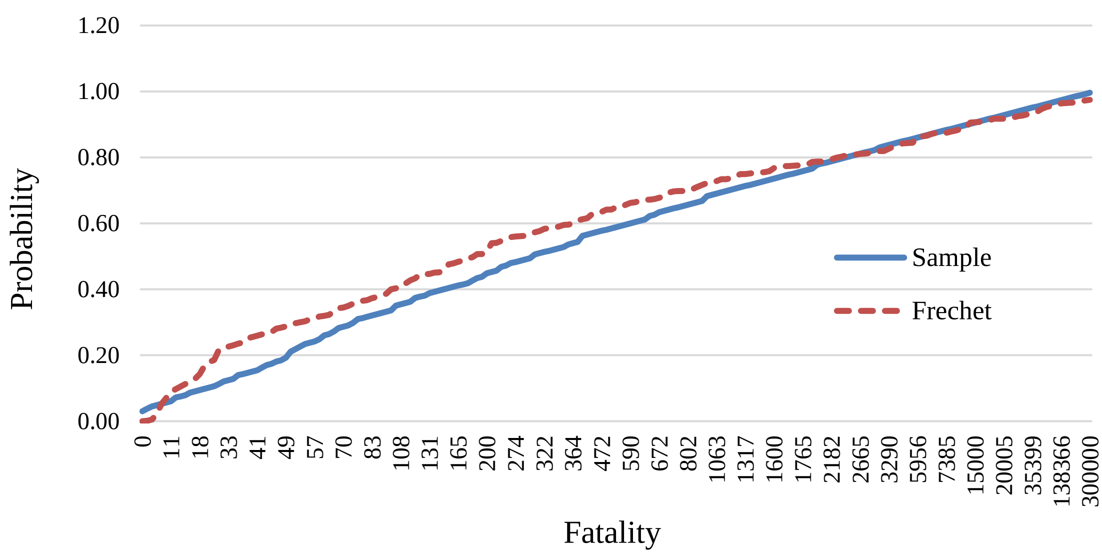


Figure 6.6 CDF of extreme fatalities for ten different natural events and the fitted Weibull distribution

Step 3B of the methodology is to combine the quantitative measure and the UDSC. It is addressed here for preliminary analysis. Table 6.3 columns 2 to 5 show the proposed preliminary fatality-based disaster scale with ten different levels that differentiate the severity of a disaster. Because fatality ranging from 0 to 7.347 billion, the world's population (World Bank 2015), the full range of fatalities (human factor) can be concentrated into ten levels, using the logarithm of fatality. This fact is explained in Section 4.2, when addressing the question “how many levels of seriousness are needed” for the UDSC. Ten levels make it easy to combine the fatality-based disaster scale and the UDSC scale as shown in Table 6.3. In addition, people are more comfortable with 10 levels. Using the Equation 6.36 (i.e., the fitted Weibull distribution), the probabilities are estimated for each severity level.

Table 6.3 Fatality-based disaster scale

Seriousness	Fatality Range		Probability	
			Sample	Weibull
UDSC 1	$1 \leq F < 10$	$\mu-0.33333\sigma \leq F < \mu-0.3333\sigma$	0	0.021
UDSC 2	$10 \leq F < 100$	$\mu-0.3333\sigma \leq F < \mu-0.333\sigma$	0.031	0.051
UDSC 3	$100 \leq F < 1{,}000$	$\mu-0.333\sigma \leq F < \mu-0.33\sigma$	0.268	0.118
UDSC 4	$1{,}000 \leq F < 10{,}000$	$\mu-0.33\sigma \leq F < \mu-0.3\sigma$	0.175	0.238
UDSC 5	$10{,}000 \leq F < 0.1M$	$\mu-0.3\sigma \leq F < \mu$	0.216	0.334
UDSC 6	$0.1M \leq F < 1M$	$\mu \leq F < \mu+3\sigma$	0.299	0.203
UDSC 7	$1M \leq F < 10M$	$\mu+3\sigma \leq F < \mu+33\sigma$	0.010	0.022
UDSC 8	$10M \leq F < 100M$	$\mu+33\sigma \leq F < \mu+333\sigma$	0	$5.27*10^{-05}$
UDSC 9	$100M \leq F < 1B$	$\mu+333\sigma \leq F < \mu+3333\sigma$	0	$1.04*10^{-11}$
UDSC 10	$1B \leq F < 10B$	$\mu+3333\sigma \leq F < \mu+33333\sigma$	0	$6.32*10^{-29}$

The magnitude of a disaster’s impact is evaluated based on the logarithm of the fatalities (Columns 2 in Table 6.3). A base 10 logarithm was selected to differentiate the severity levels, intervals, ranges or boundaries for all types of natural disasters in the fatality-based disaster scale. This is well suited because the probability of a very high classification is low (last few rows of the last two columns in Table 6.3), as severe natural disasters are rare. More severe disasters have a higher classification according to the logarithmic scale. Therefore, the log scale is well suited and can be justified because although each severity level increases by a power of 10, the probability of events that fall within the higher range of the scale is small. In addition, the base 10 measurement is easy to remember and meaningful because it differentiates one severity level from the other.

Here, a straight-forward method is used to define levels based on ranges of fatality (see Column 2 in Table 6.3). The approximate values of the mean (μ) 100,000 (= actual mean - 0.042Standard deviation) and the standard deviation (σ) 300,000 (= 97% actual value) are used. The lowest limit of the scale is the occurrence of one fatality. This can be represented as μ-0.33333σ. The fatalities increase by an order of magnitude as the seriousness of the event increases. Therefore, the severity levels in Table 6.3 introduce the derived fatality-based scale: a way to measure the severity of a natural disaster. The sample probabilities (evaluated using selected 97 extreme data points) as well as expected probabilities (evaluated using Equation 6.36), are shown in Table 6.3.

UDSC level 8 or higher disaster with very small estimated probability is expected according to the fitted Weibull distribution. These probabilities are estimated using a very low exact number of severe events (only 1 historical record for UDSC 7 and higher events as shown in Table 6.2) because there are not any historical records for UDSC 8 or higher disasters; however, there is geographical evidence of natural disasters that have occurred in the past. Therefore, the estimated probabilities for last three levels are very low, and these probabilities are indicative of their severity range, and exact number of estimated probability must not be taken seriously. Hence, further research is necessary to understand the disaster severity continuum. Therefore, a detailed analysis, consisting of 10,805 records of 33 types of natural disasters from 1977 to 2013, is performed in Section 6.2.2. In this detailed analysis, the best distribution fit of extreme fatalities for different order statistic were also conducted to determine whether 10th order statistic is more appropriate than other order statistics.

Table 6.4 illustrates the disaster classification covered by the preliminary analysis data set. This table assists in comparing the severity of different types of disasters and presents an overall picture of the severity levels. The disaster levels that are covered are indicated with '√' (check mark), while the levels that are not covered are indicated with 'x' (cross mark). In Table 6.4, the list of disasters has been ordered to show the increasing coverage of the scale. According to this classification, local disasters, such as flash floods and lightning cover the lower levels, whereas the disasters with potential regional or global level impacts cover upper levels. A flood has the ability to reach the UDSC 7 seriousness level, whereas local disasters such as flash floods, forest fires, lightning and tornadoes reach as high as UDSC 4.

Table 6.4 Preliminary Disaster Classification

Seriousness	Flash Flood	Forest Fire (Wild fire, Bush fire)	Lightning	Tornado	Volcano	Land slide	Cyclone/ Hurricane/ Typhoons	Earthquake	Tsunami	Flood
UDSC 1	√	√	√	√	√	√	√	√	√	√
UDSC 2	√	√	√	√	√	√	√	√	√	√
UDSC 3	√	√	√	√	√	√	√	√	√	√
UDSC 4	√	√	√	√	√	√	√	√	√	√
UDSC 5	×	×	×	×	√	√	√	√	√	√
UDSC 6	×	×	×	×	×	√	√	√	√	√
UDSC 7	×	×	×	×	×	×	×	×	×	√
UDSC 8	×	×	×	×	×	×	×	×	×	×
UDSC 9	×	×	×	×	×	×	×	×	×	×
UDSC 10	×	×	×	×	×	×	×	×	×	×

6.2.2 Detailed Analysis of Extreme fatalities for all types of Natural Disasters

A more detailed analysis of extreme fatalities has been conducted using the data in EM-Dat global database of Centre for Research on the Epidemiology of Disasters (CRED), for all types of natural disasters from 1977 to 2013 inclusive. Although data from 1900 to 2013 was available in EM-Dat database, data from 1977 to 2013 was obtained for this analysis because the CRED restricts the maximum amount of data issued to around 10,000 records. If the whole dataset were available, it would be possible to conduct a more comprehensive analysis. In addition, the database records data based on the country. For example, 2004 Indian Ocean tsunami data was distributed to 12 different records according to the 12 affected nations. Therefore, the actual impact of some events are not properly captured as such records are distributed to several records. There are 59 different secondary-sub types of disasters including all main types (according to the categories discussed in Disaster Profile in Chapter 2) except meteorite/asteroid in extra-terrestrial events and animal stampede in biological events. Therefore, this analysis consists of five out of six main groups of natural disasters, as shown in first five columns of Table 6.5

It is essential to determine the statistical characteristics of fatalities, along with the best probability distribution fit, that are able to describe the behaviour of fatalities. There are 10805 records of fatalities from 1977 to 2013 logged in EM-Dat database, with minimum 0 and maximum 300,000. The mean fatalities is 258 and the standard deviation is 5491.18 with 38.65 skewness and 1,686.98 kurtosis, which means the parent probability distribution of the fatalities has a more extreme events at longer fatality number's (long right tail).

Table 6.5 Events distribution according to their groups and main types of disaster profile

<table>
<tr><th>Group</th><th>No. of Events</th><th>%</th><th>Main Type</th><th>No. of Events</th><th>Category</th><th>No. of Events</th></tr>
<tr><td rowspan="7">Biological</td><td rowspan="7">1297</td><td rowspan="7">12</td><td>Animal stampede</td><td>0</td><td>Animal stampede</td><td>0</td></tr>
<tr><td rowspan="4">Epidemic</td><td rowspan="4">1219</td><td>Bacterial Infectious Diseases</td><td>646</td></tr>
<tr><td>Parasitic Infectious Diseases</td><td>42</td></tr>
<tr><td>Viral Infectious Diseases</td><td>394</td></tr>
<tr><td>Other Epidemics</td><td>137</td></tr>
<tr><td>Insect infestation</td><td>78</td><td>Grasshopper/Locust/Worm</td><td>78</td></tr>
<tr><td colspan="4" style="display:none"></td></tr>
<tr><td rowspan="7">Climatological</td><td rowspan="7">1303</td><td rowspan="7">12.1</td><td>Drought</td><td>506</td><td>Drought</td><td>506</td></tr>
<tr><td rowspan="3">Extreme temperature</td><td rowspan="3">460</td><td>Cold wave</td><td>260</td></tr>
<tr><td>Extreme winter condition</td><td>59</td></tr>
<tr><td>Heat wave</td><td>141</td></tr>
<tr><td rowspan="3">Wildfire</td><td rowspan="3">337</td><td>Forest Fire</td><td>246</td></tr>
<tr><td>Land Fire</td><td>76</td></tr>
<tr><td>Other Wild fires</td><td>15</td></tr>
<tr><td>Extraterrestrial</td><td>0</td><td>0</td><td>Meteorite/Asteroid</td><td>0</td><td>Meteorite/Asteroid</td><td>0</td></tr>
<tr><td rowspan="5">Geophysical</td><td rowspan="5">1068</td><td rowspan="5">9.9</td><td rowspan="2">Earthquake (seismic activity)</td><td rowspan="2">865</td><td>Ground shaking</td><td>838</td></tr>
<tr><td>Tsunami</td><td>27</td></tr>
<tr><td rowspan="2">Mass Movement Dry</td><td rowspan="2">43</td><td>Landslide-MMD</td><td>25</td></tr>
<tr><td>Other Mass Movement Dry</td><td>18</td></tr>
<tr><td>Volcano</td><td>160</td><td>Volcanic eruption</td><td>160</td></tr>
<tr><td rowspan="6">Hydrological</td><td rowspan="6">4251</td><td rowspan="6">39.3</td><td rowspan="4">Flood</td><td rowspan="4">3740</td><td>Flash flood</td><td>481</td></tr>
<tr><td>General flood</td><td>2368</td></tr>
<tr><td>Storm surge/coastal flood</td><td>76</td></tr>
<tr><td>Other flood</td><td>815</td></tr>
<tr><td rowspan="2">Mass Movement Wet</td><td rowspan="2">511</td><td>Landslide-MMW</td><td>432</td></tr>
<tr><td>Other Mass Movement Wet</td><td>79</td></tr>
<tr><td rowspan="11">Meteorological</td><td rowspan="11">2888</td><td rowspan="11">26.7</td><td rowspan="11">Storm</td><td rowspan="11">2888</td><td>Extratropical cyclone</td><td>99</td></tr>
<tr><td>Hailstorm</td><td>93</td></tr>
<tr><td>Severe storm</td><td>136</td></tr>
<tr><td>Snowstorm</td><td>73</td></tr>
<tr><td>Snowstorm/Blizzard</td><td>49</td></tr>
<tr><td>Blizzard, Blizzard/Tornado, Blizzard/Dust storm, Dust storm, Sandstorm/Dust storm, Sandstorm, Snowstorm/Sandstorm</td><td>25</td></tr>
<tr><td>Thunderstorm</td><td>87</td></tr>
<tr><td>Tornado</td><td>221</td></tr>
<tr><td>Other Local/ Convectional Storm</td><td>22</td></tr>
<tr><td>Tropical cyclone</td><td>1437</td></tr>
<tr><td>Other storm</td><td>646</td></tr>
</table>

In order to estimate the probability of the future events for a given number of fatalities, determining the distribution that historical data follows are necessary. Although parent distribution of fatalities could not be fitted to a known distribution with a 90% confidence level, close approximate distribution is fitted as shown in Figure 6.7 along with the cumulative sample distribution of fatalities. Note that the probabilities of Figure 6.7 are truncated because the cumulative probability value of zero fatalities is 0.32 and the sample probability of zero fatalities is 0.3. The PDF of the fitted Generalized Logistic distribution (GLPDF) with σ equals to 12.805 and μ equals to 9.6956, which is an approximate parent distribution fit for fatalities, is shown in Equation 6.37.

$$f(x) = \frac{e^{-\left(\frac{x-\mu}{\sigma}\right)}}{\sigma\left[1+e^{-\left(\frac{x-\mu}{\sigma}\right)}\right]^2} \text{ ; where } \sigma>0, \text{ and } \quad 0 < x < +\infty$$

Equation 6.37

To better fit the distribution, fatalities are transformed into natural logarithms, after eliminating zeros (3287 out of 10805 events did not have any fatalities). However, even the logarithmized data of fatalities could not be fitted to a known distribution with a 90% confidence level (although PP and QQ plots are very close to the diagonal line, A-D, C-S, and K-S tests failed); close approximate distributions were fitted as shown in Figure 6.8 along with the CDF of fatalities in a natural logarithm scale. The PDF of the Generalized Logistic distribution (GLPDF) with σ equals to 1.224 and μ equals to 0.42358, which is an approximate parent distribution fit for fatalities, is shown in Equation 6.37. Note that the GLPDF probabilities of Figure 6.8 are truncated because the cumulative probability value of -0.1 is 0.39.

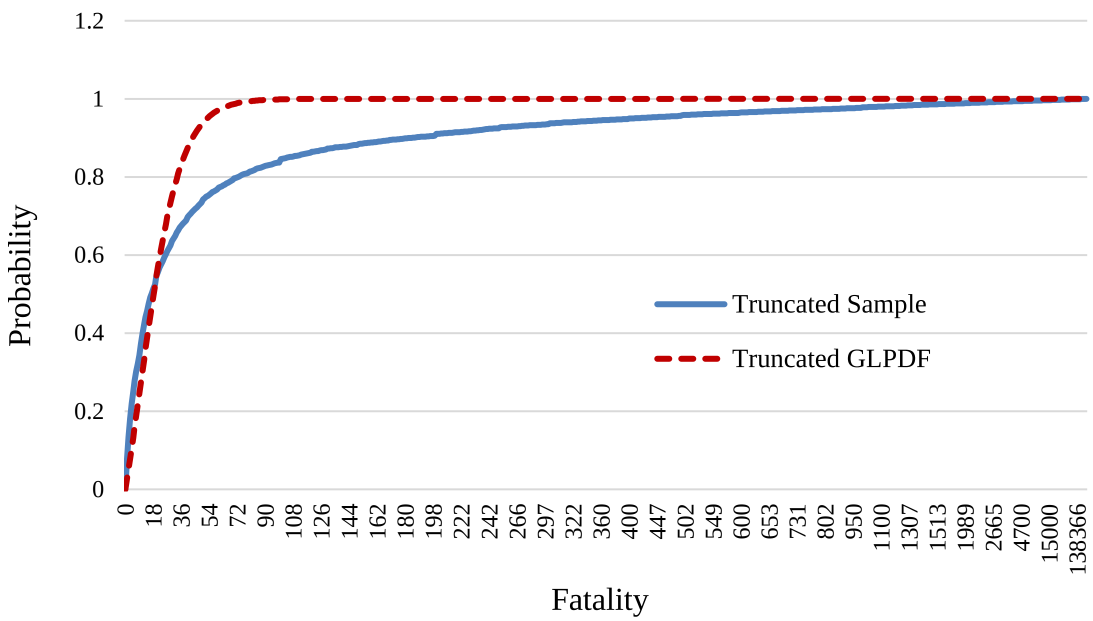


Figure 6.7 Cumulative sample distribution of fatalities with an approximate Generalized Logistic distribution

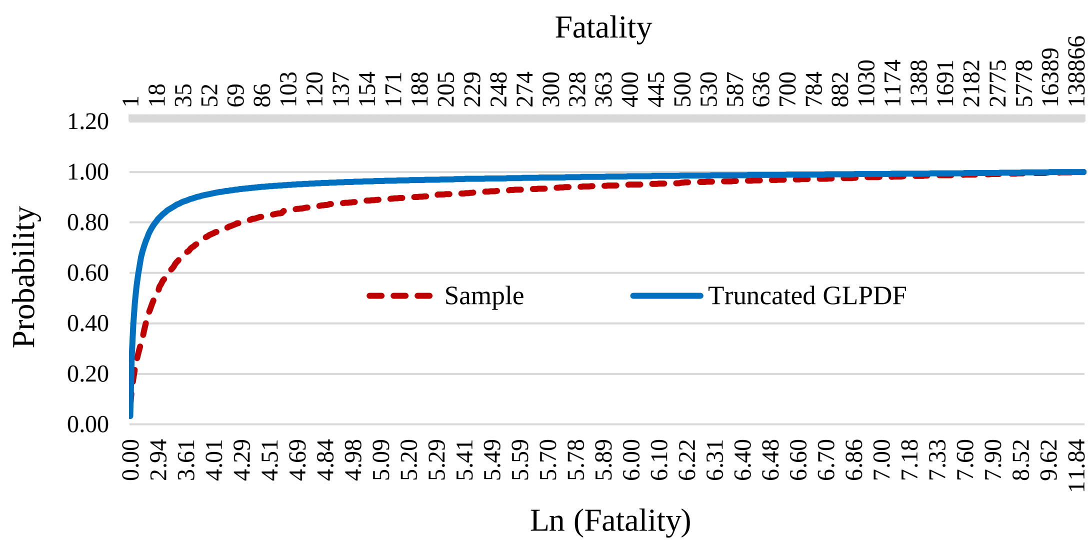


Figure 6.8 Cumulative sample distribution of fatalities in a natural logarithm scale with an approximate Generalized Logistic distribution

In order to evaluate the probability of unusually large events, it is essential to determine the distribution of the extreme events of the fatalities. Among the three different method in determining the extreme events (i.e., block maxima, R^{th} order, and peak over threshold), R^{th} order was used in this analysis because it is the best extreme selection procedure for this analysis as explained in the previous section. Extreme value selection procedure and the three models are discussed in Section 6.1.4.

To apply the extreme value theory to the random variable (number of fatalities), each block has been considered as a different type of natural disaster. Although there are 62 different secondary-sub-types of natural disaster recorded in EM-Dat database from 1977 to 2013, some secondary-sub-types have only one, two, … or less than 10 recorded events (e.g., blizzards, dust storm, freezing rain, icing, sand storm, and snow avalanche). In these cases, there are not enough number of extreme values to represent the highest R^{th} order statistic, when each secondary-sub-type of disaster represents each block in extreme value analysis. Therefore, some of these secondary-sub-types are grouped according to their sub-type and to have a minimum of 15 records in each block, because the extreme value analysis was conducted to select the best R^{th} order from 1st order (i.e., block maxima method) to 15th order. According to this criterion, 34 different categories of disasters are selected to represent each block and their frequency distribution are shown in last two columns of Table 6.5 The number of extremes gradually increases according to the order statistics as shown in Equation 6.38.

$$\text{Sample size of } \mathrm{R}^{\text{th}} \text{ oder extreme dataset} = \text{Number of categories} * \mathrm{R}^{\text{th}} \text{ Order}$$

Equation 6.38

As explained previously, in order to evaluate the extreme value distribution, first, the number of fatalities were grouped according to their category and then fatalities are ordered from highest to lowest for each category. Then, the first R number of fatalities in each category (block) was selected. Because R varies from 1 to 15, 15 different extreme fatality value data sets representing all types of natural disasters were selected for the analysis. Figure 6.9 to Figure 6.11 shows the distribution of descriptive statistics: mean, median, and standard deviation, respectively, along with their trend lines (dotted lines) and the equation for these 15 extreme data sets. The trend lines of mean, median, and standard deviation (see Figure 6.9 to Figure 6.11) are significantly close to the actual value because the R-squared value is close to 1 ($R^2 > 0.99$). The first derivative of these fitted trend lines measure the rate of change of these graphs; while the second derivative measures whether this rate of change is increasing, or decreasing. All three graph stabilizes when R^{th} order increases because the rate of change is decreasing when R^{th} order increases. This emphasized that mean, median, and standard deviation slowly stabilize to their full sample values (i.e., 258 for mean, 5,491.18 for Standard deviation) when R^{th} order increases. The sample sizes of the R^{th} order statistic increase by multiples of 34 according to Equation 6.38 because this analysis considers 34 different types of natural disasters (34 blocks).

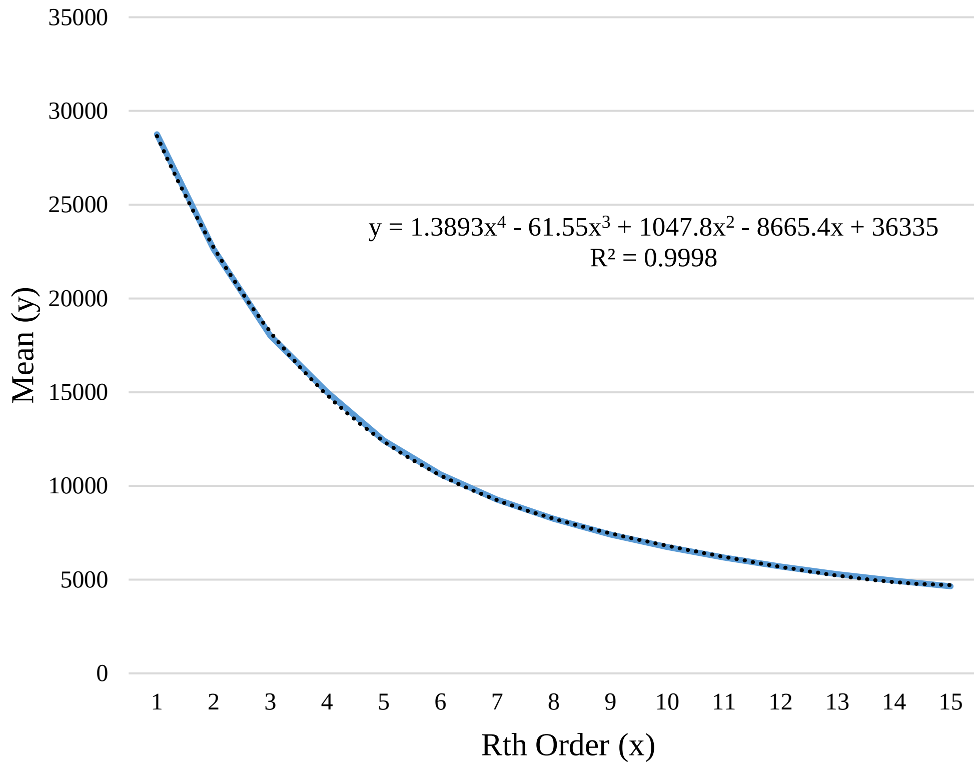


Figure 6.9 Mean distribution of Rth order extremes of all types of natural disasters

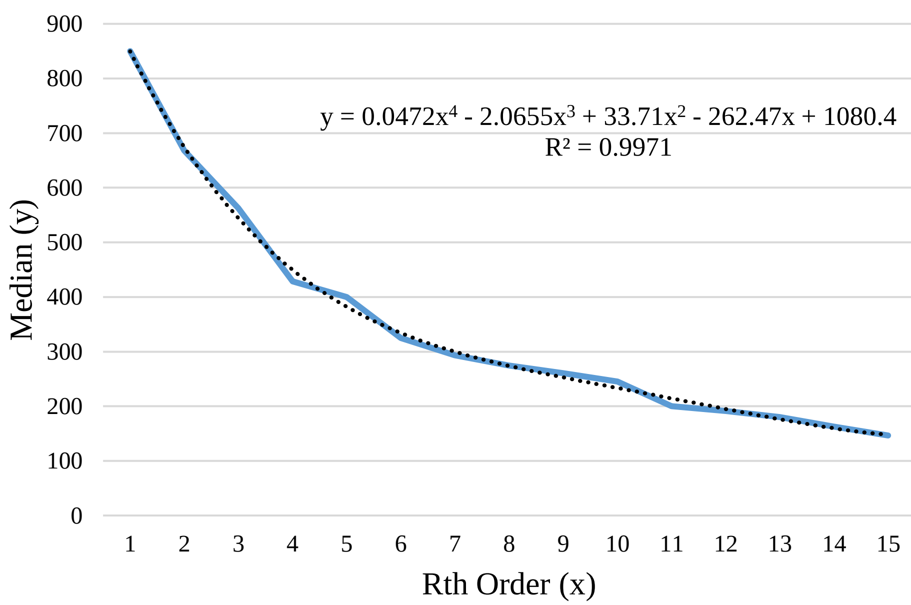


Figure 6.10 Median distribution of Rth order extremes of all types of natural disasters

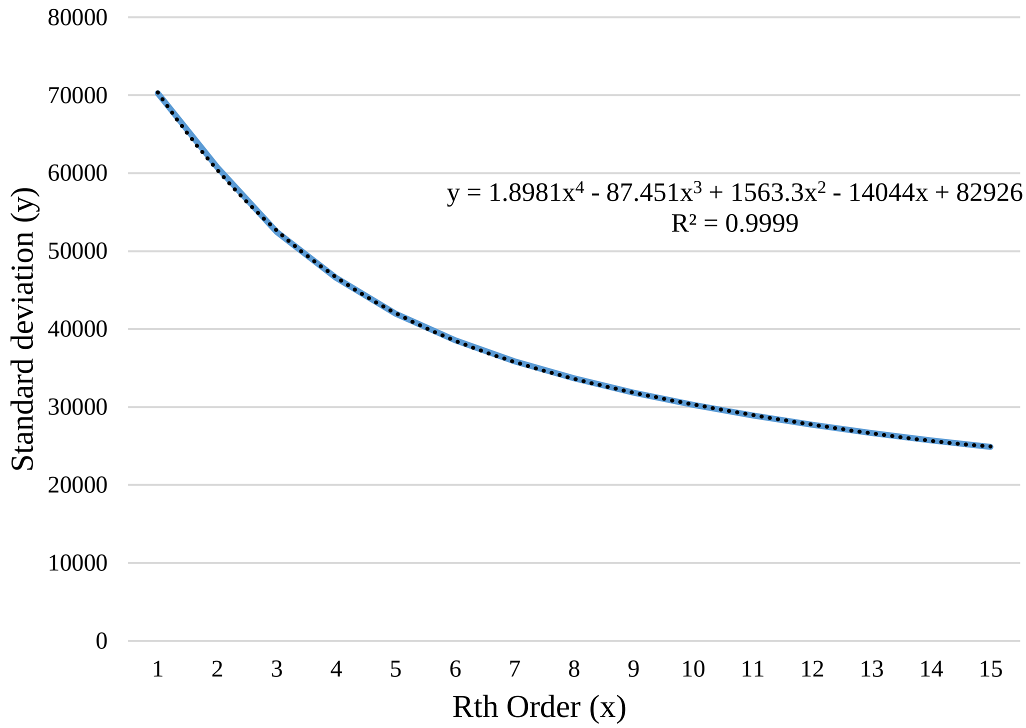


Figure 6.11 Standard deviation distribution of R^{th} order extremes of all types of natural disasters

Because Weibull, Frechet and Gumbel or Generalized Extreme Value Distribution (GEVD) are the four different distribution that can be used to describe the distribution of the R^{th} order statistic extreme events, the parameters of these distributions are determined using the EasyFit 5.5 Professional software. Then, using the mathematical equations of Weibull, Frechet, Gumbel, and GEVD distribution with the determined parameters, PP plot, QQ plot, the probability distribution along with histogram were plotted and compared. The mathematical equations of each extreme value distributions and the procedure undertaken for plotting these graphs are described in Section 6.1.5. Out of the four extreme value distributions for R^{th} order statistic (i.e., GEVD, Gumbel, Frechet, and Weibull), the Frechet distribution, that is,

$f(x_i) = \frac{\alpha}{\sigma}\left\{\left(\frac{x_i-\mu}{\sigma}\right)^{-(\alpha+1)}\left[exp\left(-\left(\frac{x_i-\mu}{\sigma}\right)^{-\alpha}\right)\right]\right\}$ for $\alpha, \sigma > 0$ and $\mu \leq x < \infty$, is the best fit for all 1st order to 15th order statistics, according to the visual analysis of the plots. Figure 6.12 shows the sample CDF of the fatalities and the fitted 8th order Frechet CDF. Figure 6.13 shows the values of parameters, α and σ for the fitted Frechet distributions for the 1st order to the 15th order. This figure also emphasizes that the two parameters of Frechet distribution are stabilized when the R^{th} order increases because their rate of change decreases with an increase in the R^{th} order. Therefore, selecting the R^{th} order which is greater than or equal to the R^{th} order threshold that stabilizes the extreme value distribution fit, gives close approximate probabilities of extremes. However, no direct methods are available for selecting this R^{th} order statistic.

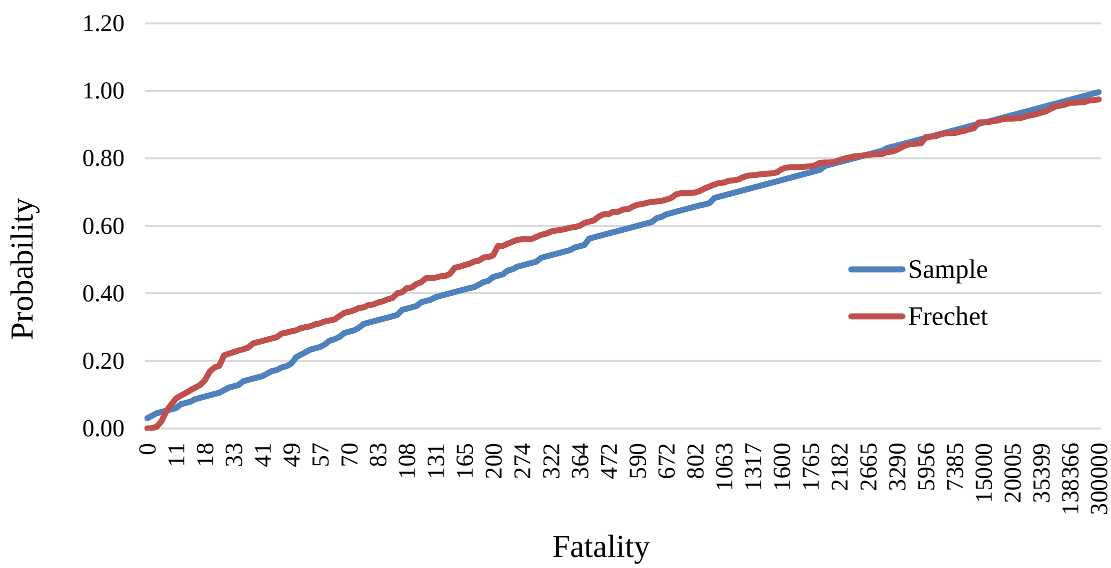


Figure 6.12 Cumulative sample distribution of fatalities with the fitted 8th order Frechet Distribution

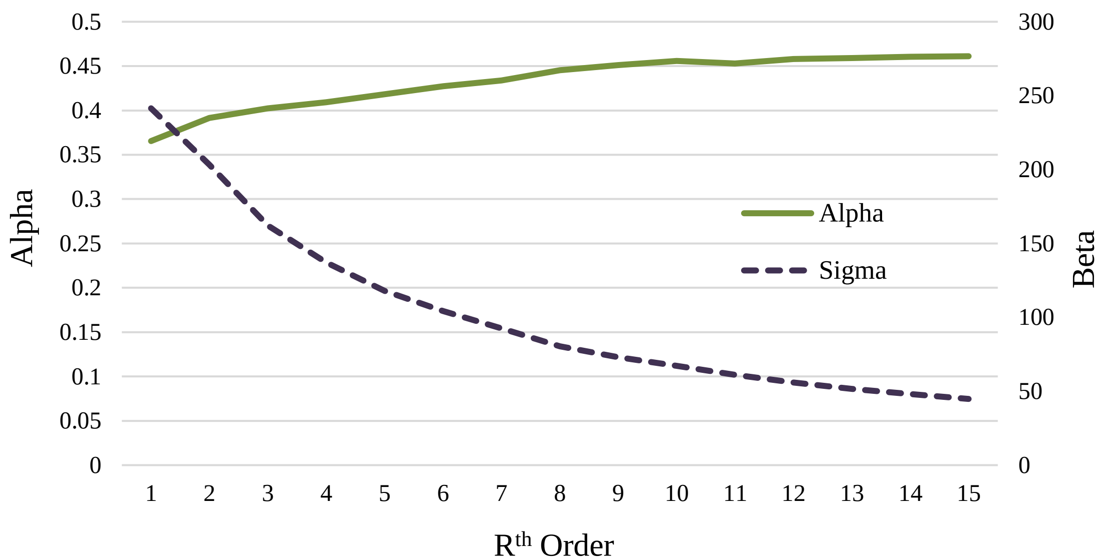


Figure 6.13 Parameter distribution of R^{th} order extremes

In order to select the threshold R^{th} order statistic, which represents the best extreme fatalities probability distribution of Frechet, residual analysis and goodness of fit tests were conducted. More details about residual analysis and goodness of fit tests are available in Section 6.1.5.4 and 6.1.5.6 respectively.

Figure 6.14 shows A-D, C-S, and K-S statistics. Both C-S and A-D test statistics, increase with the order; however, K-S statistic dramatically decreases up to 8^{th} order and exhibits small increases after 8^{th} order statistic. According to the visual interpretation, the minimum statistic of K-S is obtained in the 8^{th} order statistic.

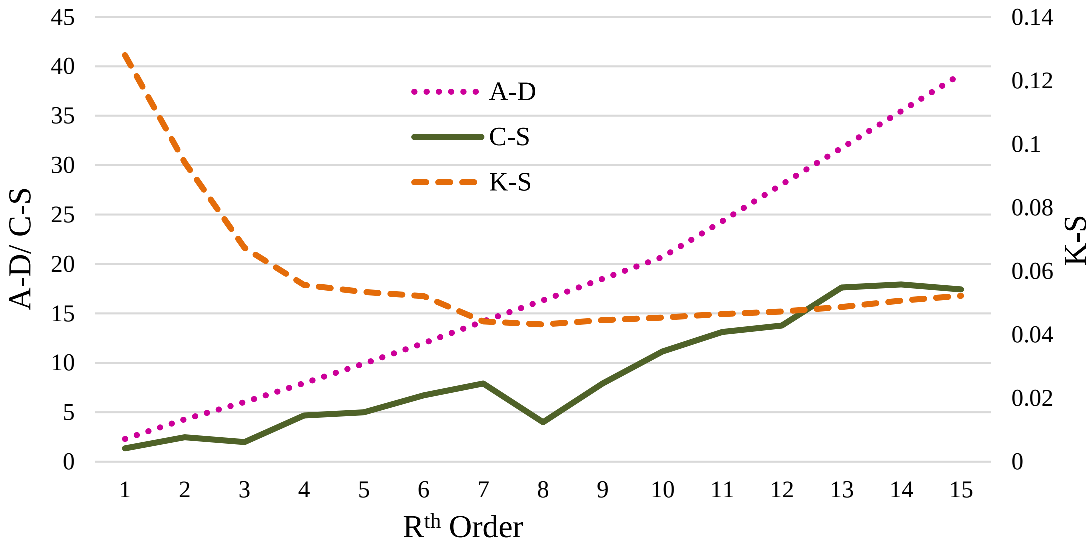


Figure 6.14 Test statistic distribution of Fitted Frechet of R^{th} order extremes

Then, the Residual analysis were conducted to select the best Frechet distribution fit of 1st (i.e., block maxima) to 15^{th} order extremes, by using IBM SPSS and Microsoft Excel. The error between Cumulative Distribution Function (CDF): F(x), and the empirical CDF: q is given in Equation 6.39. That is, the deviation of the PP plot from the diagonal line. The Mean Squared Error (MSE) and the Mean Absolute Error (MAE), were calculated and plotted for the R^{th} order statistic extremes as shown in Figure 6.15. The minimum MSE and MAE is obtained at 8^{th} order statistic, and the errors exhibit small increases after 8^{th} order.

$$\text{Error} = q_i - F(x_i) \text{ for CDF}$$

Equation 6.39

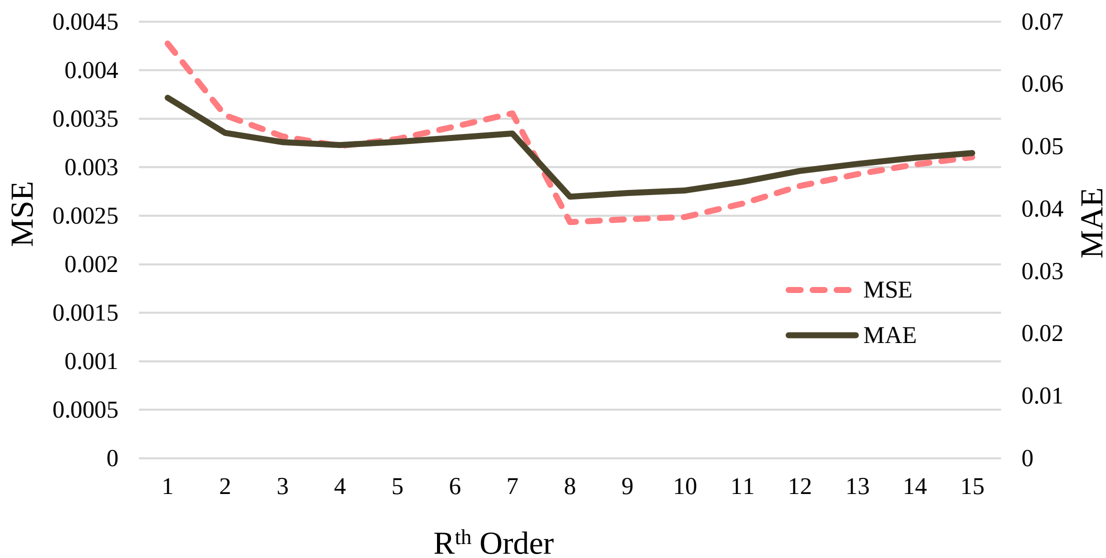


Figure 6.15 Error distribution of Fitted Frechet CDF and the Empirical CDF of R^{th} order extremes

The error between Inverse Cumulative Distribution Function (CDF): $F^{-1}(x)$, and the inverse empirical CDF: x is given in Equation 6.40. That is, the deviation of the QQ plot from the diagonal line. The Mean Squared Error (MSE) and the Mean Absolute Error (MAE), were calculated and plotted for the R^{th} order statistic extremes, as shown in Figure 6.16. The minimum MSE and MAE is obtained at 7^{th} order statistic, however, the errors dramatically increase after 7^{th} order statistic.

$$\text{Error} = x_i - F^{-1}(q_i) \text{ for Inverse CDF}$$

Equation 6.40

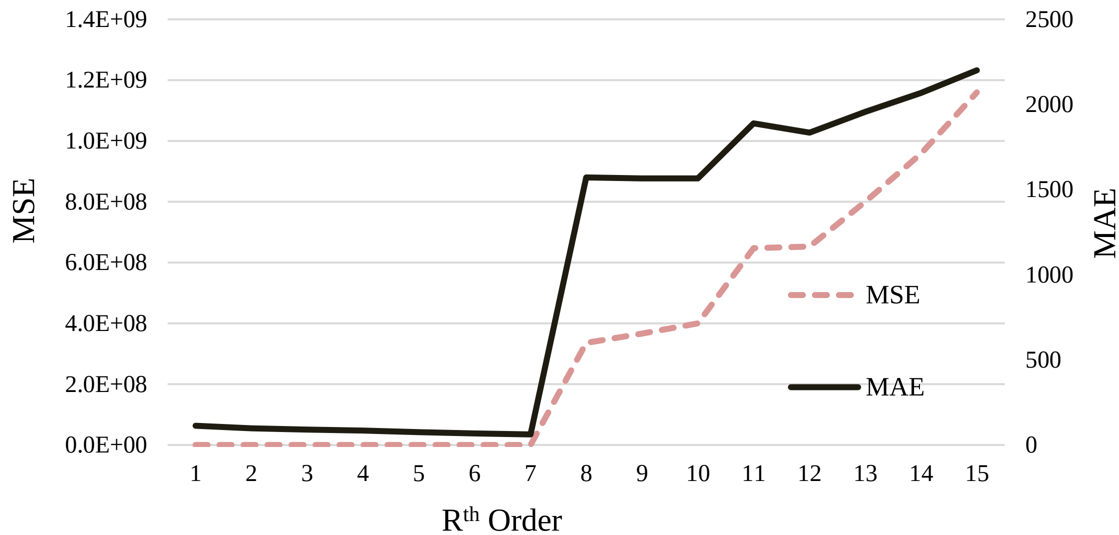


Figure 6.16 Error distribution of Fitted inverse Frechet CDF and the Inverse Empirical CDF of R^{th} order extremes

The above residual analysis and goodness of fit tests did not indicate any stabilization point for the selection of the threshold R^{th} order statistic because the errors between the inverse CDF and the inverse empirical dramatically increase after the 7^{th} order statistic. In addition, the minimums of mean, median, and standard deviation according to the fitted trend lines of Figure 6.9, Figure 6.10, and Figure 6.11, are 15.0709, 16.1426, and 15.7567, respectively, and are higher than 15. Therefore, the R^{th} order statistic that stabilizes the estimated probabilities of fitted EVD may be higher than the 15^{th} order statistic. Hence, this detailed analysis was extended to higher order statistics in order to evaluate the probability of unusually large events.

6.2.2.1 Higher order statistics

Figure 6.13 shows that the extreme value distribution will be stabilizing with an increase of the R^{th} order because the rate of change of the Frechet distribution parameters is decreasing with an increase of the R^{th} order. Therefore, the behaviour of extreme values for higher order statistics is examined to select the Rth order that stabilizes the extreme value distribution fit, and gives close approximate probabilities of extremes. However, same categorization (blocks) in the previous analysis cannot be used for this purpose as some of the categories (e.g., other wild fires) only have 15 events of fatality records. Therefore, a new categorization was used for this analysis by combining the categories that had a lesser number of events (in each block/category) in order to have at least 70 data points in each category/block. Therefore, the following categories in Table 6.5 were combined, as follows:

- the ‘Parasitic Infectious Diseases’ and ‘Other Epidemics’ categories were combined together into ‘Other Epidemics’;
- the ‘Cold wave’ and ‘Extreme winter condition’ categories were combined into ‘Cold wave or Extreme winter condition’;
- the ‘Land Fire’ and ‘Other Wild fires’ categories were combined into ‘Other Wild fires’;
- the ‘Tsunami’, ‘Mass Movement Dry Landslide’, and ‘Other Mass Movement Dry’ categories combined into ‘Other Meteorological events’; and
- the ‘Other Local/ Convectional Storm’, ‘Snowstorm/Blizzard’, and ‘Blizzard, Bilzzard/Tornado, Blizzard/Dust storm, Dust storm, Sandstorm/Dust strom, Sandstorm, Snowstorm and Sandstorm’ categories were combined into ‘Other Local/ Convectional Storm’.

According to the categorization described above, 14 different extreme datasets of 5th order statistics, 10th order statistics, 15th order statistics, …, 70th order statistics were analyzed. Similar to the previous analysis, the mean, median and standard deviation stabilize when the R^{th} order increases, as shown in Figure 6.17, Figure 6.18, and Figure 6.19 respectively.

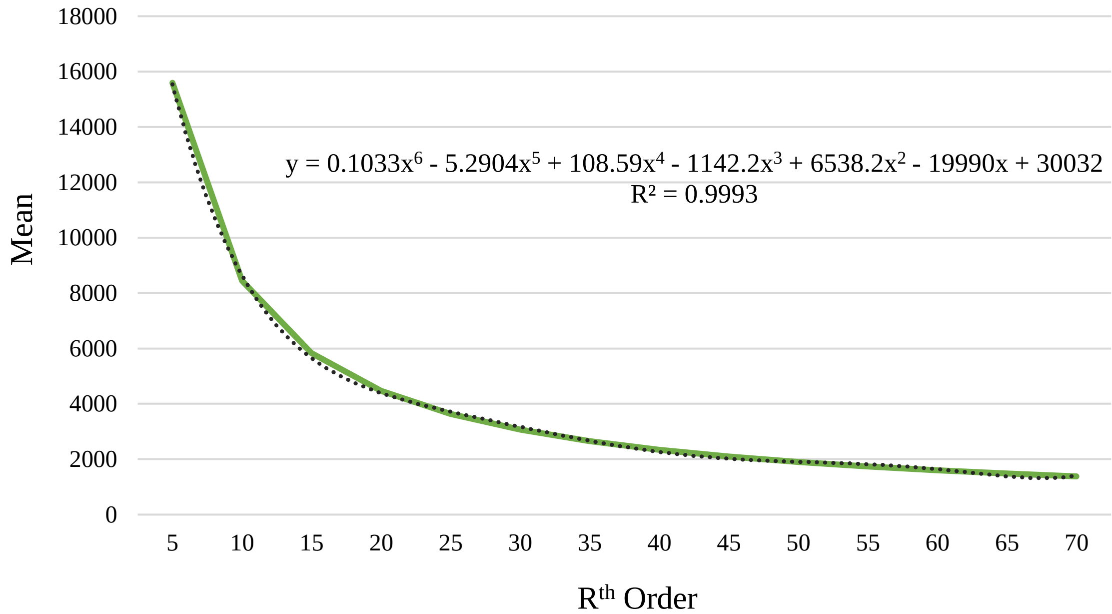


Figure 6.17 Mean distribution of R^{th} order extremes

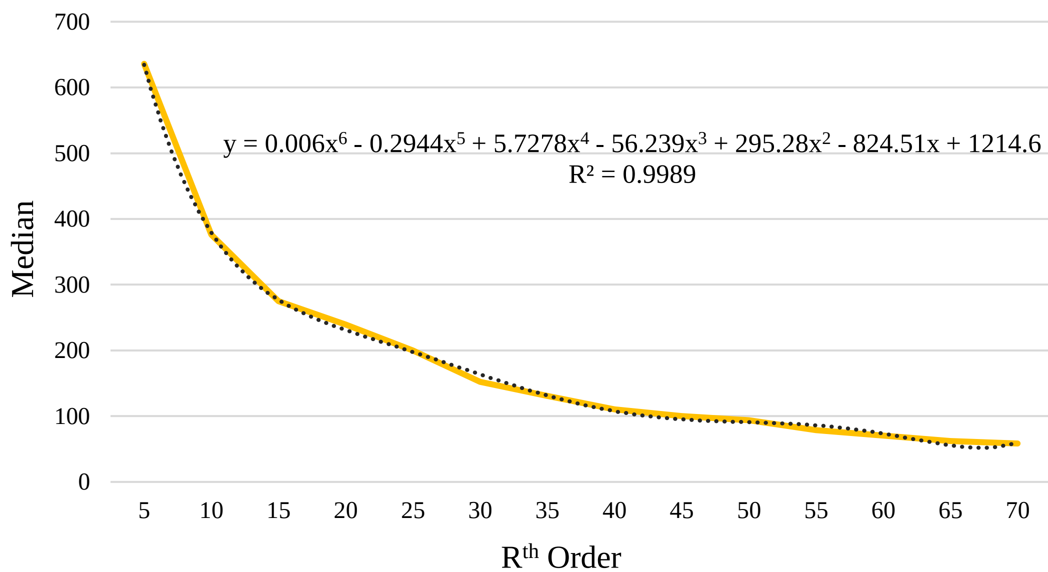


Figure 6.18 Median distribution of R^{th} order extremes

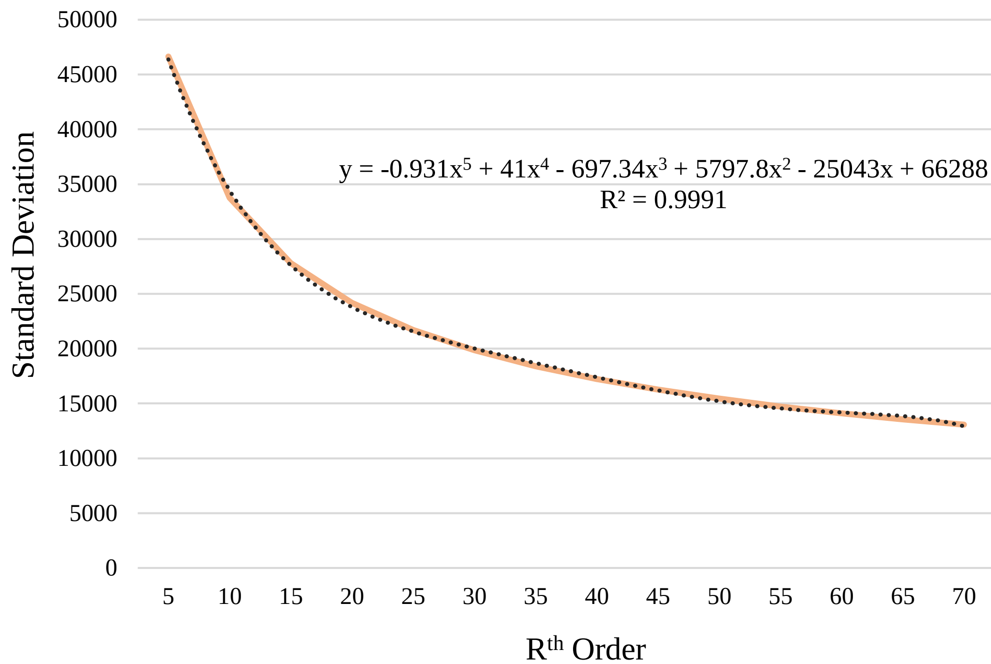


Figure 6.19 Standard deviation distribution of Rth order extremes

Then, the extreme value distributions (Frechet, Weibull, and GEVD were fitted to each dataset and the parameter distribution of each dataset with respect to each distribution is shown in Figure 6.20, Figure 6.21, and Figure 6.22. The fitted Frechet distribution's sigma parameter gradually decreases as the order statistic increases, while the alpha parameter increases up to 15th order statistics and then gradually decreases. Figure 6.20, to Figure 6.22 emphasize that the parameters of each extreme value distribution stabilize when the Rth order increases because the rate of change of these parameters is decreasing. That is, the EVD does not vary significantly after a certain minimum (threshold) Rth order (which is still unknown) is reached. Therefore, when considering EVD (both Frechet and GEVD), any Rth order that is greater than or equal to this minimum (threshold) Rth order gives close approximate probabilities for severity levels.

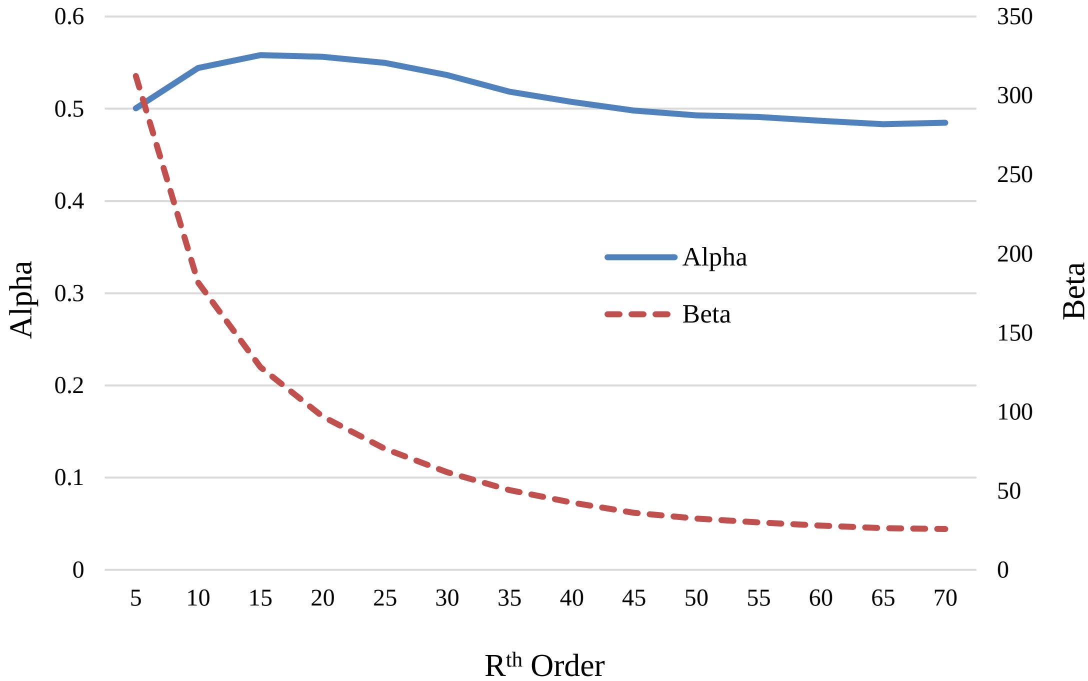


Figure 6.20 Parameters of the Frechet distribution for Rth order extremes

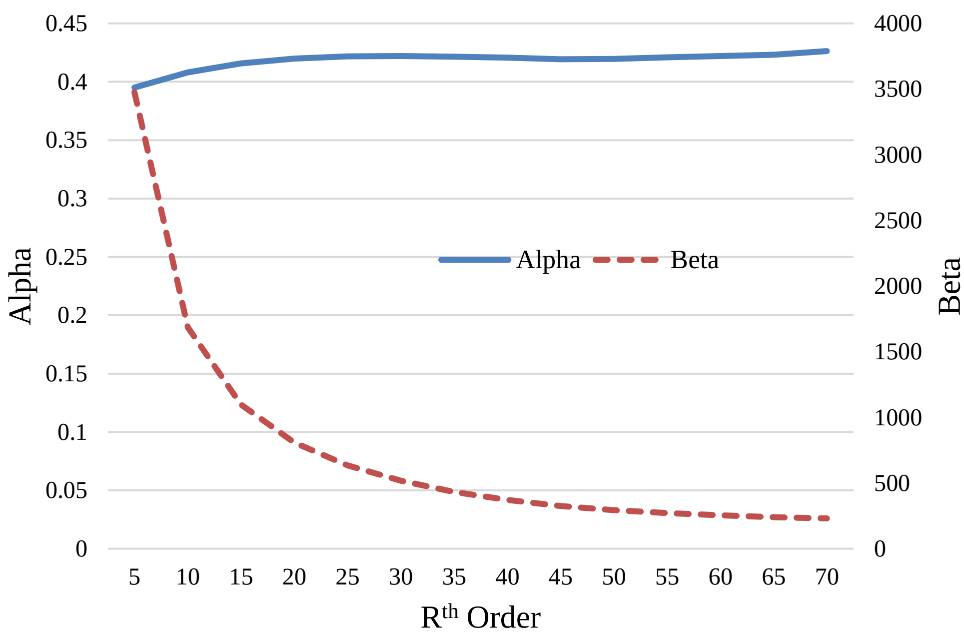


Figure 6.21 Parameters of the Weibull distribution for Rth order extremes

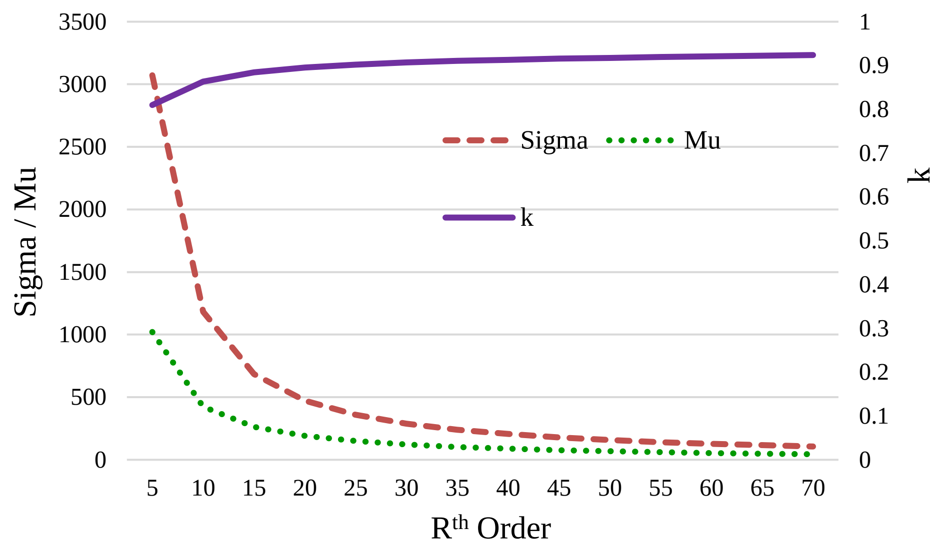


Figure 6.22 Parameters of the GEVD for Rth order extremes

As no direct methods (or direct indicators from the analysis) are available for selecting the best Rth order statistic to estimate the probabilities of severe natural disasters, the following two approaches were considered:

1. Find the Rth order that has the elbow point

   The elbow point of the given curve can be found either by selecting the data point that has the absolute maximum second derivative or by selecting the data point that maximizes the distance between the curve and the line that connect the first and last point of the curve. Since we consider more than one curve (i.e., the curves in Figure 6.17 to Figure 6.22), the range of the Rth order, which consists of the elbow points of each of these curves, is calculated. Then, the upper limit of this range is selected as the minimum Rth order. This is because the estimated probabilities of the fitted EVD of the Rth orders that are greater than the above selected minimum Rth order are slowly approaching the precise probabilities of the severe natural disasters, rather than the estimated probabilities of the fitted EVD of the R^{th} orders that are less than the above selected minimum R^{th} order (see Figure 6.23 to Figure 6.32). According to the Figure 6.17 to Figure 6.22, the R^{th} orders that represent elbow points (except for the second elbow points of the Alpha curve of the Frechet distribution) are in between the 10^{th} and 25^{th} orders. Therefore, we can select the minimum R^{th} order as the 25^{th} order statistic. Consequently, any R^{th} order of the GEVD that is greater than the 25^{th} order is better suited to evaluate the probabilities of severe natural disasters.

2. Select the percentage of error or minimum absolute error (e.g., 10-4) that is suitable for deviation from the actual to represent the probabilities of severe natural disasters.

Therefore, the estimated probability values of each severity level was analyzed with respect to the fitted Frechet, Weibull, and GEVD distribution of the R^{th} order (i.e., the 5^{th} to the 70^{th} order). However, as with the preliminary analysis (see Table 6.3) and in this case, the probabilities are decreasing as the severity level increases (see Figure 6.23 to Figure 6.32). Therefore, for each level a different level of acceptable errors should be selected because the probabilities are decreasing as the severity level increases. However, it is difficult to decide an accurate level of errors for each severity level. Hence, the best R^{th} order EVD that estimates the approximate probabilities of severe natural disasters is selected using MSE and MAE to determine the difference between the best fitted distribution and the empirical distribution.

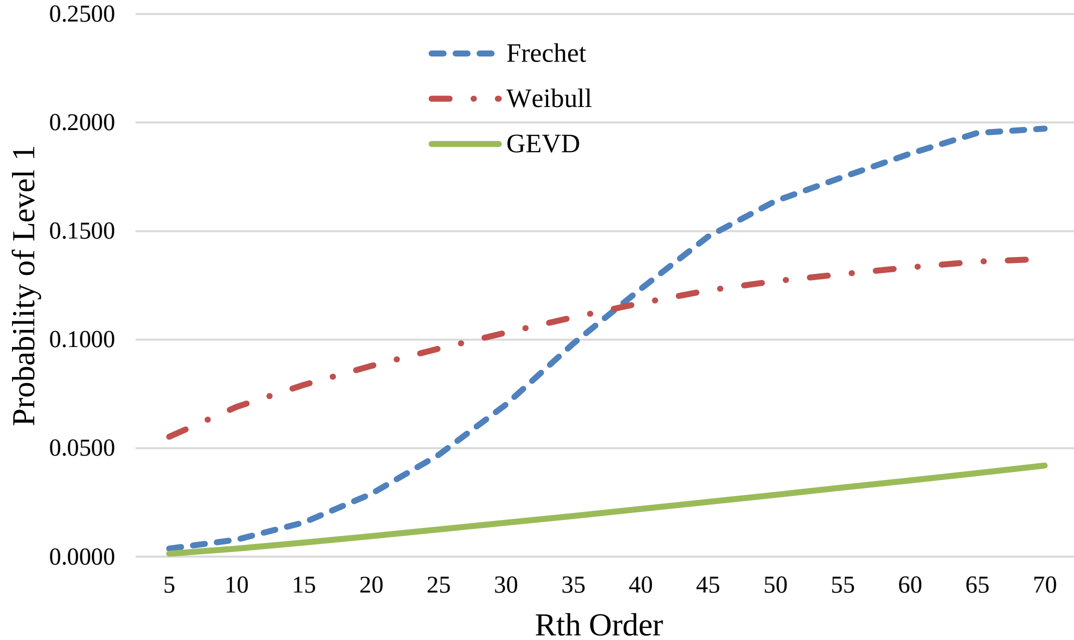


Figure 6.23 The estimated probability of Severity Level 1 for different Rth order extremes

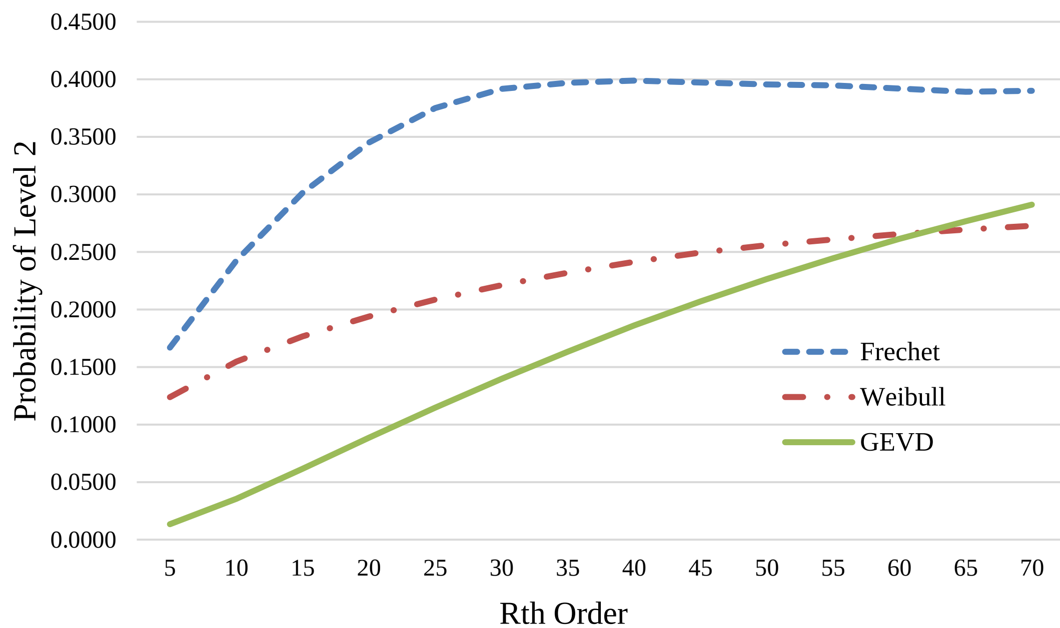


Figure 6.24 The estimated probability of Severity Level 2 for different Rth order extremes

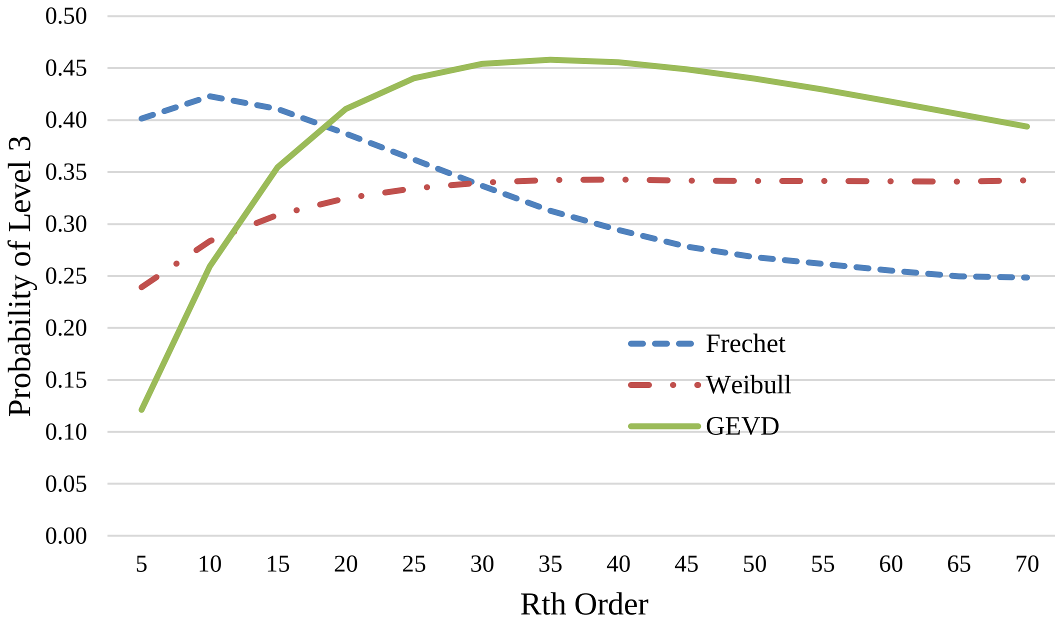


Figure 6.25 The estimated probability of Severity Level 3 for different Rth order extremes

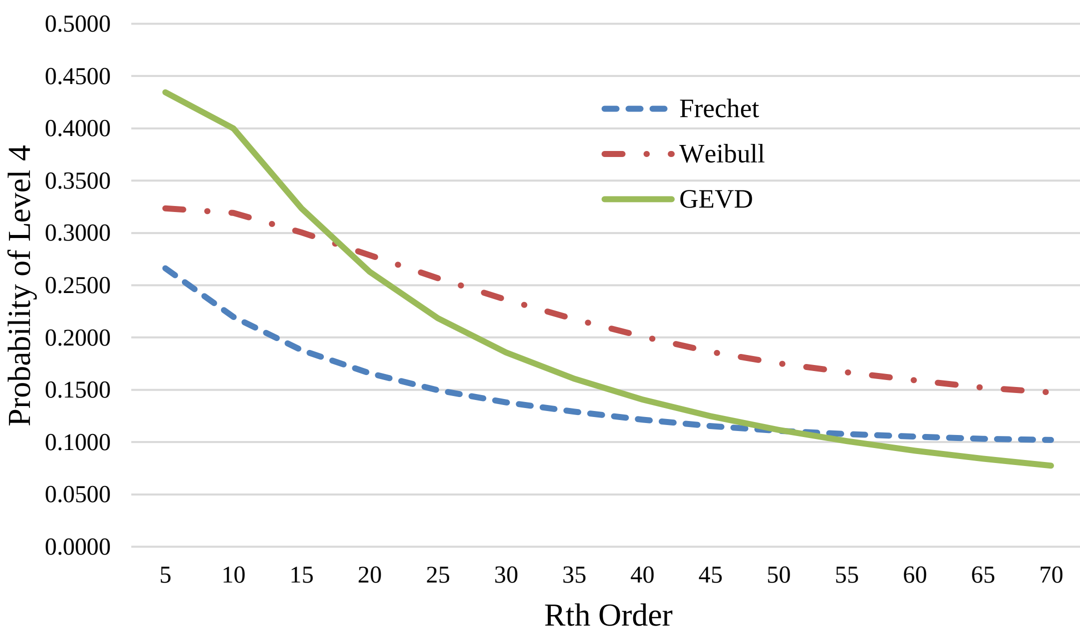


Figure 6.26 The estimated probability of Severity Level 4 for different Rth order extremes

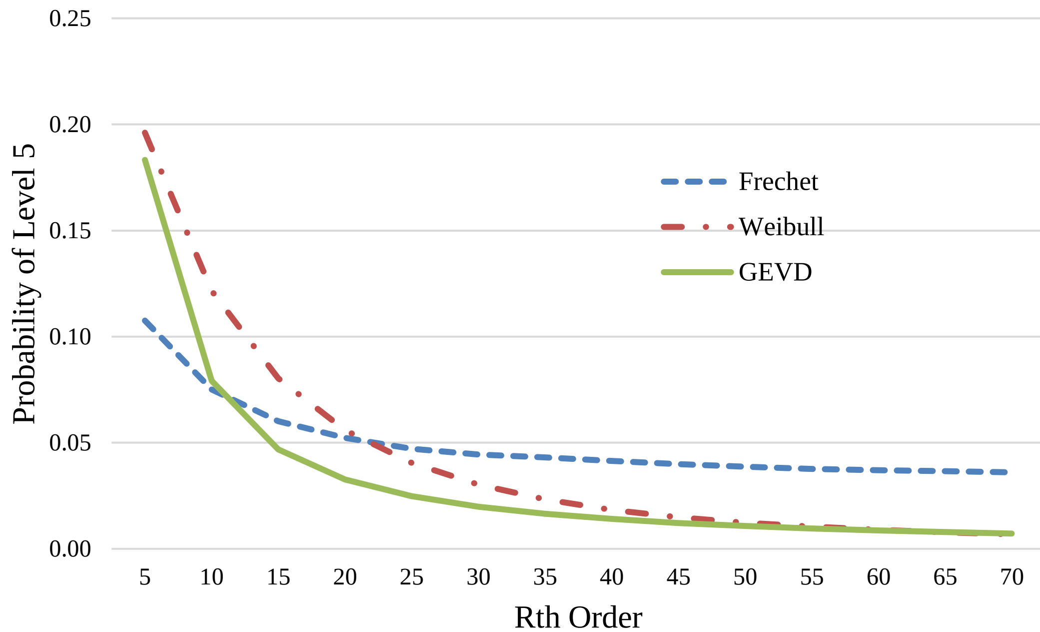


Figure 6.27 The estimated probability of Severity Level 5 for different Rth order extremes

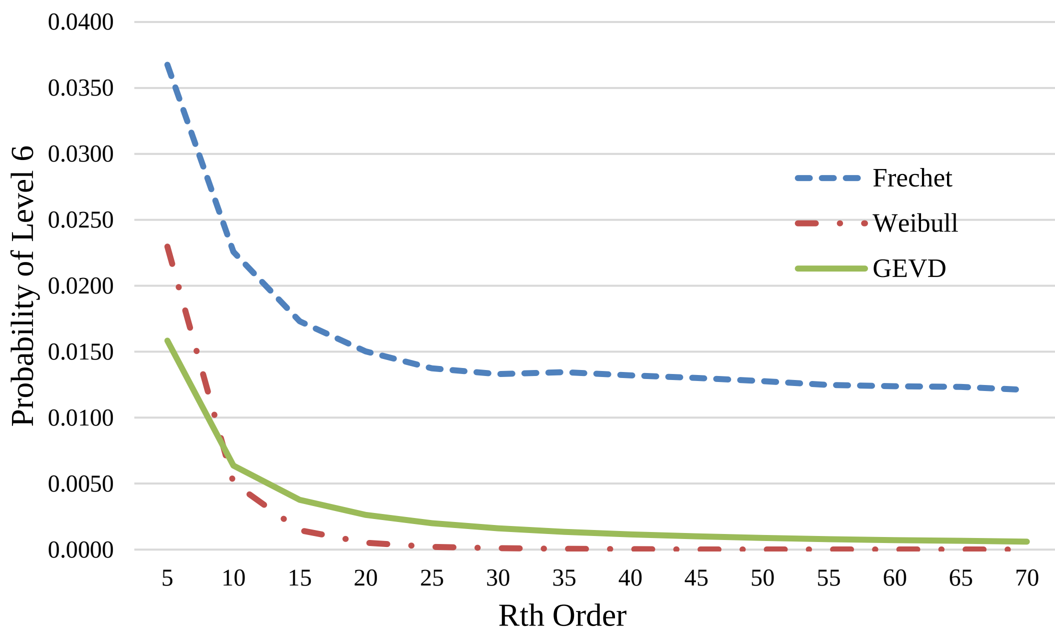


Figure 6.28 The estimated probability of Severity Level 6 for different Rth order extremes

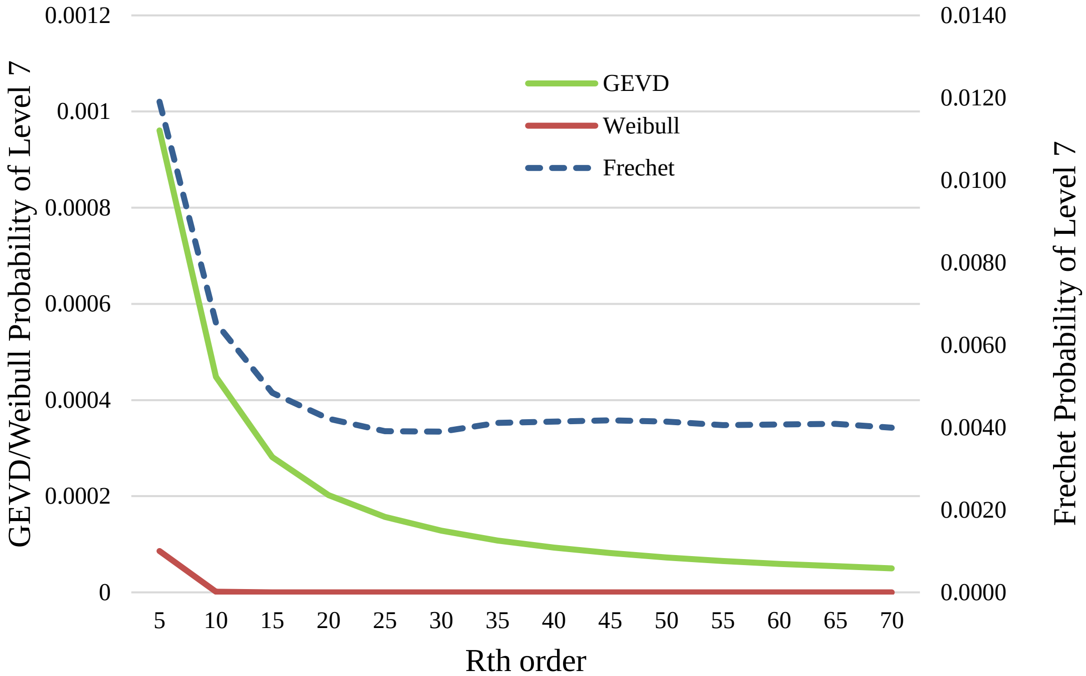


Figure 6.29 The estimated probability of Severity Level 7 for different Rth order extremes

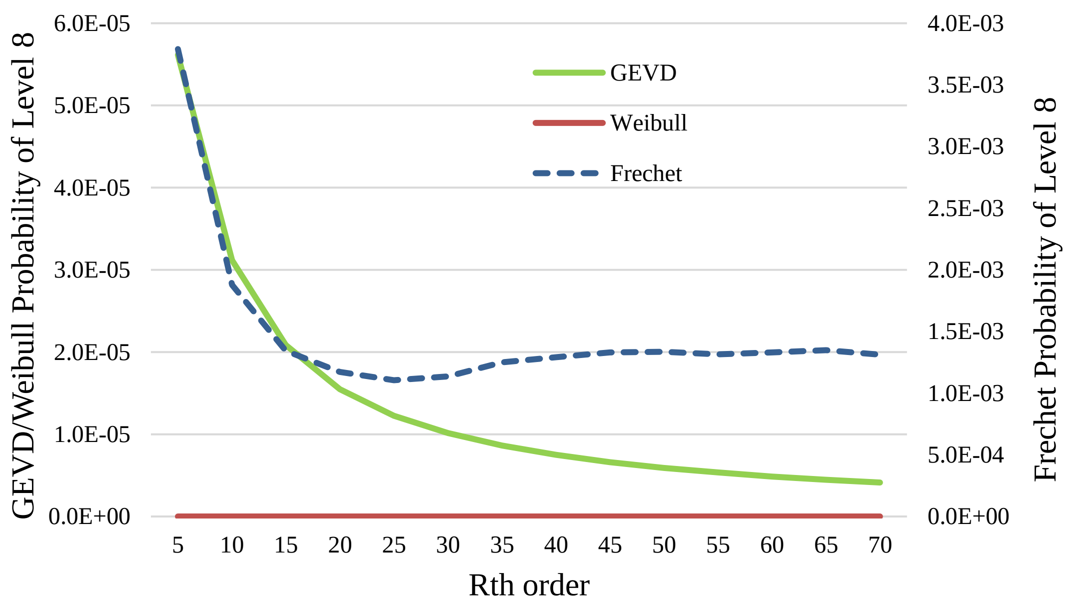


Figure 6.30 The estimated probability of Severity Level 8 for different Rth order extremes

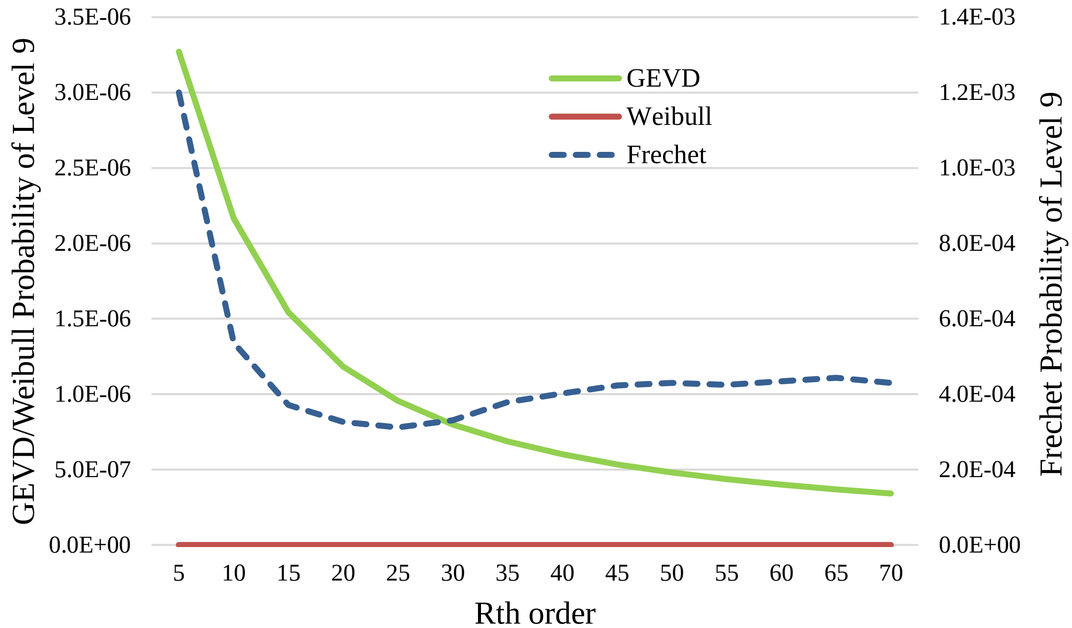


Figure 6.31 The estimated probability of Severity Level 9 for different R^{th} order extremes

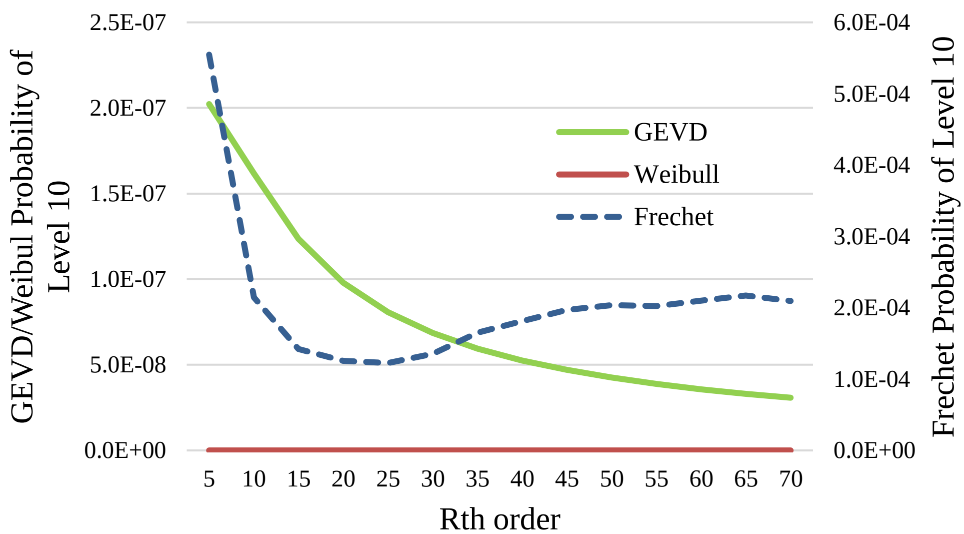


Figure 6.32 The estimated probability of Severity Level 10 for different R^{th} order extremes

To choose the best fit, the PP plot and QQ plot of each distribution are analyzed, and the error analysis are shown in Figure 6.33 to Figure 6.36, using Mean Squared Error

(MSE) and the Mean Absolute Error (MAE). In other words, the error between the Cumulative Distribution Function (CDF): F(x), and the empirical CDF is the deviation of the PP plot from the diagonal (Figure 6.33 and Figure 6.34), and the error between the Inverse Cumulative Distribution Function (CDF): $F^{-1}(x)$, and the inverse empirical CDF is the deviation of the QQ plot from the diagonal (Figure 6.35 and Figure 6.36). Figure 6.33 and Figure 6.34 show that the Frechet distribution has the lowest error when compared to the Weibull or GEVD for each order statistic, however, the error increases as the order statistic increases. On the other hand, the fitted GEVD's error gradually decreases as the order statistic increases. According to the observed trend of error distributions of Frechet and GEVD, the error of the GEVDs will be lower than error of the Frechet distributions after the 70^{th} order statistic. Figure 6.35 and Figure 6.36 show that the Frechet distribution has the lowest error when compared to the Weibull or Generalized EV distribution up to the 40^{th} order, but Weibull or Generalized EV distribution has the lowest error after the 40^{th} order. Further, the fitted Inverse Generalized EV distribution's error gradually decreases as the order statistic increases.

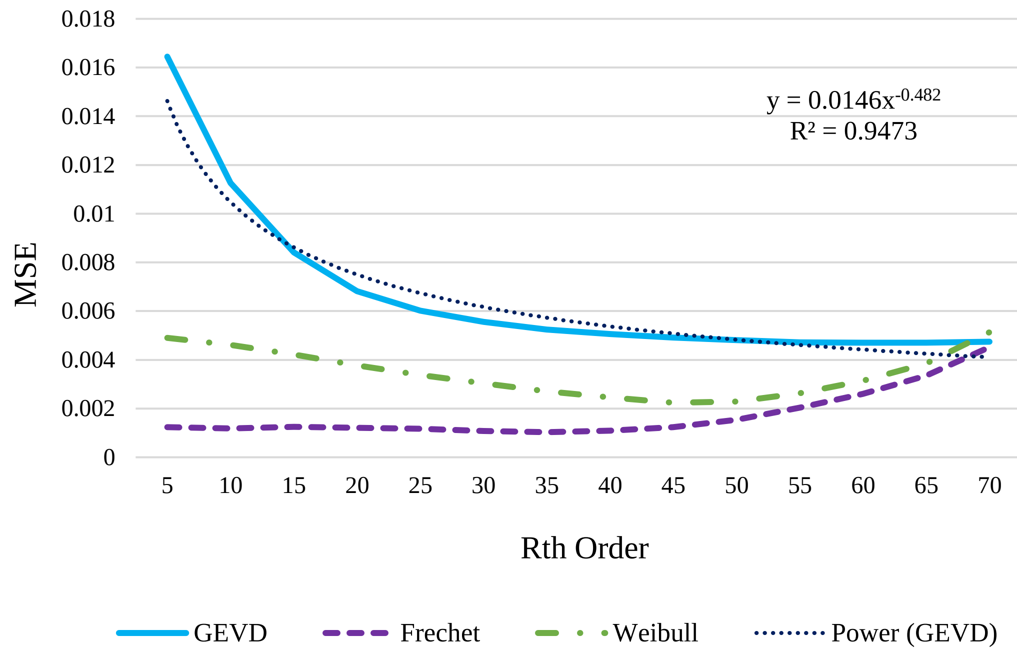


Figure 6.33 MSE distribution for the Fitted CDF and the Empirical CDF of R^{th} order extremes

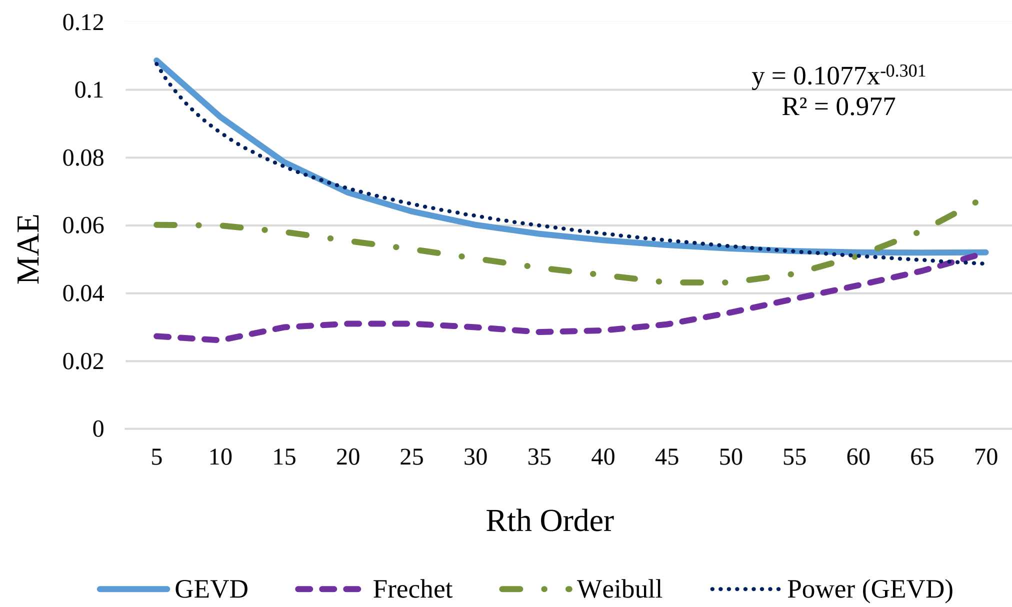


Figure 6.34 MAE distribution for the Fitted CDF and the Empirical CDF of R^{th} order extremes

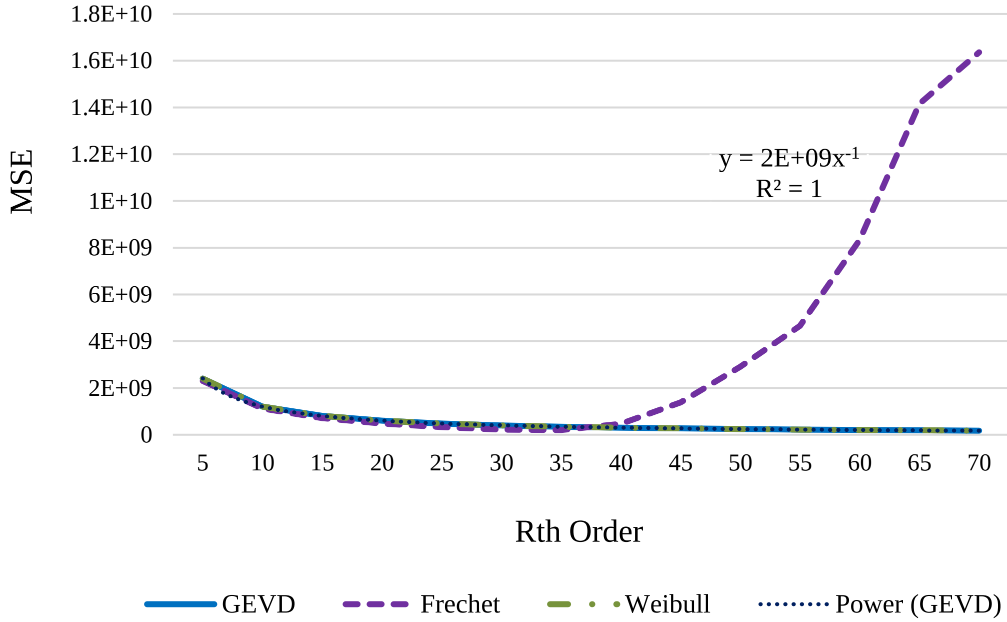


Figure 6.35 MSE distribution of the Fitted inverse CDF and the inverse Empirical CDF of R^{th} order extremes

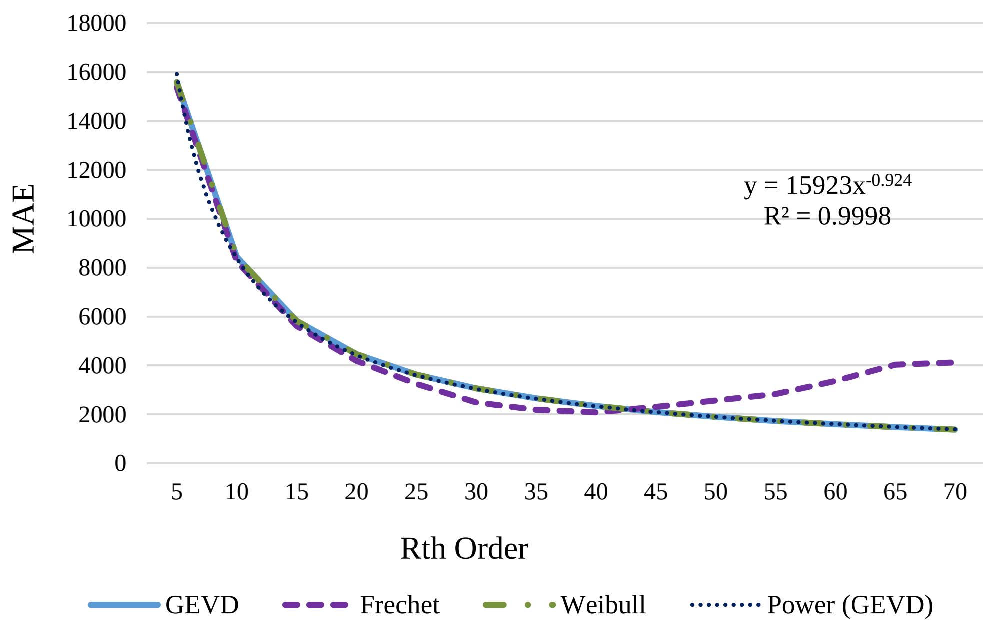


Figure 6.36 MAE distribution of the Fitted inverse CDF and the inverse Empirical CDF of R^{th} order extremes

In addition, the fitted power functions for the GEVD's errors and Inverse GEVD's errors as shown in Figure 6.33 to Figure 6.36 with more than 0.94 R^2 values confirmed that the errors of fitted GEVD's decrease as the order statistic increases. The GEVD's 70th order was selected to estimate the probabilities of severe natural disasters because the rate of change of errors decreases as the Rth order increases; the minimum error (compared to the Frechet and Weibull distribution) of the cumulative GEVD and the inverse cumulative GEVD obtained are at the 70th order; and these errors are significantly small.

Table 6.6 shows the estimated probabilities and the sample probabilities of severity level 1 to 10, and the level boundaries are defined by using the log scale. The full sample dataset from 1977 to 2013, and the 70th order statistic extreme dataset was used to calculate sample probabilities for severity levels. The 70th order statistic sample for extreme events represents 9.07% of the full dataset. The estimated probabilities of severity levels were calculated using the fitted 70th order Frechet and Weibull distribution, and the GEVD.

Out of these 10,807 sample events, two events did not have fatality records. Thus, when considering the remaining 10,805 sample events, only 69.58% of the full dataset had at least one fatality, as shown in Table 6.6, while 30.42% of events recorded zero fatalities. In addition, 12.44% of extreme events of the 70th order sample recorded zero fatalities. Moreover, the Frechet, the Weibull, and the GEVD estimated 0.80%, 9.38%, and 22.99% probabilities for zero fatalities, respectively. When comparing the estimated probabilities for higher severity levels Weibull distribution gives significantly lower probabilities when compared to GEVD and Frechet distributions. On the other hand, the estimated probabilities of Frechet distribution for the last three levels (level 7 to 10) were significantly higher compared to Weibull, and GEVD. For example, 2 out of 10,000 severe natural disasters can be considered as severity level 10 events according to the fitted Frechet distribution.

Table 6.6 Estimated probabilities of Severity Levels according to the Fitted Frchet, Weibull, and GEVD distribution for 70th order statistic

	Fatality Range	Full Sample*	70th Order			
			Frechet	**Weibull**	**GEVD**	**Sample****
1	$1 \le F < 10$	23.87 %	19.72 %	13.71 %	4.20 %	15.71 %
2	$10 \le F < 100$	34.36 %	39.01 %	27.27 %	29.11 %	29.37 %
3	$100 \le F < 1{,}000$	9.75 %	24.85 %	34.21 %	39.37 %	33.33 %
4	$1{,}000 \le F < 10{,}000$	1.36 %	10.21 %	14.75 %	7.75 %	7.78 %
5	$10{,}000 \le F < 0.1M$	0.17 %	3.61 %	0.68 %	0.72 %	0.95 %
6	$0.1M \le F < 1M$	0.07 %	1.21 %	$1.66*10^{-04}$ %	0.06 %	0.42 %
7	$1M \le F < 10M$	0 %	0.40 %	$3.77*10^{-14}$ %	$4.99*10^{-03}$ %	0 %
8	$10M \le F < 100M$	0 %	0.13 %	$6.94*10^{-40}$ %	$4.13*10^{-04}$ %	0 %
9	$100M \le F < 1B$	0 %	0.04 %	$1.45*10^{-108}$ %	$3.41*10^{-05}$ %	0 %
10	$1B \le F < 10B$	0 %	0.02 %	$7.618*10^{-292}$ %	$3.08*10^{-06}$ %	0 %

* Sample of historical data from 1977 to 2013 (10805 events out of 10807 records)
** Sample of extremes in the 70th order statistic (980 events out of 10807 records)

In addition, when compared to the estimated probabilities of Frechet and Weibul distributions, the estimated probabilities of GEVD are closer (and more reliable) to the 70th order sample probabilities for higher severity levels. Table 6.6 illustrates that 5 out of 0.1 million severe natural disasters can be considered as severity level 7 events, 4 out of 1 million severe natural disasters can be considered as severity level 8 events, 3 out of 10 million severe natural disasters can be considered as severity level 9 events, and 3 out of 100 million severe natural disasters can be considered as severity level 10 events, according to the fitted GEVD. Moreover, when compared to the estimated probabilities of Weibull, Frechet, and GEVD, the estimated probabilities of GEVD are closer (and more reliable) to the 70^{th} order statistic sample probabilities for levels 2 and levels 4 through 10, while the estimated probabilities of the Weibull distribution are closer to the sample probabilities for levels 1 and 3. Considering all these facts, the fitted GEVD of 70^{th} order statistic are used to calculate the approximate stabilizing probability values of severity levels.

In summary, the stabilization of the parameters of each extreme value distribution after a certain minimum order statistic, are emphasized that the R^{th} order extreme value distribution (Frechet and/or GEVD) gives the close approximate probabilities of severity levels. Additionally, though the Frechet cumulative distribution has the lowest error (both MSE and MAE), when compared to the cumulative distribution errors of GEVD (or Weibull) for each order statistic, up to the 70^{th} order, the errors increase for the Frechet (and Weibull) distribution as the order statistic increases, while the errors decrease (and stabilizes after 70^{th} order statistic) for GEVD. Similarly, though the Frechet inverse cumulative distribution has the lowest error (for both MSE and MAE) when compared to the Generalized EV (or Weibull) up to the 40^{th} order, the Generalized EV (or Weibull) inverse cumulative distribution has the lowest error after the 40^{th} order. Similar to cumulative errors, the Frechet inverse cumulative errors increases as the order statistic increases, while GEVD inverse cumulative errors decreases and stabilizes as the order statistic increases. This indicates that 70^{th} order statistic can be considered the minimum threshold order statistic; and is GEVD is a better fit when compared to Frechet or Weibul for each extreme dataset.

Moreover, the comparison of the estimated probabilities for each severity level with respect to the 70th order the Frechet, the Weibul, and the GEVD is emphasized so that the fitted GEVD 70th order statistics probability can be considered as the approximate estimated probability values of severity levels. This is because the 70th order GEVD estimated probabilities are closer (and more reliable) to the sample probabilities for all levels. Also, the 70th order GEVD has the minimum error compared to other distributions. Therefore, the 70th order GEVD was chosen as the best fit distribution of extremes to calculate severity levels. The CDF of the fitted 70th order GEVD as shown in Equation 6.41 together with the sample CDF are shown in Figure 6.37. Note that the probabilities of Figure 6.7 are truncated because the cumulative probability value of zero fatalities is 0.18 and the sample probability of zero fatalities is 0.12.

$$F(x) = e^{-\left[1+\gamma\left(\frac{x_i-\mu}{\sigma}\right)\right]^{\frac{-1}{\gamma}}}; \text{where } \mu = 44.396;\ \sigma = 106.06;\ \gamma = 0.92393$$

Equation 6.41

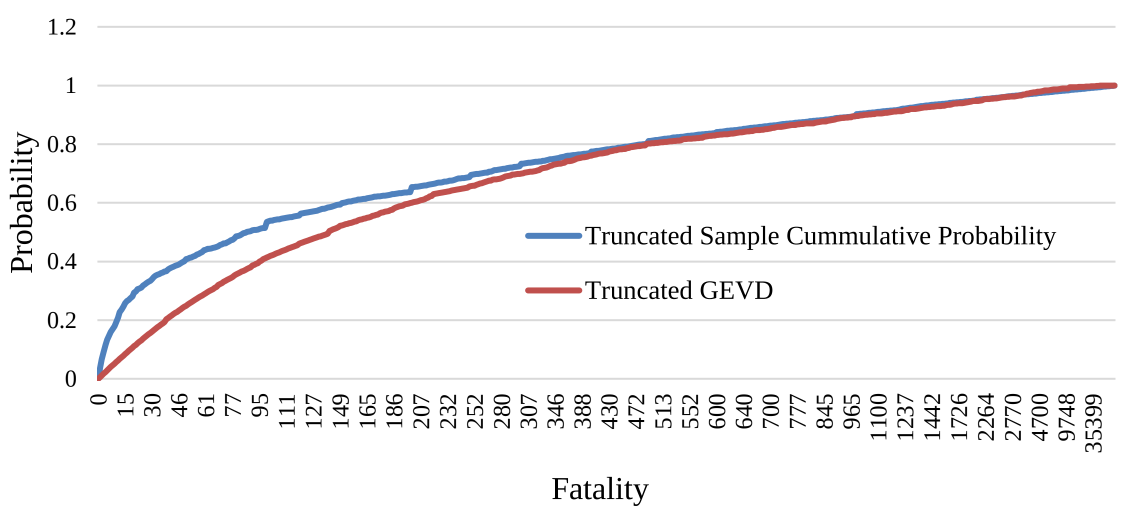


Figure 6.37 Cumulative sample distribution of fatalities with an approximate 70th order GEVD

The Step 3B of the methodology combined quantitative measure and the UDSC, was addressed by combining Table 4.3 and Table 6.6 as shown in Table 6.7. The estimated probabilities in this table was are calculated using the 70th order statistic GEVD. The magnitude of the proposed disaster severity scale is evaluated based on the logarithm of the fatalities. Since the severe events are rare, the log scale is well-suited because the probability of a very high classification is low. According to the analysis, severe natural disasters are most likely to fall into Disaster Type 2; 40% of the severe disasters will have 100 to 1,000 fatalities. The next major natural disaster will have a about 7.8% chance of being between 1,000 and 10,000 deaths.

Table 6.7 Initial Quantitative Universal Disaster Severity Classification

Bridge of UDSC	**Quantitative Technique**	
	Fatality Range	Probability*
UDSC 1	$1 \leq F < 10$	4.20 %
UDSC 2	$10 \leq F < 100$	29.11 %
UDSC 3	$100 \leq F < 1{,}000$	39.37 %
UDSC 4	$1{,}000 \leq F < 10{,}000$	7.75 %
UDSC 5	$10{,}000 \leq F < 0.1M$	0.72 %
UDSC 6	$0.1M \leq F < 1M$	0.06 %
UDSC 7	$1M \leq F < 10M$	$4.99*10^{-03}$ %
UDSC 8	$10M \leq F < 100M$	$4.13*10^{-04}$ %
UDSC 9	$100M \leq F < 1B$	$3.41*10^{-05}$ %
UDSC 10	$1B \leq F < 10B$	$3.08*10^{-06}$ %

* Estimated approximate probabilities according to the Fitted GEVD of 70th order statistic

6.2.3 Proposed technique to measure the severity of a natural disaster

The last step of measuring the severity of a natural disaster is to combine the proposed (initial) quantitative technique with the proposed UDSC and the proposed qualitative techniques (i.e., Step 4 in Section 1.5) as shown in Table 6.8. An example event representing each severity level is also given in Table 6.8.

Table 6.8 Combination of UDSC with quantitative and qualitative techniques

Qualitative Technique	Bridge of UDSC	Quantitative Technique		Example
		Fatality Range	Probability *	
Emergency	UDSC 1	$1 \leq F < 10$	4.20 %	A small landslide that kills one person
Disaster Type 1	UDSC 2	$10 \leq F < 100$	29.11 %	Edmonton tornado, Canada - 1987 - 27 deaths
Disaster Type 2	UDSC 3	$100 \leq F < 1{,}000$	39.37 %	Thailand flood – 2011 - 815 deaths
Calamity Type 1	UDSC 4	$1{,}000 \leq F < 10{,}000$	7.75 %	Hurricane Katrina, USA – 2005 - 1833 deaths
Calamity Type 2	UDSC 5	$10{,}000 \leq F < 0.1M$	0.72 %	Tohuku earthquake and tsunami, Japan - 2011 - 15882 deaths
Catastrophe Type 1	UDSC 6	$0.1M \leq F < 1M$	0.06 %	Haiti earthquake - 2010 – 316.000 deaths
Catastrophe Type 2	UDSC 7	$1M \leq F < 10M$	$4.99*10^{-03}$ %	China floods - 1931 – more than 2,500,000 deaths
Cataclysm Type 1	UDSC 8	$10M \leq F < 100M$	$4.13*10^{-04}$ %	Black death pandemic - from 1346 to 1353
Cataclysm Type 2	UDSC 9	$100M \leq F < 1B$	$3.41*10^{-05}$ %	Super Volcano (e.g. Yellowstone) – less than 1 billion estimated deaths
Partial or Full Extinction	UDSC 10	$1B \leq F < 10B$	$3.08*10^{-06}$ %	Meteor strike (diameter > 1.5 Km) - less than 1.5 billion estimated deaths Pandemic (Avian influenza) – less than 2.8 billion estimated deaths

* Estimated approximate probabilities according to the Fitted GEVD of 70th order statistic

As a qualitative technique, each level, or category, is labeled using the proposed order of the words for disasters, from 'Emergency' up to 'Partial or Full Extinction' (Solution 1 in Section 5.5.1.1). Given the vast range of fatalities, each of the events have been sub-divided into 'Disaster', 'Calamity', 'Catastrophe', and 'Cataclysm' into Types 1 and 2. The proposed definitions for these terms, emergency, disaster, calamity, catastrophe, and cataclysm in Table 6.8, are defined on the basis of the descriptions and definitions in well-known dictionaries, and commonly accepted understandings (see Table 5.8).

As a (initial) qualitative technique, severity levels are measured using the most influential factor – fatality. The magnitude of the proposed fatality-based disaster scale is evaluated based on the logarithm of the fatalities because the probability of a very high classification is low for severe natural disasters because these events are rare (Table 6.7). The estimated probabilities of these severity levels are calculated by using the approximate stabilization probabilities of best-fitted GEVD distribution.

The quantitative and qualitative techniques described above are combined using the bridge of the proposed UDSC. UDSC colour-coding is also used to represent the severity levels in order to eliminate language barriers and confusion that could arise due to the diverse meanings of the words. This makes it easier to explain the seriousness of the disaster to citizens of distinct countries and languages by using a colour-coding scheme.

Example events for each level are shown in this table. According to the considered data set the maximum fatality record was 300,000, which falls into Catastrophe Type 1. However, according to the fitted 70^{th} order GEVD, it is expected that 5 in 1 million severe events are Catastrophe Type 2 or higher disasters. This estimate is reasonable considering events which were not included such as China's 1931 flood with more than 2.5 million deaths (Catastrophe Type 2) and the Black death pandemic, with more than 20 million fatalities (Cataclysm Type 1). There are many studies on super volcano and meteor strikes; they have estimated the number of deaths that might occur and those probabilities are very low.

The minimum level of the scale, 'emergency', accounts for a situation when there is at least one fatality and less than ten fatalities. The highest level 'Partial or Full Extinction' is defined when fatalities exceed one billion. The severity level of the most extreme disaster that occurred, and for which data is available, is categorized as Catastrophe Type 2 (China flood in 1931 where more than 2.5 million deaths were recorded). However, a Cataclysm Type 1 or higher disaster with 0.000005 probability is expected according to the fitted GEVD distribution. Although there is geographical evidence of Cataclysm Type 1 or higher natural disasters that have occurred in the past, there are no historical records that could be considered for the probability estimation process of these events.

Nevertheless, disasters such as a meteoroid impact have the potential to vary from 'Emergency' (UDSC 1) to 'Partial or Full Extinction' (UDSC 10). It ranges from a small meteor strike that explodes in the atmosphere, to a large asteroid that collides with the earth causing extinction-level impacts. Although, there are no recorded fatalities caused by meteoroid impact, the falling of "meteoroids" has gained much attention after the Russian meteor strike in 2013 that injured more than 1,000 people. Analyzing the risk and response to unimaginable but not impossible events that have the potential of causing the extinction of the human race are curtailed as there are no historical records though there are geographical records of events that have occurred in the past.

6.2.3.1 Disaster Classification

Table 6.9 to Table 6.13 illustrate the levels covered by each disaster according to the historical sample data considered from 1977 to 2013. It covered 59 categories of natural disasters and the list of disasters has been ordered to show the increasing coverage of the scale and group by their main type. According to this classification, local disasters cover the lower levels, whereas the disasters with potential regional- or global-level impacts cover the upper levels. An insect infestation such as Grasshopper or Locust did not report any fatalities. Hence, it does not have the ability to reach the UDSC 1 seriousness level, Emergency. On the other hand, tropical cyclones, tsunamis, earthquakes, and drought have the ability to reach the UDSC 6 seriousness level (Catastrophe Type 1). Biological events have the ability to reach UDSC 4, Hydrological events have the ability to reach UDSC 5, and Climatological, Geophysical, and Meteorological events have the ability to reach UDSC 6.

Table 6.9 Disaster Classification of Biological disasters using sample data

Main Type	**Insect infestation**	**Epidemic**			
Category	Grasshopper/ Locust	Viral Infectious Diseases	Parasitic Infectious Diseases	Bacterial Infectious Diseases	Other Epidemic
UDSC 1		√	√	√	√
UDSC 2		√	√	√	√
UDSC 3		√	√	√	√
UDSC 4		√	√	√	√
UDSC 5					
UDSC 6					
UDSC 7					

'√' - levels covered by a disaster

Table 6.10 Disaster Classification of Climatological disasters using sample data

Main Type	**Extreme temperature**					**Wildfire**				**Drought**
Category	Icing	Freezing Rain	Cold wave	Extreme winter conditions	Heat wave	Other Wildfire	Scrub/ Grassland fire	Bush/ Brush fire	Forest fire	Drought
UDSC 1	√	√	√	√	√	√	√	√	√	√
UDSC 2		√	√	√	√	√	√	√	√	√
UDSC 3			√	√	√			√	√	√
UDSC 4				√	√					√
UDSC 5					√					√
UDSC 6										√
UDSC 7										

'√' - levels covered by a disaster

Table 6.11 Disaster Classification of Geophysical disasters using sample data

Main Type	**Mass Movement Dry**								**Seismic Activity**			**Volcano**
Category	Other Mass Movement Dry	Debris flow	Sudden Subsidence	Mud slide	Snow Avalanche	Rock fall	Avalanche	Landslide	Other Seismic Activity	Tsunami	Earthquake (ground shaking)	Volcanic eruption
UDSC 1	√	√	√	√	√	√	√	√	√	√	√	√
UDSC 2	√	√	√	√	√	√	√	√	√	√	√	√
UDSC 3					√	√	√	√		√	√	√
UDSC 4										√	√	√
UDSC 5										√	√	√
UDSC 6										√	√	
UDSC 7												

'√' - levels covered by a disaster

Table 6.12 Disaster Classification of Hydrological disasters using sample data

Main Type	**Flood**					**Mass Movement Wet**							
Category	General flood/Mudslide	Storm surge/ coastal flood	General Flood	Other Flood	Flash flood	Other Mass Movement Wet	Snow Avalanche	Rock fall	Debris flow	Avalanche	Sudden Subsidence	Mudslide	Landslide
UDSC 1	√	√	√	√	√	√	√	√	√	√	√	√	√
UDSC 2	√	√	√	√	√	√	√	√	√	√	√	√	√
UDSC 3		√	√	√	√				√	√	√	√	√
UDSC 4			√	√	√								√
UDSC 5					√								
UDSC 6													
UDSC 7													

'√' - levels covered by a disaster

Table 6.13 Disaster Classification of Meteorological disasters using sample data

Main Type	**Storm**												
Category	Extratropical cyclone (winter storm)	Blizzard	Thunderstorm	Snow storm	Extratropical cyclone	Sandstorm	Local storm	Dust storm	Hail storm	Severe storm	Tornado	Other Storm	Tropical cyclone
UDSC 1	√	√	√	√	√	√	√	√	√	√	√	√	√
UDSC 2	√	√	√	√	√	√	√	√	√	√	√	√	√
UDSC 3							√	√	√	√	√	√	√
UDSC 4												√	√
UDSC 5													√
UDSC 6													√
UDSC 7													

Main Type	**Storm**					
Category	Blizzard/ Tornado	Severe storm/ Hail storm	Snow storm and Sand storm	Blizzard/ Dust storm	Sand/ Dust storm	Snow storm/ Blizzard
UDSC 1	√	√	√	√	√	√
UDSC 2		√	√	√	√	√
UDSC 3					√	√
UDSC 4						
UDSC 5						
UDSC 6						
UDSC 7						

'√' - levels covered by a disaster

All type of disasters classified in preliminary analysis (Table 6.4) except lightning were included in the detailed analysis. Lightning was not included as there was no record of lightning data in EM-Dat database that has at least one fatality records from 1977 to 2013. Both preliminary analysis and detailed analysis have similar categorization for tornadoes, volcanic eruptions, earthquakes and tsunamis. However, the detailed analysis has categorised flash flood up to UDSC 6, which is one level up when compared to the preliminary analysis categorization. In contrast, detailed analysis has categorised forest fires and tornadoes up to UDSC 3, which are one level down for both forest fires and tornadoes when compared to the preliminary analysis categorization. In addition, the detailed analysis has categorised land slide and flood up to UDSC 4, which is two levels down for land slides and three levels down for flood when compared to the preliminary analysis categorization.

However, it is noted that this extreme fatality analysis used historical events from 1977 to 2013 recorded in the EM-Dat database, where fatalities have not exceeded 300,000 (Catastrophe Type 1). In addition, as mentioned previously, the database records depend on the country (e.g., 2004 boxing day tsunami data are not recorded as one event but 12 different events because 12 different nations were affected). Moreover, there might be events before 1977 (e.g., the 1931 China flood reached the Catastrophe Type 2), or if conditions change, there may be future events that exceed these numbers. Therefore, predictions from the model need to consider possibilities outside the proposed UDSC range, and must be used with caution because decision makers may believe them to be absolute.

In addition, I have not paid attention to simultaneous disaster events (e.g., an earthquake and tsunami striking, or the impact of a hurricane and peripheral tornadoes, on the same area) in this analysis. Such events can cause the classification to progress one or more levels. Additionally, infrastructure failure can be added to an event or simultaneous events. The nuclear plant failure subsequent to the Great North East Japan Earthquake and Tsunami illustrates compounding events. A meteoroid impact on land close to population centers, or into the ocean (causing massive tsunamis hundreds of meters high), or major infrastructure failures subsequent to some other natural cataclysm, could cause millions of fatalities. Further, I have not considered extinction-level events, such as a major asteroid strike.

Although the analysis is subject to many limitations, it provides a good foundation to develop an advanced multi-dimensional scale in order to classify disaster occurrences worldwide based on a combination of several independent factors. This analysis also provides an overall picture of the scale of each type of disaster. With this kind of a scale, it is easy to recognize an event occurrence and enter it into a database.

6.3 Discussion

The Universal Disaster Severity Classification (UDSC) proposed in this chapter, can be used to measure the severity of a natural disaster. The UDSC will serve as a bridge between qualitative and quantitative techniques used in emergency management systems. Qualitative and quantitative techniques can be integrated to produce management and size measurement systems respectively (see Figure 4.1) as discussed in Chapter 4.

Use of the English words with colour coding and fatality-based disaster scale proposed in this chapter, are used as a case studies to show how qualitative and quantitative techniques are combined using the proposed universal UDSC, which combine the management system and size measurement systems.

Each level of the proposed UDSC is named using the proposed order of the commonly used words that describes the various magnitude of a disaster, from ‘Emergency’ to ‘Partial or Full Extinction’. The magnitude is evaluated based on the nonlinear, logarithmic fatalities, thus, moving up the scale requires an order of magnitude increase in the severity of the disaster as it diversely affects people or an ecosystem. It is meaningful because the probability of a very high classification is low for severe natural disasters as the events are rare.

In formulating a scale, a certain degree of arbitrariness is unavoidable; therefore, the scale is not totally objective. For example, levels or categorization can be separated into various hierarchical levels depending on the intended application or disaster. What is important is the relative comparison among various disaster degrees.

By using the proposed UDSC introduced in Table 6.8 and disaster classification in Table 6.9 through Table 6.13, it is easy to compare and contrast different types of disasters. Moreover, by knowing the expected probabilities according to historical disasters, disaster managers and emergency responders can have a clear sense of the scale of the severity of each type of disaster. This knowledge can be used to deploy the needed resources when disaster strikes.

6.4 Conclusion

This initial scale provides an overall picture of the severity of natural disasters, as well as a set of criteria that can be employed to make comparisons for all types of disasters. This enable ranking according to severity in order to help governments and relief agencies quickly respond when disaster strikes.

According to the method used in this work, “fatalities” is the most influencing common impact factor to introduce an initial scale. However, using the initial scale with one factor only addresses one aspect of the disaster, as noted previously. For, example fatal disasters are better represented using this scale; however, do not address the economic impact of a disaster. There is currently no severity measurement available to capture the other aspects, such as affected population, number of evacuees, number of houses damaged or destroyed. Therefore, a method needs to be created to measure the severity combining all the impact factors. The severity of extreme events should then be analysed according to their importance or relationship with the factors and the severity. As the data is not available to test the proposed method, the people’s perspective regarding the severity should be measured from this instrument (Fatality-based disaster scale).

Chapter Seven: ANALYSIS OF DIFFERENT TYPE OF DISASTERS USING THE INITIAL UNIVERSAL DISASTER SEVERITY CLASSIFICATION

In this chapter, *Deliverable X* is achieved and the *research sub-question c(ii) (i.e., how does this substitute quantitative technique adequately compare the severity level of natural disasters?),* is further answered in Sections 7.1.2 and 7.2.

7.1.1 Separate analysis for each disaster

The proposed UDSC provides a set of criteria to compare all types of disaster that occur anywhere in the world at any time. To better understand the disaster continuum, the overall picture of severity by different type of disaster is helpful as well as the depth analysis of the severity of each type of disaster. In other words, though the estimated overall probabilities clarify the overall picture of the different types of disasters, the estimated probabilities for each type of disaster provides a better understanding of each type of disaster. Also, this information would be more helpful to compare the same type of disaster in different parts of the world or in the same place but during different time periods, etc. Therefore, a depth analysis has been conducted of extreme fatalities for several types of disasters.

By using the proposed UDSC, a separate analysis for tornadoes, volcanic eruptions, earthquakes, and tsunamis was conducted. Volcanic eruptions and tornado disasters were selected to for a detailed separate analysis. In this chapter, the same data sets that were used to analyse the relationship between impact factors and severity in Section 3.3 for tornadoes, volcanic eruptions, earthquakes, and tsunamis are used.

7.1.1.1 Tornadoes

Before conducting the extreme value analysis for tornado fatalities, stationarity of the fatality data was tested. A stationary process, guarantees that its statistical properties, such as the mean value and variance, do not change over time. It is a process whose probability distribution for a fixed time is the same for all time periods. Figure 7.1 shows the plotted fatality data over time.

A stationary time series has no predictable patterns in the long-term. In other words, a stationary time series has an unchanging casual structure. It is uncertain why the observed minor variations occurred in Figure 7.1, however, there is no trend or cyclic variation to be seen; hence, data stationarity is assumed for tornado fatalities. Therefore, it is reasonable to assume that the results obtained from extreme probability distributions for North American data from 1996 to 2013 is the same for all time periods.

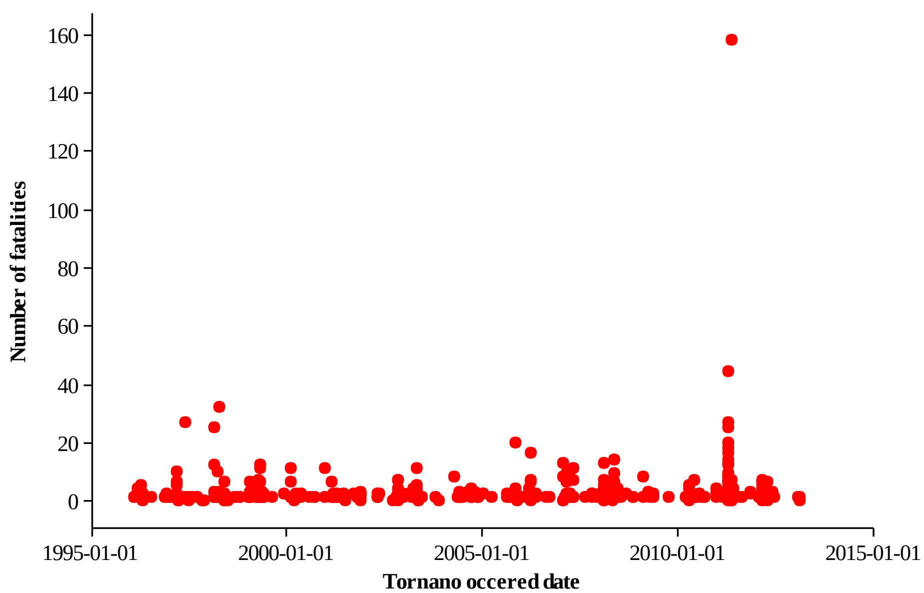


Figure 7.1 Scatter plot of fatalities over time

Strong and violent tornadoes develop infrequently because the required environmental conditions rarely occur (Brooks 2013). However, these types define the destructive capacity of tornadoes. They are at the tail end of the above defined probability distribution, and extreme value theory helps to study their behaviour. Determining the extreme value distribution (EVD) is essential to evaluate the probability of extreme tornado events. Two different methods: block maxima and peak over threshold method were used to analyse the extreme fatalities of tornadoes.

7.1.1.1.1 Extreme value analysis: block maxima model

Each thunderstorm is comprised of several tornadoes; therefore, each thunderstorm is considered a unique block to apply the extreme value theory to the block maxima model. In this approach, different data sources such as Wikipedia (2013) and REPORTER (2011) are used to group the tornadoes within the thunderstorm. According to this approach, there were 87 tornado outbreaks (each outbreak contained one or more tornadoes with a fatality) in 18 years (from 1996 to 2013) identified in North America; the tornado with the maximum fatality recorded in each outbreak is considered in the extreme value analysis to evaluate the extreme value distribution of tornado fatalities. That is, each tornado outbreak is considered as a single block.

Maximum likelihood estimators (MLE) are used to determine the distribution parameters using Xtremes 4.1 software (Reiss and Thomas 2007). More details are available in Section 6.1.5. As shown in Equation 7.1, the fitted distribution for fatalities is Frechet (α=1.14213, μ=0, σ=2.01878). Figure 7.2 shows the histogram of fatalities and the fitted Frechet distribution plotted in the same graph.

$$F(x_i) = \begin{cases} 0 & \text{for } x_i < 0 \\ e^{-\left(\frac{x_i}{2.019}\right)^{-1.142}} & \text{for } x_i \geq 0 \end{cases}$$

Equation 7.1

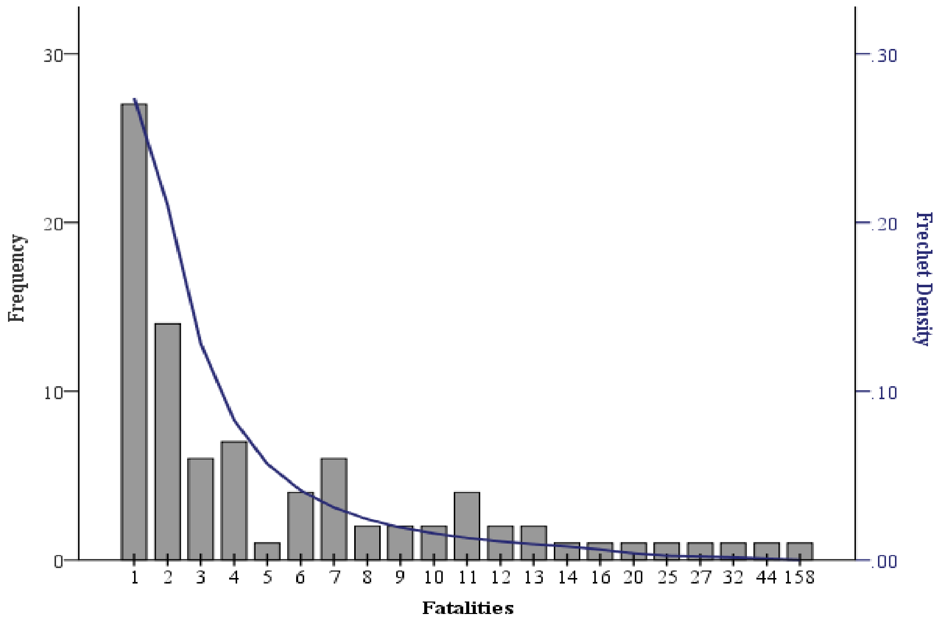


Figure 7.2 Histogram of extreme fatalities per outbreak for Tornadoes in the block maxima model with a fitted Frechet distribution

Figure 7.3 demonstrates the return level plot for the fitted distribution. It can be estimated that a tornado that causes 100 fatalities has a return number of 85 outbreaks, and a tornado that causes 150 fatalities has a return number of 135 outbreaks. In this study, the R^{th} order statistic model is not used, as there was enough data (87 tornado outbreaks) for a block maxima model.

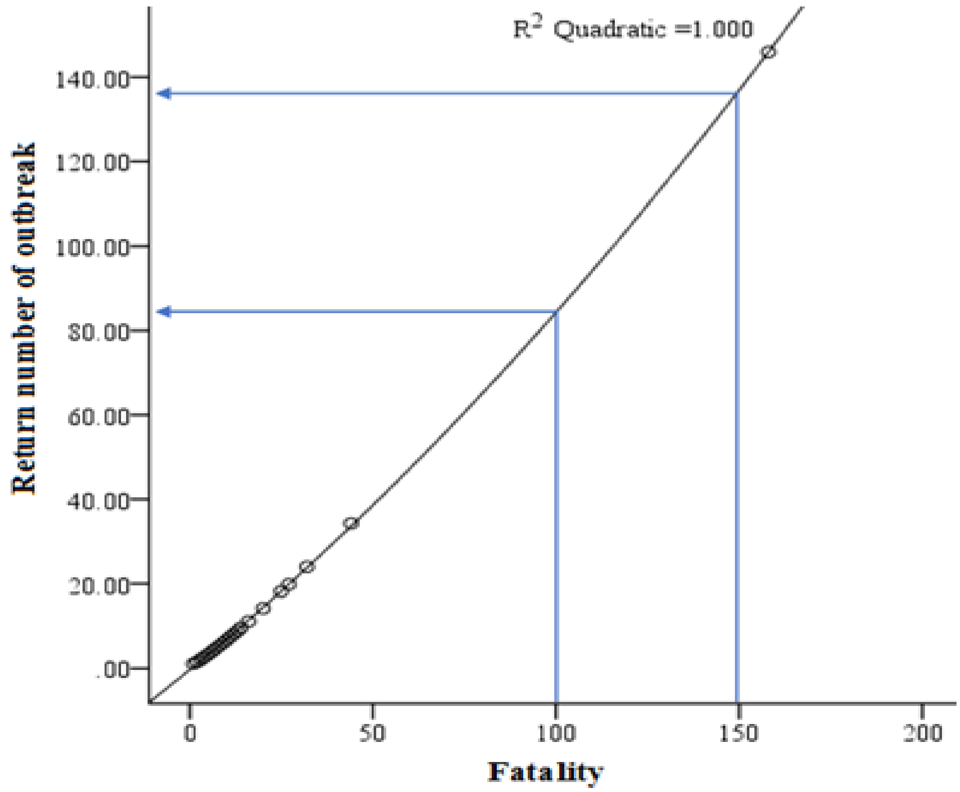


Figure 7.3 Return level plot

7.1.1.1.2 Extreme value analysis: peak over threshold model

The peak over threshold method has limitations, but they are different from those of the block maxima method. In block maxima, the choice of block size implies a balance between bias and variance. In block maxima and Rth order statistic, excessively wide block sizes generate fewer numbers of extreme values that are likely to have small variance. Excessively narrow block sizes generate larger numbers of extreme values that are likely to have high variance. Therefore, the block size needs to be handled with care. Similarly, in the peak over threshold model, too low a threshold is likely to violate the asymptotic basis of the model leading to bias; too high a threshold generates too few values above the threshold that the model can use to estimate the probability distribution of extremes which leads to a high variance (Coles 2001). Different methods were applied to select the threshold value u_0 in the peak over threshold model as follows.

A mean residual plot helps in the estimation process of the threshold, u_0. For u> u_0, E(X-u/ X>u) is a linear function of u, and E(X-u/ X>u) is the mean of the values that exceed the threshold, u. The sample mean of the threshold values above u provides an empirical estimate, and these estimates are expected to change the linearity of E(X-u/ X>u) at some value of u along the u-axis. The value of u at which linearity changes is the suitable threshold value for which the generalized Pareto model is appropriate (Coles 2001). The mean residual plot equals $\left\{\left[u, \frac{1}{n_u}\sum_{i=1}^{n_u}(x_{(i)} - u)\right] : u < x_{max}\right\}$, in which x(1), …x($n_u$) consists of the n_u observations that exceed u. Figure 7.4 shows the mean residual plot for the number of fatalities. The graph is approximately linear from u=0 to u= 18; it is also approximately linear after u= 18, but with a steep slope. This change in slope suggests that u_0=18 is a threshold; however, only nine values exceed the threshold u=18, and, consequently, there are too few data points to make meaningful inferences.

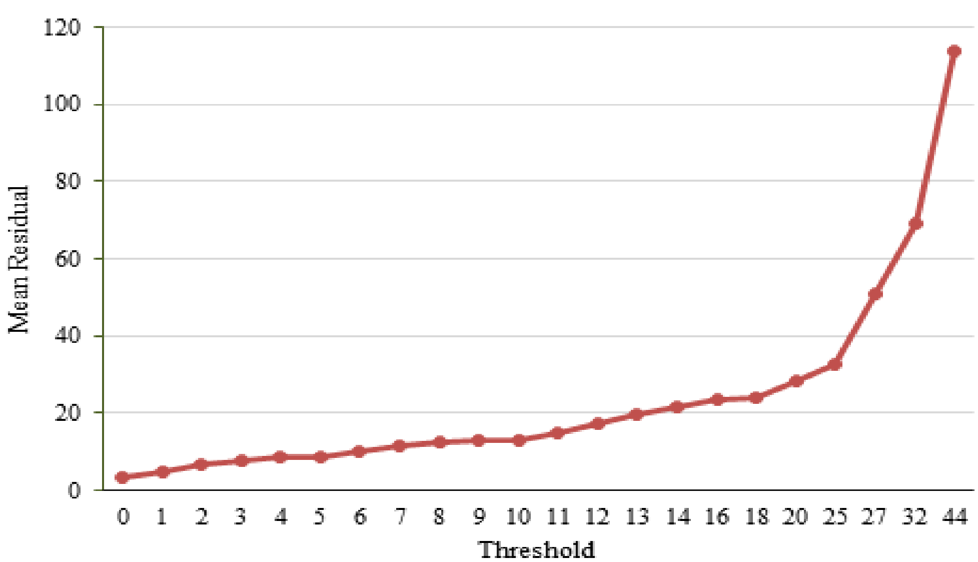


Figure 7.4 Mean residual plot

Another method for selecting the threshold is to use the ratio of k to n (k/n), where k is the number of tail data and n is the total number of data points; k/n should be equal to 0.02 for $50 < n \leq 500$ and k/n should equal 0.1 for $500 < n < 1000$ (Boos 1984). According to this method, k is 10 because n=500. Consequently, the threshold, u_0, is 16; however, there are just ten values that exceed the threshold $u_0=16$, which is too few to make meaningful inferences. Hasofer (1996) suggests that k can be taken to equal approximately $1.5\sqrt{n}$. In that method, k is equal to 33.54. When the threshold is equal to 7, 38 data points exceed the threshold. However, the threshold should be selected by balancing bias and variance. Therefore, the finite sample mean square error (MSE) method for threshold value selection (Caers and Maes 1998), which is a summation of both square bias and variance (Equation 7.2), was chosen as the best method for assessing the stability of parameter estimates based on fitting the models across a range of different thresholds. Minimizing the MSE would balance the bias and variance because the MSE is the sum of both the square bias and variance.

$$\mathrm{MSE}(\hat{\theta}) = E\left[\left(\hat{\theta} - \theta\right)^2\right] = \left(E\left[\hat{\theta}\right] - \theta\right)^2 + E\left[\left(\hat{\theta} - E\left[\hat{\theta}\right]\right)^2\right] = bias^2(\hat{\theta}) + var(\hat{\theta})$$

Equation 7.2

Out of several different estimation methods, the finite sample mean square error (MSE), which is a summation of both square bias and variance, was chosen as the best method to assess the stability of parameter estimates based on the models that best fit the data across a range of different thresholds. Several different estimation methods were used to estimate parameters; parameters of the distribution need to be known to estimate MSE. MLEs were used to determine the distribution parameters of the general Pareto distribution

(GP); MLE and Hill estimators were applied estimate the Pareto distribution (GP1) using the Xtremes 4.1 software. In addition, EasyFit 5.0 Professional software also estimated the GP parameters. Figure 7.5 shows that the sample MSE for different threshold values, which are calculated using the inverse GP and inverse GP1 equations and Equation 7.3, was employed to calculate the MSE values. Figure 7.5 indicates that the calculated MSE values for GP and GP1, using MLE, are identical; hence, the data follows the Pareto distribution. Figure 7.5 demonstrates that the minimum MSE is obtained when the threshold equals one for all estimators. Consequently, if more than one fatality occurred during a tornado outbreak, that tornado is an extreme event. Although Easyfit 5.0 professional software gives the minimum MSE most of the time, Table 7.1 shows that Xtreme 4.1 calculates the MLE, which yields a minimum MSE of the threshold equal to one. Tornadoes with more than one fatality are considered when evaluating the MLE and to estimate the parameters of threshold u_0 =1, 172.

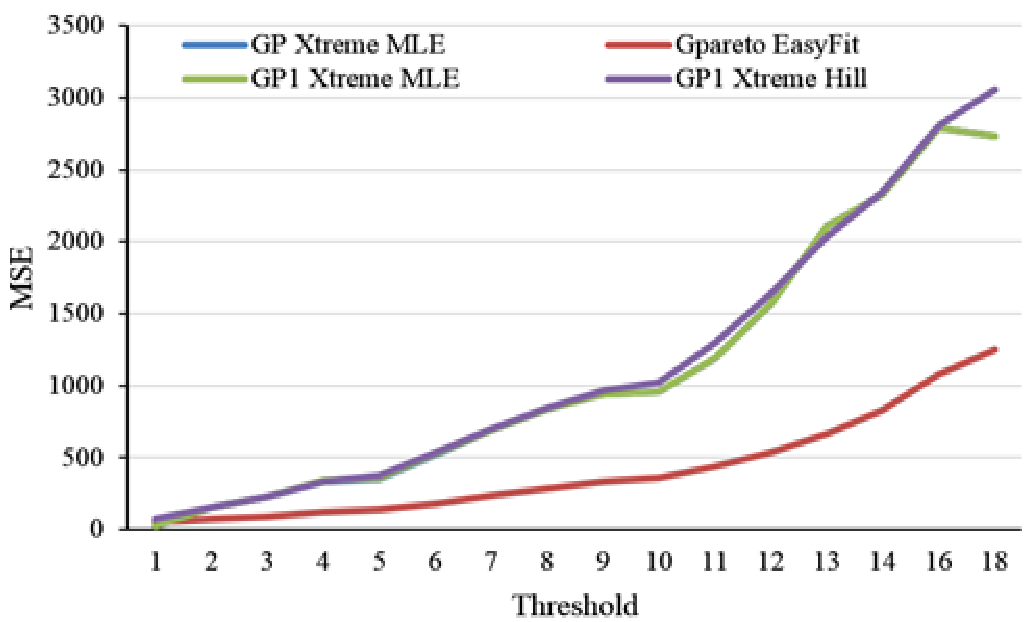


Figure 7.5 Mean square errors for different threshold values

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2$$

Equation 7.3

Table 7.1 MSE values for thresholds equal to one

Peak Over Threshold	GP1 Xtreme MLE	GP1 Xtreme Hill	GP Xtreme MLE	GP EasyFit
1	28.926	77.669	28.925	50.471

The minimum MSE is obtained when the threshold equals one and the data follows the Pareto distribution. Consequently, if more than one fatality occurred during a tornado outbreak, that tornado is an extreme event. Therefore, 172 tornadoes exceed one fatality and, therefore, follow the Pareto distribution with a shape parameter (α) = 0.878, scale parameter (σ) = 0.308, and location parameter (μ) = 0.963 (Equation 7.4). Moreover, the Pareto distribution is bounded below at 1 (Reiss and Thomas 2007). Figure 7.6 shows the histogram of fatalities with a fitted Pareto distribution plotted in the same graph.

$$F(x) = \begin{cases} 1 - \left(\dfrac{x - 0.963}{0.308}\right)^{-0.878} & , x > 1 \\ 0 & , x \leq 1 \end{cases}$$

Equation 7.4

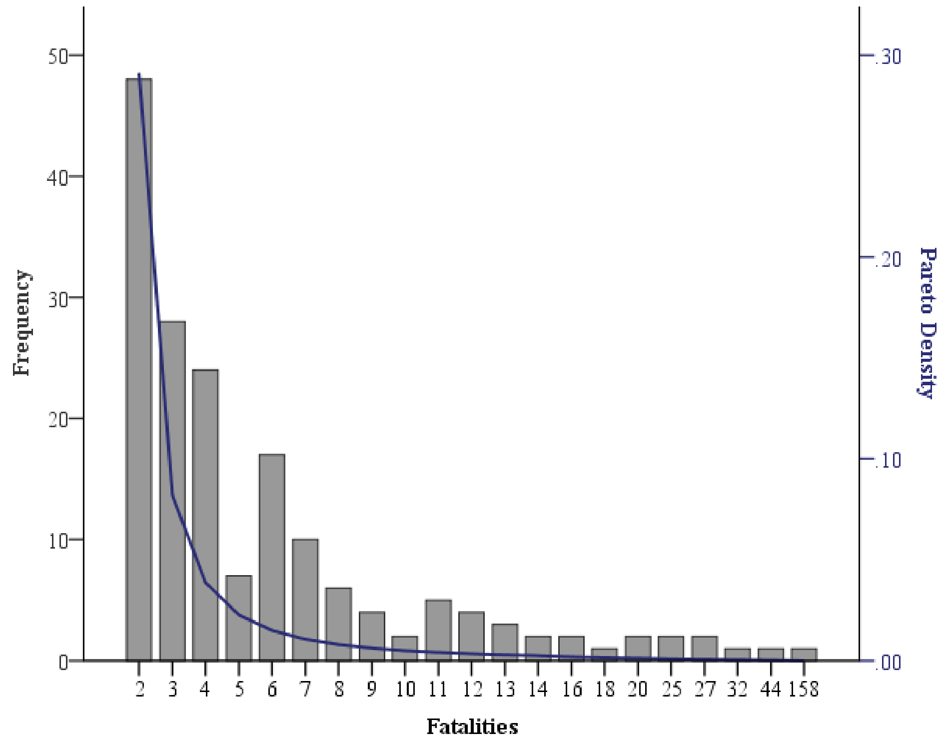


Figure 7.6 Histogram of fatalities in the peak over threshold model with a fitted Pareto distribution

7.1.1.1.3 Estimated probabilities for severity levels

This section examines how severity levels are related to the number of fatalities, specifically by defining the intervals, ranges, or boundaries of number of fatalities, which differentiate one severity level from the other. A fitted extreme value distribution can be applied to arrange the severity levels. Further, a logarithmic scale is used to differentiate the levels in the UDSC for all types of natural disasters. In the first four columns of Table 7.2, a severity scale for tornadoes is presented, which combines the fitted extreme value distribution for tornadoes and the UDSC. However, the defining ranges in the fatality-based disaster scale should be justifiable.

Table 7.2 Probabilities of a tornado to be of the given type

Severity Level	Fatality Range	Estimated Probability		Sample Probability	
		Block Maxima	Peak Over Threshold	Exclude zero fatality	Include zero fatality
Emergency	1 ≤ F < 10	0.851*	0.949	0.940	0.882*
Disaster Type 1	10 ≤ F < 100	0.137	0.045	0.058	0.054
Disaster Type 2	100 ≤ F < 1,000	0.011	0.005	0.002	0.002
Calamity Type 1	1,000 ≤ F < 10,000	0.001	0.001	0	0
Calamity Type 2 and higher	10,000 ≤ F	0.00006	0.0001	0	0

* Include zero fatality

In the block maxima and peak over threshold models in Table 7.2, the probability of tornadoes decreases with an increase in the severity of a tornado outbreak. More simples, the probability of a very high classification is low for severe tornadoes as these events are rare. More severe tornadoes have a higher classification according to the scale. Therefore, an increase in the severity ranges by a power of 10, as the level increases in the logarithmic scale, can be justified by the fact that the probability of such events is rare. In addition, the base 10 measurement is justifiable because it is meaningful. According to the considered data set, North American tornadoes have been classified as high as Disaster Type 2 as the maximum fatality record is 158; however, according to the extreme value probability, there is a 0.01% chance that a Calamity Type 2 tornado, or higher, will occur.

There are 31 tornadoes in the sample that have no associated fatalities. Sample probabilities, including and excluding tornadoes that have no fatalities, are also shown in Table 7.2. The probability of an emergency with zero fatalities is less than emergencies with more than one fatality, as indicated in Table 7.2. However, the severity scale is introduced for tornadoes that have fatalities. Therefore, the sample probabilities with more than one fatality are compared with the models. The peak over threshold model is more suitable than the block maxima model in this tornado analysis as the peak over threshold model reflects the studied sample severity levels for three reasons.

First, the initial severity level starts from one fatality: the block maxima model estimates 10.745% of tornadoes have zero fatalities because its range starts at zero; the peak over threshold model estimates 0% of tornadoes have either 0 or 1 fatality because its range begins at two. According to the block maxima model, 85% of tornadoes are classified as an emergency, while the peak over threshold model estimates 95% as an emergency with fatality rates between 1 and 10. Fourteen percent of tornadoes are Disaster Type 1 in the block maxima model compared to only 5% in the peak over threshold model. For Disaster Type 2, the block maxima estimate 1% compared to 0.5% in the peak over threshold model. The block maxima model assigns a higher probability of Disaster Type level 1 and 2 than the peak over threshold model; a similar probability was estimated for Calamity Type 1 tornadoes. Both models estimate that 0.07% of tornadoes are Calamity Type 1. Second, when zero fatalities are excluded in the sample probabilities, the sample probabilities are closer in value to the estimated probabilities in the peak over threshold model. Third, both models indicate that 7 in 10,000 tornadoes in North America have the ability to reach Calamity Type 1, although there is no evidence in the dataset from 1996 to 2013 in North America. One example of a Calamity Type 1 tornado occurred in 1989 in Bangladesh, which had 1,300 fatalities.

Table 7.2 indicates that Calamity Type 2 and higher is the uppermost severity level because tornadoes are local events and, therefore, extensive damage does not occur. Further, a tornado with such a high severity has not occurred before. Consequently, 0.011%

and 0.006% of tornadoes are classified as Calamity Type 2 and higher according to the peak over threshold and block maxima models, respectively. The peak over threshold model estimates a higher probability of occurrence of Emergency level and Calamity Type 1 level tornadoes than the block maxima model. Thus, the peak over threshold model has a high probability around the mean and then sharply declines with more probabilities in the higher value range (thicker right tail) when compared with the block maxima model. A sample probability, with or without zero fatalities, is closer to the estimated peak over threshold model probability than the estimated block maxima probability, which justifies the suitability of the peak over threshold model.

7.1.1.1.4 Summary of tornado data analysis

Tornadoes and tornado outbreaks are more common in North America when compared to the rest of the world. Therefore, North American tornadoes from 1996 to 2013 were taken as a sample to analyze the severity of tornadoes and tornado outbreaks around the world. Damage, which is one of the variables to consider in a multi-dimensional scale, was covered in the EF scale. However, the correlation coefficient between the EF scale and damage is 0.32. The correlation coefficient between the EF scale and both fatalities and injuries is close to 0.34. The low values of the correlation coefficients demonstrate that there is not enough evidence to confirm a linear relationship between the three variables and the EF scale. As explained in Chapter 3 and shown in Figure 3.8 to Figure 3.10, a relationship between the impact factors and the EF scale is not apparent. In addition, there is not enough evidence to confirm a nonlinear relationship between the EF scale and the impact factors. A correlation between tornado factors, such as length and width, does not show a direct relationship to fatalities, injuries, or damage. As a result, the damage caused to humans is only partially assessed by the existing scale; the EF scale simply assesses the damage to the environment and property. The EF scale is an indication of the strength of a tornado, but not the severity of a tornado. Therefore, the EF scale is not suitable to differentiate between the severity levels of a tornado and a new scale should be introduced to define the severity levels by using fatalities, injuries, or damage. Damage in dollars closely relates to time and inflation. Injuries can range from minor to severe, but the terms 'minor,' 'moderate,' and 'severe,' are ambiguous. In contrast, death is permanent, and populations are most sensitive to disastrous events with high fatalities. Therefore, the number of fatalities for a given population density becomes the best choice among the variables.

The potential severity levels of tornadoes were studied using extreme value theory. To analyze the extreme fatalities of tornadoes, two models were considered; the block maxima and peak over threshold models. In general, the block maxima give a full range of scale without bounding to minimum extremes; the peak over threshold model sometimes restricts the full range of data, but this restriction did not occur in this specific situation. The interpreter has the responsibility to make a decision depending on the situation, as one model cannot be preferred for all scenarios. The highest fatality tornado within each outbreak was analyzed using the block maxima model as one method to study extreme fatalities. The extreme values of fatalities for 87 tornado outbreaks from 1996 to 2013 in the USA are shown to be distributed as a Frechet (α=1.142, μ=0, σ=2.019) distribution. A total of 172 individual tornadoes with more than one fatality were selected to be used as data in a second method. These fatalities in the peak over threshold model are distributed as a Pareto (α = 0.878, μ = 0.963, σ = 0.308) distribution.

Both models justify the logarithmic scale introduced as a fatality-based disaster scale (UDSC). The probability of a tornado outbreak is decreased in both models as the level increases; therefore, the severity levels in Table 7.2 introduce a way to measure the severity of a tornado. This measurement is justifiable because it is meaningful; an increase in the severity ranges as the severity level increases is reasonable, as the probability of such events is rare. The block maxima model gives a fair distribution of the probability of tornado outbreaks, though the method omits some valuable extremes and requires the evaluation of artificial blocks. Conversely, the peak over threshold model exaggerates some probabilities when compared to the block maxima, but considers the extreme values. In this particular data set, the peak over threshold model considers almost all the tornadoes that caused more than one fatality. Hence, the peak over threshold model results are preferred over the block maxima model, because they better explain the real situations that occurred in North America from 1996 to 2013. Columns 1, 2, and 4 from Table 7.2 are duplicated in Table 7.3 and represent the fatality-based severity scale for tornadoes. Historical examples of global tornadoes are also classified up to a Calamity Type 1 as shown in Table 7.3. The maximum fatality is 158, classified as Disaster Type 2, in the considered data set of North American tornadoes that occurred between 1996 and 2013. The tornado that occurred in 1989 in Bangladesh that resulted in 1,300 fatalities is the most extreme tornado event for which data is available, and can be categorized as a Calamity Type 1 in the fatality-based severity scale. However, 11 out of 100,000 tornadoes have the ability to reach a Calamity Type 2 or higher, according to the fitted Pareto distribution in the peak over threshold model.

Table 7.3 A Fatality-based severity scale for tornadoes

Severity Level	Fatality Range	Estimated Probability	Global Tornado Event
Emergency	$1 \leq F < 10$	0.949	Saroma, Hokkaidō Tornado, Japan (2006)- 9 deaths
Disaster Type 1	$10 \leq F < 100$	0.045	Marshfield MO Tornado, USA (1930)- 99 deaths
Disaster Type 2	$100 \leq F <$ 1,000	0.005	Bangladesh Tornado, Bangladesh (1969)- 923 deaths
Calamity Type 1	$1{,}000 \leq F <$ 10,000	0.001	Daulatpur-Salturia Tornado, Bangladesh (1989)- 1,300 deaths
Calamity Type 2 and higher	$10{,}000 \leq F$	0.0001	-

In conclusion, the results show that the EF scale, which is an indication of the strength of a tornado, is not suitable to differentiate between the severity levels of a tornado. Consequently, a new scale should be introduced to define the severity levels using fatalities, or injuries, or damage. Table 7.3 shows the fatality-based severity scale for tornadoes according to the results of an extreme value analysis of tornado fatalities.

7.1.1.2 Volcanic Eruptions

Separate analysis to describe the severity of volcanic eruption also done using the 236 volcanic eruption which have at least one eruption in the NOAA database.

7.1.1.2.1 Extreme Value Analysis: block maxima model

In the block maxima method each volcano is considered as one block and the full lifetime of the volcano is considered as the width of each block. Therefore, only the maximum fatality recorded for each volcano is considered for extreme value data analysis (e.g., in terms of volcanic effects, the Mount Tombora 1815 eruption recorded 10,000 fatalities, the Mount Krakatoa 1883 eruption recorded 2,000 fatalities and so on). The fatality records which are blank in the database represent either no fatality or no record found, and are not considered. Accordingly, extreme fatality recorded eruptions for 136 volcanoes are shown to be distributed as a 3 parameter Weibull (α=0.33925, μ= 1, σ= 109.04) distribution (Equation 7.5) with sample mean 1202.81, sample variance 4251.75 and the maximum 30,000. Figure 7.7 shows the histogram of the extreme fatality volcano effects and the fitted Weibull (3P) density (dashed line). R^{th} order statistic method is not used in the volcano study because there are enough data (136) for the extreme fatality analysis.

$$F(x) = 1 - e^{-\left(\frac{x-1}{109.40}\right)^{0.33925}}$$

Equation 7.5

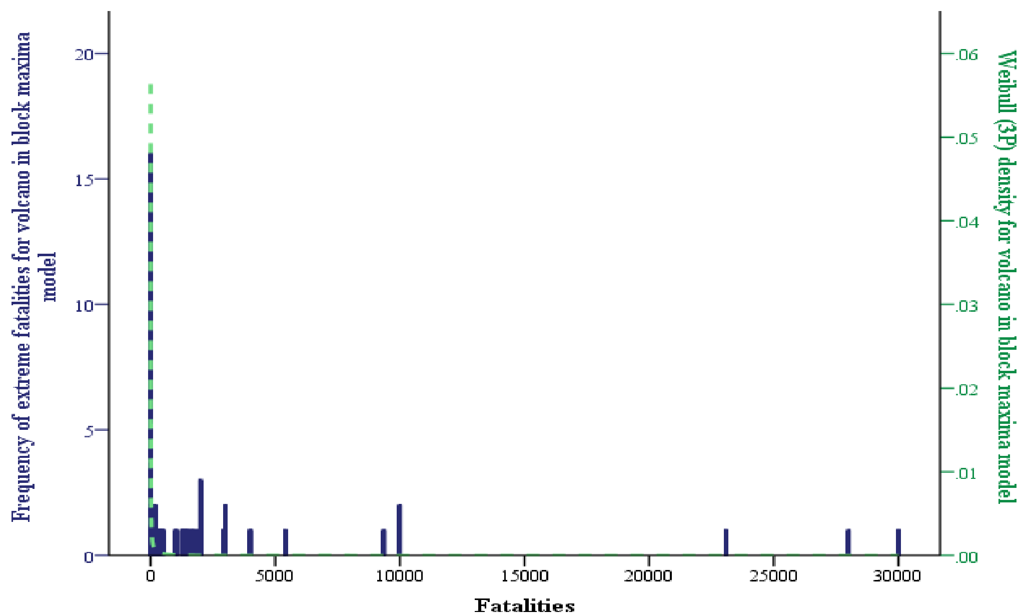


Figure 7.7 Histogram of extreme fatalities for volcano in block maxima model and the fitted density

7.1.1.2.2 Extreme Value Analysis: peak over threshold model

Figure 7.8 shows the mean residual plot for the number of fatalities. The graph is approximately linear from u=0 to u ≈ 153, beyond which it appears to curve until u ≈ 10,000, whereupon it decays sharply. There is no stability until u = 10,000, after which there is approximate linearity. Thus, u_0 = 10,000, but there are only three exceedances of the threshold u_0 = 10,000, resulting in too little data to make meaningful inference. Moreover, the information in the plot for large values of u is unreliable due to the limited amount of data on which the estimates are based. The second procedure for threshold selection is to estimate the threshold value approximately equal to $1.5\sqrt{n}$ as suggested by Hasofer (1996). Accordingly, a threshold is set at u_0 = 26.28 where there are 307 eruption records with at least one fatality. There are 113 volcano eruptions that exceed 26 fatalities and follow the Pareto distribution (Figure 7.9) with a shape parameter (α) = 0.41937, and scale parameter (σ) = 27 as shown in Equation 7.6.

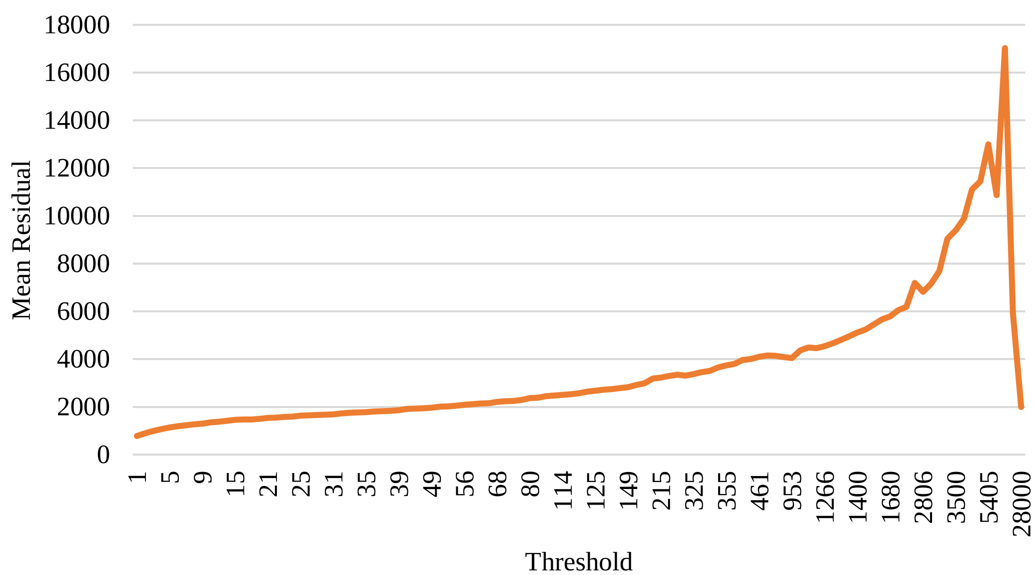


Figure 7.8 Mean residual plot

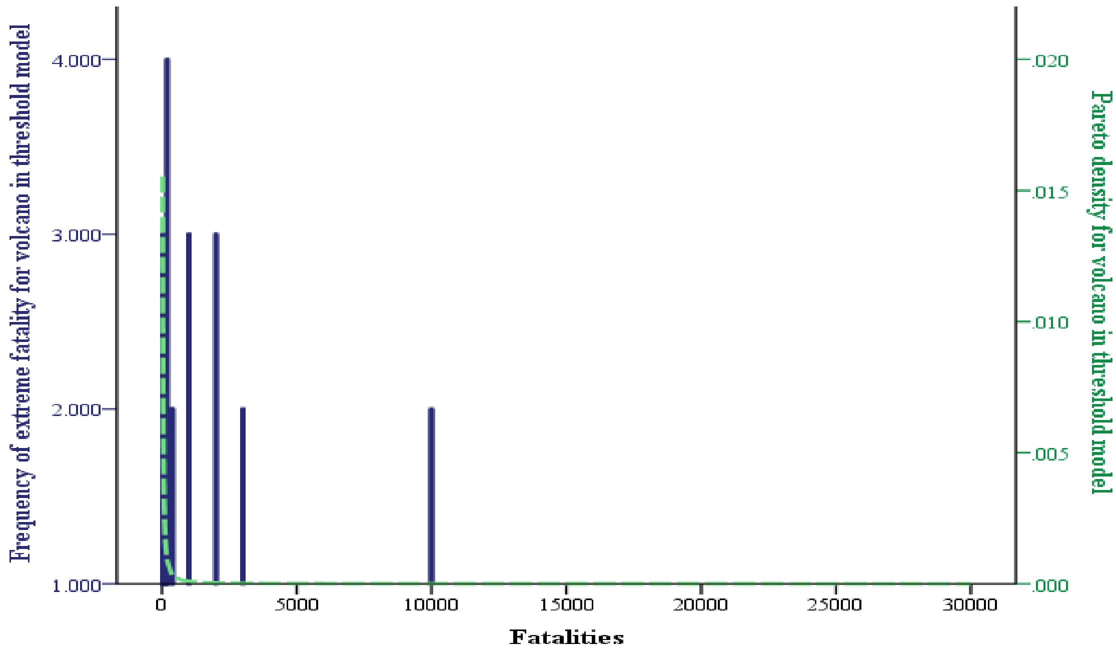


Figure 7.9 Histogram of extreme fatalities for volcano effects and the fitted Pareto density (dash line)

$$F(x) = 1 - \left(\frac{27}{x}\right)^{0.41937}$$

Equation 7.6

7.1.1.2.3 Estimated probabilities for severity levels

According to the fatality-based disaster scale severity boundaries given in Table 7.4, the estimated probabilities of extreme volcano eruptions are calculated using the best fitted Weibull distribution and Pareto distribution as shown in Table 7.4. Sample probabilities of volcano disaster are also calculated for severity levels of the fatality-based disaster scale, using the 307 eruption records that have at least one fatality. In the block maxima and peak over threshold models in Table 7.4, the probability of volcanic eruptions decreases with an increase in the severity of a volcanic eruption. Similar to the tornado analysis, the probability of a very high classification is low for severe volcanic eruptions, as these events are rare. More severe eruptions have a higher classification according to the scale. Therefore, an increase in the severity ranges by a power of 10 can be justified by the fact that the probability of such events is rare.

Expected Pareto probability is higher than the expected Weibull probabilities as it considers all eruptions which have more than 26 fatalities. In contrast, Weibull distribution has the full range of expected fatalities, although it does not consider all of the extreme fatality records. Weibull probabilities are closer to sample probabilities than Pareto probabilities. According to the fitted Weibull distribution for volcanic eruptions, 35 percent of the eruptions are the Emergency Type; 27% and 26% of eruptions are Disaster Type 1 and 2, respectively; and 11% and 1% of eruptions are Calamity Type 1 and 2, respectively (Table 7.4).

Table 7.4 Probability of an eruption to be of the given type

Type	**Fatality Range**	**Sample probability**	**Expected Probability**		**Example**
			Block Maxima	**Peak Over Threshold**	
Emergency	$1 \leq F < 10$	0.531	0.35	-	Nabro volcano, Eritrea (2011) – 7 deaths
Disaster Type 1	$10 \leq F < 100$	0.225	0.27	0.423*	Marapi volcano, Indonesia (1975) – 80 deaths
Disaster Type 2	$100 \leq F < 1{,}000$	0.130	0.26	0.358	Pinatubo volcano, Philippines (1991) – 450 deaths
Calamity Type 1	$1{,}000 \leq F < 10{,}000$	0.098	0.11	0.136	Lamington volcano, Papua New Guinea (1951) – 2942 deaths
Calamity Type 2	$10{,}000 \leq F < 100{,}000$	0.0163	0.01	0.052	Ruiz volcano, Colombia (1985) – 23080 deaths
Catastrophe Type 1 and higher	$100{,}000 \leq F <$ 1M	0	0.00004	0.032	-

$^*27 \leq F < 100$

The severity level of the most extreme volcanic eruption for which data is available (450 A.D. -Ilopango, El Salvador, 30,000 fatalities) can be categorized as Calamity Type 2. However, expected probabilities indicate that volcanic eruptions can be even more destructive. For example, 4 in 100,000 eruptions have the ability to reach the Calamity Type 1 or higher, according to the fitted Weibull distribution, whereas the estimate is 3 in 100 according to the fitted Pareto distribution. Note that the probabilities calculated according to the fitted extreme value distributions, are conditional probabilities because the considered volcanic eruption caused at least one fatality. Volcanic eruptions can vary from Emergency to the Calamity Type 2 level. However, unusually large (super volcanic) eruptions have the potential to exceed the above-mentioned levels, and can possibly cause a Calamity or even a Partial or Full extinction.

7.1.1.2.4 Summary of volcanic eruption data analysis

Volcanic eruption records were also employed to test the relationship between the intensity scales and the impact factors. There were 652 volcanic eruptions from 4360 B.C. to 2014 A.D. in the NOAA database. As volcanic eruptions have an ability to trigger earthquakes, tsunamis or landslides, there are conjoint impacts as well as direct impacts recorded in the database. Therefore, the relationship between the "direct volcanic effects" and "total effects" were also studied. The results showed an excellent linear relationship with the corresponding variable for volcanic effects and total effects with $\rho > 0.9$ for all pairs. That means the volcanic effect can be used to test the hypothesis. To address the multicollinearity effect, the relationship between impact factors was also studied. The damage measured in millions of USD has a very good linear relationship with houses damaged (ρ=0.9), which means that damaged can be explained using houses damaged and vice versa. As damage in dollars closely relates to time and inflation, it is omitted from the models, while keeping the houses damaged in the models. Other pairs, that is, fatalities and injuries, fatalities and houses damaged, and injuries and houses damaged, are not highly correlated but have a moderate to good relationship ($0.5 \leq \rho < 0.75$). Therefore, fatalities, injuries and houses damaged were used to find the relationships between the VEI scale and other impact factors that represent the human impact of an eruption. Ordinal logistic regression analysis was employed because the VEI is an ordinal categorical variable ranging from 0 to 8. The results highlight the fact that individual variables of fatalities, injuries and houses damaged are better than the combinations of the above variables in explaining the relationship with the VEI scale. Moreover, one variable becomes significant with the presence of another variable, because of the multicollinearity between two variables. Therefore, there might be evidence of an unexplainable component in this relationship.

In conclusion, the results show that the VEI scale can only partially evaluate the severity, which means a scale is required to compare the impact of a volcanic eruption, as well as to compare different disasters. Table 7.4 shows the fatality-based severity scale for volcanic eruptions according to the results of an extreme value analysis of volcanic eruption fatalities.

7.1.2 Combined analysis

Extreme fatality analysis was also conducted for earthquake and tsunami, similar to the above tornado disasters and volcano eruption analysis. By considering block maxima and peak over threshold models, the probabilities of extreme disaster events were calculated for the severity levels introduced in a fatality-based disaster scale. Table 7.5 shows the summarized version of the probabilities for expected extreme volcanoes, earthquakes, tsunamis and tornadoes. The same concept can be applied to any type of disaster. Using this classification, makes it easier to compare and contrast disasters, such as volcanoes, earthquakes, tsunamis, and tornadoes.

According to the block maxima method (fitted Weibull distribution), 2 in 1,000 extreme tsunamis or earthquakes can have more than 1 million fatalities (i.e., Catastrophe Type 2 or higher events), although there are no historical events to confirm this. Extreme tsunamis have the highest probability of being a Catastrophe Type 2 severity level, when compared to volcanic eruptions, earthquakes and tornadoes, according to the peak over threshold model which considers all of the worst disaster records. In contrast, because tornado are local events, they have the least probability (0.01%) to be a Calamity Type 2 or higher event, when compared to the worst disaster records for volcanic eruptions, earthquakes and tsunamis. When compared to the Earthquake probabilities for Catastrophe Type 1, there is a 5% chance that the most severe earthquake in a specific country will be Catastrophe Type 1, whereas, there is a 18% chance that the most severe earthquake will be Catastrophe Type 1. When, comparing these two probabilities with R^{th} order statistic model, there is 16% chance that the most severe earthquake from next 100 earthquakes will be Catastrophe Type 1.

Table 7.5 Expected probabilities of volcanic eruptions, earthquakes, tsunamis and tornadoes based on the block maxima model

<table>
<tr><th rowspan="2">Type</th><th rowspan="2">Seriousness level and colour code</th><th rowspan="2">Fatality Range</th><th colspan="2">Volcano</th><th colspan="2">Earthquake</th><th colspan="2">Tsunami</th><th colspan="2">Tornado</th></tr>
<tr><th>Weibull</th><th>Pareto</th><th>Weibull</th><th>Pareto</th><th>Weibull</th><th>Pareto</th><th>Weibull</th><th>Pareto</th></tr>
<tr><td>Emergency</td><td>UDSC 1</td><td>$1 \leq F < 10$</td><td>0.35</td><td>-</td><td>0.24</td><td rowspan="4"></td><td>0.11</td><td rowspan="3"></td><td>0.74</td><td>0.949</td></tr>
<tr><td>Disaster Type 1</td><td>UDSC 2</td><td>$10 \leq F < 100$</td><td>0.27</td><td>0.423[*]</td><td>0.13</td><td>0.14</td><td>0.14</td><td>0.045</td></tr>
<tr><td>Disaster Type 2</td><td>UDSC 3</td><td>$100 \leq F < 1000$</td><td>0.26</td><td>0.358</td><td>0.16</td><td>0.26</td><td>0.01</td><td>0.005</td></tr>
<tr><td>Calamity Type 1</td><td>UDSC 4</td><td>$1000 \leq F < 10000$</td><td>0.11</td><td>0.136</td><td>0.24</td><td>0.32</td><td>77.7[#]</td><td>$8*10^{-4}$</td><td>0.001</td></tr>
<tr><td>Calamity Type 2</td><td>UDSC 5</td><td>$10000 \leq F < 0.1M$</td><td>0.01</td><td>0.052</td><td>0.18</td><td>0.817[‡]</td><td>0.16</td><td>19.7</td><td rowspan="3">$6*10^{-5}$ [a]</td><td rowspan="3">$1*10^{-4}$ [a]</td></tr>
<tr><td>Catastrophe Type 1</td><td>UDSC 6</td><td>$0.1M \leq F < 1M$</td><td>$4*10^{-5}$</td><td>0.02</td><td>0.05</td><td>0.176</td><td>0.01</td><td>2.3</td></tr>
<tr><td>Catastrophe Type 2 and higher</td><td>UDSC 7</td><td>$1M \leq F$</td><td>0</td><td>0.012</td><td>0.002</td><td>0.007</td><td>0.002</td><td>0.27</td></tr>
</table>

[*] $27 \leq F < 100$; [‡] $30000 \leq F < 100000$; and [#] $2000 \leq F < 10000$; [a] Calamity Type 2 and higher

7.2 Discussion

Three different models: the block maxima, R^{th} order statistic, and peak over threshold methods are used to analyse extreme natural disasters based on fatalities, for the purpose of determining a severity scale and classification. Depending on the application, different models are suitable. For example, the block maxima estimated probabilities based on a country are useful to evaluate the probability of the worst tsunami that local authorities/governments should consider for preparation, while the block maxima or the R^{th} order statistic based on location is useful for planners to use to evaluate the probability of the worst tsunamis that could occur during the next 150 years, which should be considered for building codes and safety. The same concept can be applied to any type of disaster including floods, windstorms, convective storms, snowstorms, wildfires, cyclones, and so on.

7.3 Conclusion

This analysis provides an overall picture of the severity of each type of disaster, as well as a set of criteria used to make comparisons for all types of disasters and to rank them to help governments and relief agencies respond quickly when disaster strikes.

Chapter Eight: DISCUSSION AND CONCLUSIONS

This chapter presents a detailed review of the contributions made by this research to the current knowledge of disaster management field, outlining the applications including proposals to improve the disaster information management, to improve emergency response management (as the *Deliverable XI*). The thesis concludes with discussions on the research limitations, recommendations and directions for the possible future research.

8.1 Discussion

In this section, the answers to the research questions specified in the Chapter 1 are discussed. Additionally, a summary of the results of this research are compared to the results of other existing methods.

The two key research questions are: 1) how many levels are required to clearly differentiate the impact of natural disasters? and 2) how are these levels used to clearly distinguish the various degrees of natural disasters?

There is possibly no straightforward answer to the first question, because the size of impact of a disaster is a complex mixture of different factors (human, economic, social, regional, and so on), and some of these factors are spatially and temporally dependent (e.g., damage, population density, available technology, education levels of locals), and have wide range. Therefore, the number of levels required to measure the impact depend on the application. However, considering only humans and their possessions, that is, representing wide ranges of both human factors [according to the world's population is 7.347 billion (World Bank 2015)] and material damage impact factors [according to maximum Gross Domestic Product (GDP) in 2014 is 78.089 trillion USD (World Bank 2016)], the log scale is used and ten different levels are considered in designing a classification for disaster impact (see Table 4.1 and Table 4.2).

The second question is "How are these levels used to clearly distinguish the various degrees of natural disasters?" The levels require clearly distinguishable degrees of severity, which is satisfied by the Universal Disaster Severity Classification proposed in Table 8.1, based on consistent quantitative (fatality ranges) and qualitative (clear order and definitions) methods, combining Table 6.8 and Table 5.8. Clear definition is achieved by combining both improved quantitative and qualitative techniques. In addition, UDSC colour-coding is used to represent the severity levels in order to eliminate language barriers and confusion that could arise due to diverse meanings of the words. This makes it easier to explain the seriousness of the disaster to citizens of distinct and diverse countries and languages by using a colour-coding scheme.

This new classification introduced in this research is a combination of quantitative (i.e., an improved method using statistics) and qualitative methods (i.e., an improved method of descriptive terms). It also serves as a bridge between quantitative and qualitative methods. Under the quantitative section of the table (i.e., seriousness levels defined using fatalities), a new analysis was developed using most influencing factor and extreme cases of natural disasters to demonstrate how common impact factors can be used to differentiate the severity levels. Under the qualitative section for the headings "Proposed words" and "Description", English words are used and were chosen to better describe the severity of a disaster and to improve the descriptions that accompany each severity level. Then, the combination of these two (English words and analysis of fatalities) techniques is used to demonstrate how quantitative and qualitative techniques are combined using the classification.

Table 8.1 Universal Disaster Severity Classification

Quantitative		Seriousness level and colour code	Qualitative	
Fatalities (F)	**Probability**		**Proposed word**	**Definition**
$0<F\leq10$	4.20 %	UDSC 1	Emergency	A ***sudden*** natural **event** that causes **damage**, **injuries,** and ***some*** **fatalities**
$10<F\leq100$	29.11 %	UDSC 2	Disaster Type 1	A ***major*** natural **event** that causes ***significant*** **damage**, ***many serious*** **injuries,** and ***many*** **fatalities**
$100<F\leq1{,}000$	39.37 %	UDSC 3	Disaster Type 2	
$1{,}000<F\leq10{,}000$	7.75 %	UDSC 4	Calamity Type 1	A ***large-scale*** natural **disturbance** that causes ***severe*** **destruction, a *major number of*** **injuries,** and ***great number of*** **fatalities**
10,000<F ≤0.1 million	0.72 %	UDSC 5	Calamity Type 2	
0.1 million<F ≤1 million	0.06 %	UDSC 6	Catastrophe Type 1	A ***very large-scale*** natural **disturbance** that causes ***widespread continental*** **destruction**, ***a massive number of*** **injuries,** and ***an extensive*** **loss of life**
1 million<F ≤10 million	$4.99*10^{-03}$ %	UDSC 7	Catastrophe Type 2	
10 million<F ≤100 million	$4.13*10^{-04}$ %	UDSC 8	Cataclysm Type 1	An ***extremely large-scale*** natural **upheaval** that causes ***global*** **devastation**, an ***uncountable number of*** **injuries,** and ***unimaginable*** **loss of life**
100 million<F ≤1 billion	$3.41*10^{-05}$ %	UDSC 9	Cataclysm Type 2	
1 billion<F	$3.08*10^{-06}$ %	UDSC 10	Partial or Full Extinction	A ***world-scale*** natural **upheaval that causes *universal*** **devastation, *partial or full extinction of humans***

For the first time, a 10 level system is proposed to measure the severity of natural disasters. A 10 level system is suitable because a base 10 log scale covers almost all the wide ranges in socio-economic factors. Additionally, people are generally comfortable with 10 point scales. The extreme value analysis is used to figure out the probabilities of disasters falling into these different categories. Then, the proposed words for each levels and their clear definitions represent each level of severity. We can find matching words in many languages, however given the low literacy rate in some areas, a colour coding system is also proposed. Therefore, the proposed UDSC can be adapted to any language, country, or society. All of these aspects: the number of levels, colour coding, fatality ranges, probabilities, words for each levels, and clear definitions for these words are new and proposed for the first time.

The proposed Universal Disaster Severity Classification (UDSC) eliminates the weaknesses of the existing method. In this technique, the descriptive terms are clearly defined and are used to differentiate the different levels of the UDSC, while the boundaries of these levels are defined according to fatalities. Existing definitions were improved in the following ways: (1) by clearly re-defining the existing terms without using one term to define another; (2) by mentioning different factors (i.e., damage, injuries, and fatalities) that should normally be considered to show the impact factors of a disaster, and (3) by using better descriptive words and adjectives to reflect the increasing levels of seriousness of these factors. Moreover, combining these terms with the quantitative techniques gives clear boundaries and guidelines. These descriptive words have clear differentiations between each other. Therefore, unlike the existing definitions of the descriptive terms, the UDSC provides a consistent method of differentiating between the descriptive terms as the UDSC clearly articulates the real magnitude of different severity levels.

Unlike the intensity/ magnitude scales, the UDSC shows the direct relationship between severity levels and impact factors (using the fatalities). The Initial UDSC with the most influencing factor that is common to all types of disaster can compare the severity of different types of natural disasters. By using such a scale, natural disasters can be ranked and compared based on their impact. However, the initial scale certainly does not capture all aspects of the impact. Yet, a scale representing all the impact factors would be extremely complex because each factor gives a very different interpretation of an event and there is no relationship currently identified between these factors. This initial UDSC is uniquely supported with data that can rate the severity of any natural disasters. Nevertheless, a global classification (even using one impact factor) for all types of natural disaster, (rather than the variety of unrelated scales for some specific disasters), is more informative, and consistent for assessing severity. The boundaries of different levels are clearly defined, and can be differentiated. Therefore, an overall picture of the disaster continuum is visible through this gateway. Another important point is that this UDSC links or inter-connects the disaster severity matrices, because it serves as a bridge between quantitative and qualitative techniques.

Therefore, severity levels of any type of natural disaster can be clearly compared using the UDSC as it categorises using clearly defined terms and differentiates using fatality. For both civilians and responders, this classification generates a common platform of communication to compare the impacts of disasters.

8.2 Research Summary and Conclusions

This research provides a global level of classification that includes a broad range of natural disasters from low (such as lightning) to high (such as earthquakes). All types of natural disasters are studied from origin to mitigation including: winter disasters (specific to cold areas); regional specific disasters (specific to some regions); slow-moving disasters (such as pandemics, droughts, insect infestation); and combine disaster (such as droughts though they do not usually cause direct fatalities).

Therefore, the comparative analysis reflects a situation from first detection of an event through to the completion of an evacuation, when necessary. In particular, thirty-six disaster types, covering all six groups of natural disasters, are identified and nineteen different types were studied. In order to understand the whole picture, four main aspects are compared and contrasted. The following are the four major outcomes from the point of view of: 1) physical aspects, 2) prediction and detection, 3) disaster impacts, and 4) mitigation.

1. The magnitude metric of each disaster has separate and unrelated classifications. Some disasters have no systemized matrices available and are simply assessed by geographic measures.
2. Disaster impact times vary from extremely short time periods measured in seconds, to years or even decades.
3. The range of different types of impact factors (i.e., fatalities, total number of affected people, area destroyed, economic damage) considers the total extent of severities. The different impact factors may help in distinguishing diverse characteristics of these disasters, because the extreme case of each impact factor defines the impact level for each disaster category. Thus, the cumulative impact of several historical disaster events is evident.
4. Depending on the physical aspects and characteristics of a disaster, mitigation techniques vary.

The first point illustrates that measuring the severity of a disaster using the existing systematized matrices is problematic, because some disasters have no systemized matrices available, and those that do have matrices that are not related to each other. Therefore, the existing systematized matrices are not suitable for differentiating between the severity levels of a disaster. Consequently, a new common scale is necessary to define the severity levels.

The severity of natural disasters increases with human exposure, and power of the event. On the other hand, the severity level decreases the larger the distance between the event and the population centers and with preparedness for the given disaster. Therefore, the severity directly or indirectly relates to all the factors, which can be grouped into human impact (i.e., effects to human), regions' preparedness, or characteristics of the disaster (i.e., power of the event). As explained previously, a scale representing all these factors will be extremely complex because each factor gives a very different interpretation/ idea of impact and there is no relationship currently identified between these factors. Therefore, the scale that presents the severity of natural disasters should be based on a cross-section of most influencing factors.

The severity directly relates to human impact, and relates indirectly to the characteristic of disasters and regions' preparedness. Therefore, the most influencing factor should be within the category of human impact (exposure). Many factors could be considered under this category to determine severity levels, but a lack of historical data prevents in-depth analysis. In addition to incomplete data, there is inaccuracy and ambiguousness in the current records or statistics, which complicate the relationship between influencing impact factors, and the severity of a natural disaster. If there is more accurate and detailed information available, a more advanced analysis can be performed and more sophisticated scale can be introduced.

Fatalities, injuries, cost of damage, and houses damaged are selected, according to the analysis, as the most influencing common impact factors available in the database that can be considered for a developing a scale. However, these impact factors are highly correlated. Therefore, two approaches can be applied to measure the severity using these correlated factors: measure the severity using one of these factors, or develop a complex disutility function that includes several factors. As the scope of this research is to develop the initial disaster severity scale, the simplest approach is selected. Therefore, out of four impact factors (i.e., fatalities, injuries, and damage or houses damaged) fatalities is selected as the most representative of severity in order to develop the initial severity scale.

Therefore, in this research, an initial global severity scale is developed and combined with clearly defined terminologies through the UDSC (see Table 8.1), which is a bridge between quantitative and qualitative techniques, in order to compare different types of disasters.

The initial UDSC can be directly applied to an emergency response management system. Having an overall picture about the severity of the disaster, emergency responders and disaster managers can quickly recognize the disaster's severity potential and appropriately allocate resources.

8.3 Main Research Contributions

This research will improve communication (Section 8.3.3) and understanding of disaster risk (Section 8.3.2), which align with the priority of the Sendai Framework for Disaster Risk Reduction 2015-2030.

8.3.1 Common Severity Scale for All Types of Natural Disasters

The main advantage of this new classification is that it provides a common platform to compare natural disasters. Therefore, comparisons across regions and time for any type of natural disaster is feasible using this novel classification.

In addition, this scale is not confined to disasters resulting from rapid-onset, relatively clearly defined events such as earthquakes and tornadoes. Disasters resulting from events that are more diffuse in space and time are also incorporated, such as droughts and epidemics. Conditions that become disastrous but with less clear start and end points are also incorporated because the scale also consider slow moving disasters.

As this scale considers the full range of world population, it incorporates conditions that become Armageddon events or massive phenomena (such as a major asteroid strike; super volcanoes; a meteoroid impact on land close to population centers, or into the ocean causing massive tsunami; or some other natural cataclysm). Analysing the risk and response to unimaginable but not impossible events that have the potential to cause the full or partial extinction of the human race is crucial, but curtailed as there are no historical records.

8.3.2 Improve Understanding of Disaster Risk

The UDSC is designed to provide an overview of the estimated severity of impact resulting from any type of disaster. It is not a replacement for first-hand damage and needs assessment information, but can support prioritisation during the early stages of a response. As the response continues the UDSC can be updated to take into account improvement to the severity model and sources of data (quality, timeliness and scale), that are validated via first-hand reports and changing requirements. Therefore, this new universal classification provides benefits to several groups of people as explained in Sections 8.3.2.1, 8.3.2.2, 8.3.2.3, and 8.3.3.

Another advantage of this global classification is that it can also help to advance the UDSC (severity model) itself (see Figure 1.2) because it improves the disaster terminology and can improve the quality of data, recording systems, and databases as explained in the previous paragraph.

8.3.2.1 For Emergency Response Management and Disaster Management

As explained in Section 8.3.2, disaster managers and emergency respondent personnel can have a clear sense of scale about the severity of each type of disaster by considering the expected probabilities according to historical disasters. This knowledge can be used to deploy the resources as needed when disaster strikes.

The initial assessment of the disaster is based on the estimates shortly after the event strikes and it is frequently updated. For example, first evaluations are used for planning such as, whether to call a state of emergency, evacuate, request international assistance, or involve military forces. Other decisions regarding planning include the following: the resources, such as food, water, medicine, and clothes, that should be stored and delivered to the stricken area; the hospitals that should be assembled and to what extent; and the shelters to mobilize, where to set up temporary housing, and for how long. Therefore, predicting the severity can accelerate the recovery process.

Furthermore, consistent identifications of disaster impacts will help to prevent disaster managers from either over- or under-compensating in their allocation of resources for disaster mitigation. Overcompensation could result in a large waste of resources, while under-compensation could increase the severity of impact.

In addition, public awareness, education level, and response rates to warnings can be increased using this initial UDSC because a direct relationship between a disaster and the probability of human impacts is made explicit. Further, the initial UDSC based on human impacts should also be used as a mitigation method that can help change public opinion regarding the impact of disasters; the application of the scale can save lives. Therefore, warnings can be communicated using the initial UDSC, improving public response. Proper communication regarding life-threatening situations may increase public awareness and provide time and information for the public to attain a safe location during a disaster, subject to proper pre-planning.

8.3.2.2 For Information Management

As explained in Section 8.3.2, from information management and processing, database managers may benefit by easily recognizing an event occurrence and having a set of standard terms in the initial UDSC. They can then develop a standardized database terminology and manage the associated data to avoid missing or inaccurate data.

8.3.2.3 For Insurance Management

By having an overall picture of each disaster and its potential impact levels, this classification helps insurance managers and estimators to create specific criteria to clarify common disaster compensation packages and insurance policies.

8.3.3 Improve Communication

The UDSC will serve as a bridge between qualitative and quantitative techniques used in emergency management systems. Here qualitative and quantitative techniques are integrated to produce management and size measurement systems, respectively (see Figure 4.1 in Chapter 4). Therefore, UDSC avoids inconsistencies and, most importantly, connect severity metrics in order to generate a clear understanding of the degree of emergency and the potential impacts. This has the potential to improve the mutual understanding between different countries of emergency management systems at all levels: international, continental, regional, national, provincial, and local.

In addition, this classification generates a common platform of communication to compare the impacts of disasters for many other groups such as the research community, the media, and the general public by providing clear definitions that help convey the impact levels or severity potential of a disaster and the subsequent steps the public and responders must take.

8.4 Research Limitations

As this scale is used for post event, the classification of the severity of the event may change as reports on the number of fatalities are updated. Therefore, the degree of severity changes with time and with frequent and updated reporting about the disaster. For example, an earthquake, which occurs in seconds, can be categorized as a “disaster” in terms of severity *within the first few hours* after the earthquakes hits according to the reported impacts and causalities. However, the impact and causalities can increase days or weeks after the event. Accordingly, the severity of the earthquake, first classified as a “disaster,” can be reclassified as “calamity” *within a day or two* after the event; it could potentially be considered a catastrophic event *within weeks*.

Although disasters may unfold over a range of time periods, the severity cannot be measured as quickly as they strike. For example, there are slowly developing disasters, such as global warming, famine, and pollution, and there are rapidly developing disasters, such as earthquakes, tornadoes, and tsunamis. The pollution of air and water progress slowly, and are measured in years or decades, whereas earthquakes occur over extremely short time periods, measured in seconds. Although the accuracy of the severity can change with frequent updates of the impact, it is vital to estimate the severity shortly after the event strikes to provide information to first-responders and for public reporting and planning as explained previously in this section.

This primary classification proposed a methodology to measure the severity for all types of natural disasters under one single scale. The number of fatalities, is chosen as the most influencing factor because it encapsulates many effects on humans because it is correlated with several factors. Fatalities as a factor is highly correlated with injuries and missing, and moderately correlated with houses damaged and cost of damaged. However, it is noted that, one factor alone cannot represent the severity of an event and is not sufficient to measure the severity of a disasters. This is because the single factor may not address some aspects of the severe events. For example, a disaster may affect only a geographic area without any direct and immediate impact on humans. Consider that a wildfire in an uninhabited forest may have long-term adverse effect on the local and global ecosystem, although no human is immediately killed, as a result of the event. Such severe events are not properly addressed by a single factor. A further example is as the recent (2016) Fort McMurray fire, which had no fatalities and the referred event is not represented using fatality only scale. In “Fort McMurray Fire The Great Escape” (Markusoff et al. 2016), the Fort McMurray fire was labelled a ‘catastrophe’ and “disaster”. One may also consider the 2013 Alberta flood, which had 4 fatalities and damage in the billions of dollars, but, is not properly represented using this scale. Both disasters were named as the costliest Canadian disaster in history. Therefore, a more advanced multidimensional scale, combining all independent impact factors such as fatalities, injuries, homeless, affected population, area affected and cost of damage is needed to properly address the full range of disaster impact.

8.4.1 Research challenges

The main challenge was obtaining the raw data for the research. The data was acquired by signing the Letter of Understanding (LOU) between University of Calgary and the Centre for Research on the Epidemiology of Disasters (CRED), in Brussels, Belgium, which is responsible for ”The International Disaster Database”. Compromising was difficult and time consuming; acquiring the data from CRED took more than one year (from June 2013 to September 2014). Therefore, preliminary analysis was done using the data from different websites as previously mentioned.

The analysis was limited because the expected amount of data could not be obtained due to the strict requirements of CRED. Although data from 1900 to 2013 was requested, we could only obtain data from 1977 to 2013 as the CRED restricts the maximum amount of data issued to around 10,000 records.

In addition, faulty data storage systems in the lab, where sensitive data was stored according to the the LOU, caused the loss of secured data and four months of analysis work.

8.5 Recommendations for Future Research

This initial scale can be further advanced to consider impact factors in order to properly express the level of impact of a natural disaster. A comparison of statistics requires a proper technique to measure disasters using the most influencing impact factors. The model for a primary disaster classification can be further advanced by including injuries, damage, and vulnerability of housing and population. Further research is needed to identify, then combine, the multiple measures of impact to obtain an overall disutility.

Moreover, the order of seriousness of the words is subjected to change depending upon the most commonly accepted definitions within English-speaking populations, because current definitions' order of seriousness is unclear and culturally dependent, and change over time. Therefore, a survey can help to evaluate commonly accepted understandings of the order of seriousness of the descriptive terms.

References

AEMA. (2015). “Making Communities More Resilient Incident Management Teams and Regional Partnerships.” *Alberta Emergency Management Agency*, <http://www.aema.alberta.ca/documents/ema/D5_Incident_Management_Teams_and_Regional_Partnerships.pdf> (Oct. 29, 2015).

AMS. (2015). “Meteorology Glossary, American Meteorological Society.” <http://glossary.ametsoc.org/wiki/Tornado>.

Ansari Esfeh, M., Caldera, H. J., Heshami, S., Moshahedi, N., and Wirasinghe, S. C. (Chan). (2016). “The severity of earthquake events – statistical analysis and classification.” *International Journal of Urban Sciences*.

Australian Institute of Criminology. (2009). “The number of fires and who lights them.” *Bushfire arson bulletin no. 59*, <http://www.aic.gov.au/publications/current series/bfab/41-60/bfab059.html> (Mar. 26, 2013).

BBC. (2016). “Predicting and preparing for volcanoes.” *Managing tectonic hazards*, <http://www.bbc.co.uk/schools/gcsebitesize/geography/natural_hazards/managing_hazards_rev1.shtml> (Oct. 21, 2016).

Below, R., Wirtz, A., and Guha-Sapir, D. (2009). *Disaster Category Classification and peril Terminology for Operational Purposes*. Brussels.

Bin, P., Haiyan, Z., and Peng, H. (Eds.). (2009). *Natural Disaster Mitigation : A Scientific and Practical Approach*. Science Press, Beijing.

de Boer, J. (1990). “Definition and classification of disasters: Introduction of a disaster severity scale.” *The Journal of Emergency Medicine*, 8(5), 591–595.

Boos, D. D. (1984). “Using Extreme Value Theory to Estimate Extreme Value Theory

Using Large Percentiles." *Technometrics*, 26(1), 33–39.

Brooks, H., and Doswell III, C. A. (2001a). "Some aspects of the international climatology of tornadoes by damage classification." *Atmospheric Research*, 56(1–4), 191–201.

Brooks, H. E. (2004). "On the relationship of tornado path length and width to intensity." *Weather and forecasting*, 19, 310–319.

Brooks, H. E. (2013). *Estimating the Distribution of Severe Thunderstorms and Their Environments Around the World*.

Brooks, H. E., and Craven, J. P. (2002). "A database of proximity soundings for significant severe thunderstorms, 1957-1993." *21st Conference on Severe Local Storms*, American Meteorological Society, San Antonio, Texas, 639–642.

Brooks, H. E., Doswell, C. a., and Kay, M. P. (2003). "Climatological Estimates of Local Daily Tornado Probability for the United States." *Weather and Forecasting*, 18(4), 626–640.

Brooks, H. E., and Doswell III, C. A. (2001b). "Normalized Damage from Major Tornadoes in the United States: 1890–1999." *Weather and Forecasting*, 16(1), 168–176.

Burbidge, D., Cummins, P. R., Mleczko, R., and Thio, H. K. (2008). "A probabilistic tsunami hazard assessment for Western Australia." *Pure and Applied Geophysics*, 165(11–12), 2059–2088.

Bureau of Meteorology. (2016). "Tsunami Frequently Asked Questions." *Commonwealth of Australia*, <http://www.bom.gov.au/tsunami/info/faq.shtml> (Jun. 29, 2016).

Caers, J., and Maes, M. A. (1998). "Identifying tails, bounds and end-points of random variables." *Structural Safety*, 20(1), 1–23.

Caldera, H. J., and Wirasinghe, S. C. (2014). "Analysis and Classification of Volcanic Eruptions." *The 10th International Conference of the International Institute for Infrastructure Resilience and Reconstruction (I3R2)*, R. R. Rapp and W. Harland, eds., Purdue University., West Lafayette, Indiana, 20–22.

Caldera, H. J., Wirasinghe, S. C., and Zanzotto, L. (2016a). "AN APPROACH TO CLASSIFICATION OF NATURAL DISASTERS BY SEVERITY." *5th International Natural Disaster Mitigation Specialty Conference, CSCE Annual Conference*, Canadian Society for Civil Engineering, London, Ontario, Canada, NDM-528-1 to NDM-528-11.

Caldera, H. J., Wirasinghe, S. C., and Zanzotto, L. (2016b). "Severity scale for tornadoes." *Natural Hazards*.

Camerer, C. F., and Kunreuther, H. (1989). "Decision Processes for Low Probability Events: Policy Implications." *Journal of Policy Analysis and Management*, 8(4), 565–592.

Coles, S. (2001). *An Introduction to Statistical Modeling of Extreme Values*. Springer, London.

Colton, T. (1974). "Chapter 4." *Statistics in medicine*, Little, Brown, Boston, 372.

Commonwealth Scientific and Industrial Research Organisation (CSIRO). (n.d.). "No Title." <http://www.csiro.au/en/Outcomes/Safeguarding-Australia/BushfireTypes.aspx> (Mar. 26, 2013).

Craw, M. L. (2008). "Probabilistic approach for tsunami inundation mapping." *Defense*.

CRED. (2013). "EMDAT- International Disaster Database : Centre for Research on the

Epidemiology of Disasters." *Www.Emdat.Be*, 1–5.

CRED. (2016). "EMDAT- International Disaster Database : Centre for Research on the Epidemiology of Disasters." *Www.Emdat.Be*.

Cresswell, J. (2009). *The Oxford Dictionary of Word Origins*. Oxford University Press.

Department of Atmospheric Sciences (DAS) the University of Illinois. (n.d.). "Dangers to People." <http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/cld/prcp/zr/dang/home.rxml>.

"Dictionary.com." (2013). *Dictionary.com, LLC.*, <http://www.dictionary.com/> (Jan. 1, 2013).

Doswell III, C. A., Brooks, H. E., and Dotzek, N. (2009). "On the implementation of the enhanced Fujita scale in the USA." *Atmospheric Research*, Elsevier B.V., 93(1–3), 554–563.

Doswell III, C. A., and Burgess, D. W. (1988). "On Some Issues of United States Tornado Climatology." *Monthly Weather Review*, 116(2), 495–501.

Durage, S. W. (2014). "Mitigation of the Impact of Tornadoes in the Canadian Prairies." University of Calgary.

Durage, S. W., Kattan, L., Wirasinghe, S. C., and Ruwanpura, J. Y. (2014). "Evacuation behaviour of households and drivers during a tornado: Analysis based on a stated preference survey in Calgary, Canada." *Natural Hazards*, 71(3), 1495–1517.

Durage, S. W., Ruwanpura, J., and Wirasinghe, S. C. (2012). "Analysis of the Tornado Detection , Warning and Communication System in Canada." *Conference on Building Resilience, International Institute for Infrastructure Renewal and Reconstruction (IIIRR)*, Kumamoto, Japan, 457–466.

Durage, S. W., Wirasinghe, S. C., and Ruwanpura, J. (2013). “Comparison of the Canadian and US tornado detection and warning systems.” *Natural Hazards*, 66(1), 117–137.

Durage, S. W., Wirasinghe, S. C., and Ruwanpura, J. Y. (2015). “Decision Analysis for Tornado Warning and Evacuation.” *Natural Hazards Review*, 4015014.

Edinburgh, A., and Black, C. (1889). *Encyclopædia Britannica*.

Environment Canada. (n.d.). “Canadian Lightning Danger Map - Canada.” <http://www.weatheroffice.gc.ca/lightning/> (Mar. 26, 2013).

Esfeh, M. A., Caldera, H. J., Heshami, S., Moshahedi, N., and Wirasinghe, S. C. (2016). “The severity of earthquake events – statistical analysis and classification.” *International Journal of Urban Sciences*, 20(sup1), 4–24.

Farlex, I. (2013). “The Free Dictionary.” <http://www.thefreedictionary.com/>.

Fujita, T. T. (1971). *Proposed characterization of tornadoes and hurricanes by area and intensity*. Satellite and Mesometeorology Research Project, Department of the Geophysical Sciences, University of Chicago.

Fujita, T. T. (1973). “Tornadoes around the World.” *Weatherwise*, 26(2), 56–83.

Gad-el-Hak, M. (2008a). “The art and science of large-scale disasters.” *Large-Scale Disasters*, M. Gad-el-Hak, ed., Cambridge University Press, Cambridge, 5–68.

Gad-el-Hak, M. (2008b). “Introduction.” *Large-Scale Disasters*, M. Gad-el-Hak, ed., Cambridge University Press, Nwe York, 1–4.

Geist, E. L., and Parsons, T. (2006). “Probabilistic analysis of tsunami hazards.” *Natural Hazards*, 37(3), 277–314.

GeoNet. (2016). “Monitoring Methods.”

<http://info.geonet.org.nz/display/volc/Monitoring+Methods> (Oct. 21, 2016).

Goliger, A. M., and Milford, R. V. (1998). “A review of worldwide occurrence of tornadoes.” *Journal of Wind Engineering and Industrial Aerodynamics*, 74–76, 111–121.

“Google Glossary.” (2014). <www.google.ca> (Jan. 1, 2013).

Government of Alberta. (2016). “Final Update 39: 2016 Wildfires (June 10 at 4:30 p.m.).” *Government of Alberta news releases*, <http://www.alberta.ca/release.cfm?xID=41701E7ECBE35-AD48-5793-1642C499FF0DE4CF> (Jun. 29, 2016).

Government of Canada. (2015). “The Canadian Disaster Database.” *Public Safety Canada*, <http://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-eng.aspx> (Jan. 19, 2016).

de Groot, W. J., Goldammer, J. G., Keenan, T., Brady, M., Lynham, T. J., Justice, C. O., Csiszar, I. A., and O’Loughlin, K. (2006). “Developing a global early warning system for wildland fire.” *The 5th International Conference on Forest Fire Research*, D. X. Viegas, ed., Elsevier, Amsterdam, The Netherlands, Figueira da Foz, Portugal, 12p.

Guzzetti, F., Galli, M., Reichenbach, P., Ardizzone, F., and Cardinali, M. (2006). “Landslide hazard assessment in the Collazzone area , Umbria , Central Italy.” *Natural Hazards and Earth System Science*, 6(1), 115–131.

Harper, D. (2001). “Online Etymological Dictionary.” <http://www.etymonline.com/> (Nov. 21, 2014).

Hasofer, A. M. (1996). “Non-parametric Estimation of Failure Probabilities.”

Mathematical models for structural reliability analysis, F. Casciati and B. Roberts, eds., CRC Press, 195–226.

Hosek, J., Musilek, P., Lozowski, E., and Pytlak, P. (2011). "Forecasting severe ice storms using numerical weather prediction: The March 2010 Newfoundland event." *Natural Hazards and Earth System Science*, 11(2), 587–595.

Hristidis, V., Chen, S.-C., Li, T., Luis, S., and Deng, Y. (2010). "Survey of data management and analysis in disaster situations." *Journal of Systems and Software*, Elsevier Inc., 83(10), 1701–1714.

Jamieson, J. B. (1995). "Avalanche Prediction for Persistent Snow Slabs." THE UNIVERSITY OF CALGARY.

Katz, A. J., and Herman, S. W. (1997). "Improved estimates of fixed reproducible tangible wealth, 1929-95." *Survey of Current Business*, May, 69–76.

Kelman, I. (2008). "Addressing the root causes of large-scale disasters." *Large-Scale Disasters*, M. Gad-el-Hak, ed., Cambridge University Press, New York, 94–119.

Kenya Meteorological Department. (n.d.). "Understanding Droughts." <http://www.meteo.go.ke/imtr/Understanding Droughts.pdf> (Mar. 26, 2013).

Korotev, R. L. (2015). "Some Meteorite Statistics." *Department of Earth and Planetary Sciences Washington University in St. Louis*, <http://meteorites.wustl.edu/meteorite_types.htm>.

Kotz, S., and Nadarajah, S. (2000). *Extreme value distributions: theory and applications*. Imperial College Press, London.

"Lightning strike." (2013). *Wikipedia, The Free Encyclopedia*, <http://en.wikipedia.org/wiki/Lightning_strike> (Jan. 1, 2013).

"List of deadliest floods." (2013). *Wikipedia, The Free Encyclopedia*, <https://en.wikipedia.org/wiki/List_of_deadliest_floods> (Jan. 1, 2013).

"List of flash floods." (2013). *Wikipedia, The Free Encyclopedia*, <http://en.wikipedia.org/wiki/List_of_flash_floods> (Jan. 1, 2013).

"List of landslides." (2013). *Wikipedia, The Free Encyclopedia*, <http://en.wikipedia.org/wiki/List_of_landslides> (Jan. 1, 2013).

"List of natural disasters by death toll." (2013). *Wikipedia, The Free Encyclopedia*, <https://en.wikipedia.org/wiki/List_of_natural_disasters_by_death_toll> (Jan. 1, 2013).

Löw, P., and Wirtz, A. (2010). "Structure and needs of global loss databases of natural disasters." *International Disaster and Risk Conference IDRC*, Davos, Switzerland, 1–4.

Mackerras, D., Darveniza, M., Orville, R. E., Williams, E. R., and Goodman, S. J. (1998). "Global lightning: Total, cloud and ground flash estimates." *Journal of Geophysical Research: Atmospheres*, 103(D16), 19791–19809.

Markusoff, J., Macdonald, N., and Gillis, C. (2016). "Fort Mcmurray Fire The Great Escape." *MACLEAN'S*.

Merriam- Webster. (2013). "Merriam- Webster Thesaurus." <http://www.merriam-webster.com> (Jan. 1, 2013).

Meyer, R. J. (2006). "Why We Under-Prepare for Hazards?" *On Risk and Disaster: Lessons from Hurricane Katrina*, R. J. Daniels, D. F. Kettl, and H. Kunreuther, eds., University of Pennsylvania Press, Philadelphia, Pennsylvania, 153–173.

Mills, B., Unrau, D., Pentelow, L., and Spring, K. (2010). "Assessment of lightning-related damage and disruption in Canada." *Natural Hazards*, 52(2), 481–499.

Ministers Responsible for Emergency Management. (2011). *An Emergency Management Framework for Canada*. Emergency Management Policy Directorate, Public Safety Canada.

MunichRE. (2013). "NatCatSERVICE: Downloadcenter for statistics on natural catastrophes." <http://www.munichre.com/en/reinsurance/business/non-life/georisks/natcatservice/default.aspx> (Mar. 26, 2013).

NASA. (2013). "Hurricanes: The Greatest Storms on Earth. Hurricane Climatology." *Earth Observatory*, <http://earthobservatory.nasa.gov/Features/Hurricanes/hurricanes_3.php>.

NASA: National Aeronautics And Space Administration. (n.d.). "Near Earth Object Program." <http://neo.jpl.nasa.gov/faq/#pha> (Mar. 26, 2013).

National Oceanic and Atmospheric Administration. (2009). "Glossary - National Weather Service." <http://w1.weather.gov/glossary/index.php?letter=b> (Jun. 29, 2016).

National Oceanic and Atmospheric Administration -NOAA. (n.d.). "Global Climate Change Indicators." *National Centers for Environmental Information*, <http://www.ncdc.noaa.gov/indicators/>.

Natural Environment Research Council. (2006). *Natural hazards scientific certainties and uncertainties*. Swindon, UK.

Newhall, C. G., and Self, S. (1982). "The volcanic explosivity index (VEI) an estimate of explosive magnitude for historical volcanism." *Journal of Geophysical Research*, 87(C2), 1231–1238.

"NOAA." (n.d.). *National Oceanic and Atmospheric Administration*,

<http://www.aoml.noaa.gov/general/lib/defining.html> (Mar. 26, 2013).

NOAA. (2007). “Enhanced F Scale for Tornado Damage.” <http://www.spc.noaa.gov/faq/tornado/ef-scale.html>.

NOAA. (2013). “Storm Events Database, National Oceanic and Atmospheric Administration (NOAA).” *National Climatic Data Center*, <http://www.ncdc.noaa.gov/stormevents/> (Jul. 15, 2013).

NOAA. (2015). “NGDC/WDS Global Historical Tsunami Database.” <http://www.ngdc.noaa.gov/hazard/tsu_db.shtml> (May 1, 2015).

NSSL. (2015). “SEVERE WEATHER 101: Tornado Basics.” *The National Severe Storms Laboratory (NSSL)*, <http://www.nssl.noaa.gov/education/svrwx101/tornadoes/> (Oct. 7, 2015).

Oxford University. (2010). *Oxford Dictionary of English*. (A. Stevenson, ed.), Oxford University Press.

Oxford University Press. (2014). “The Oxford English Dictionary (OED).” <http://www.oed.com/> (Nov. 21, 2014).

Pacific Disaster Center (PDC). (n.d.). “No Title.” <http://www.pdc.org/iweb/wildfire.jsp?subg=1> (Mar. 26, 2013).

Parwanto, N. B., and Oyama, T. (2014). “A statistical analysis and comparison of historical earthquake and tsunami disasters in Japan and Indonesia.” *International Journal of Disaster Risk Reduction*, Elsevier, 7, 122–141.

Pelling, M. (2001). “Natural Disasters?” *Social nature: Theory, practice, and politics*, N. Castree and B. Braun, eds., Blackwell Publishers, Oxford, Malden, MA, 170–188.

Penuel, K. B., Statler, M., and Hagen, R. (2013). *Encyclopedia of crisis management*.

SAGE Publications, Inc, Thousand Oaks, Calif.

Photo-bear.com. (2010). “Moscow after freezing rain.” <http://www.photo-bear.com/news_2010_12_27_2_moscow_frozen_rain.htm>.

PreventionWeb. (n.d.). “Tornado.” <http://www.preventionweb.net/english/hazards/> (Mar. 26, 2013).

Reiss, R.-D., and Thomas, M. (2007). *Statistical analysis of extreme values: With applications to insurance, finance, hydrology and other fields*. Birkhäuser Basel, Basel.

REPORTER. (2011). “Tornado outbreak killed 342 biggest history 226 twisters 1 day.” <http://www.dailymail.co.uk/news/article-1382902/> (Jul. 5, 2013).

Rhome, J. (n.d.). “Storm Surge Overview.” *National Hurricane Center, National Oceanic And Atmospheric Administration*, <http://www.ametsoc.org/Meet/fainst/2010shortcoursetropicalweatherpresentations/Tab 7_Rhome.pdf> (Mar. 26, 2013).

Richter, C. F. (1935). “An instrumental earthquake magnitude scale.” *Bulletin of the Seismological Society of America*, 25, 1–32.

Schwartz, R. M., and Schmidlin, T. W. (2002). “Climatology of Blizzards in the Conterminous United States , 1959 – 2000.” *Journal of Climate*, 15(13), 1765–1772.

Self, S. (2006). “The effects and consequences of very large explosive volcanic eruptions.” *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*, 364(1845), 2073–97.

Shakespeare, W. (1600). “Internet Shakespeare Editions.” *Internet Shakespeare Editions*, R. Gaby, ed., University of Victoria.

Siebert, L., Simkin, T., and Kimberly, P. (2010). *Volcanoes of the world*. Smithsonian Institution, Washington, D.C.

Sigurdsson, H. (2000). *Encyclopedia of volcanoes*. Academic Press, San Diego, Calif.

Simkin, T. (1981). *Volcanoes of the world : a regional directory, gazetteer, and chronology of volcanism during the last 10,000 years*. Hutchinson Ross, Stroudsburg, Pa.

Soloviev, S. L., and Go, C. N. (1974). *A catalogue of tsunamis on the western shore of the Pacific Ocean*. Nauka Publishing House, Moscow, USSR.

Statistic Brain Research Institute. (2016). "Tsunami Statistics." <http://www.statisticbrain.com/tsunami-statistics/> (Jun. 29, 2016).

Tanguy, J.-C., Ribière, C., Scarth, A., and Tjetjep, W. S. (1998). "Victims from volcanic eruptions: a revised database." *Bulletin of Volcanology*, 60(2), 137–144.

The International Federation of Red Cross and Red Crescent Societies (IFRC). (n.d.). "Geophysical hazards: Mass movement dry." <http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/geophysical-hazards-mass-movement-dry/> (Jun. 29, 2016).

The Natural Resources Defense Council. (n.d.). "Global Warming 101." <https://www.nrdc.org/stories/global-warming-101> (Mar. 26, 2013).

The Planetary and Space Science Centre (PASSC) - University of New Brunswick Canada. (2011). "Impact Cratering on Earth." *Earth Impact Database*, <http://www.passc.net/EarthImpactDatabase/IntrotoImpacts.html>.

Tierney, K. (2008). "Hurricane Katrina: Catastrophic Impact and Alarming Lessons." *Risking House and Home: Disasters, Cities, Public Policy*, J. M. Quigley and L. A.

Rosenthal, eds., Berkely Public Policy Press, Institute of Governmental Studies Publications, Berkely, California, 119–136.

USGS. (2016). “Comprehensive monitoring provides timely warnings of volcano reawakening.” *United States Geological Survey (USGS)*, <https://volcanoes.usgs.gov/vhp/monitoring.html> (Oct. 21, 2016).

Vergano, D. (2013). “Russian Meteor’s Air Blast Was One for the Record Books.” *National Geographic*.

“Volcanoes.” (2006). *The Medium*, 45(3), 27–26.

Wickramaratne, S. (2010). “Design and Analysis of Tsunami Warning and Evacuation Systems.” University of Calgary.

Wickramaratne, S., Ruwanpura, J., Ranasinghe, U., Walawe-Durage, S., Adikariwattage, V., and Wirasinghe, S. C. (2012). “Ranking of natural disasters in Sri Lanka for mitigation planning.” *International Journal of Disaster Resilience in the Built Environment*, 3(2), 115–132.

Wickramaratne, S., Ruwanpura, J. Y., and Wirasinghe, S. C. (2011). “Decision analysis for a tsunami detection system - Case study: Sri Lanka.” *Civil Engineering and Environmental Systems*, 28(4), 353–373.

Wikipedia. (2013). “List of North American tornadoes and tornado outbr; List of 21s tcentury Canadian tornadoes and tornad; Tornado records; Super Outbreak; List of tornadoes causing 100 or more deaths; List of tornadoes by calendar day.” <http://en.wikipedia.org/> (Jul. 5, 2013).

“Wikipedia: The Free Encyclopedia.” (n.d.). *Wikimedia Foundation, Inc.*

Wirasinghe, S. C. (2012). “Approaches To Classifying Natural Disasters & Planning To

Mitigate Natural Disasters – Example of Indian Ocean Tsunami & Prairie Tornadoes." York University, Toronto, ON.

Wirasinghe, S. C., Caldera, H. J., Durage, S. W., and Ruwanpura, J. Y. (2013). "Preliminary Analysis and Classification of Natural Disasters." *The 9th Annual International Conference of the International Institute for Infrastructure Renewal and Reconstruction*, P. H. Barnes and A. Goonetilleke, eds., Queensland University of Technology, Brisbane, Queensland, Australia, 11.

Wood, H. O., and Neumann, F. (1931). "Modified Mercalli Intensity scale of 1931." *Bulletin of the Seismological Society of America*, 21(4), 277–283.

WordPress.com. (2013). "April 3, 1856: Palace of the Grand Masters Explosion, Rhodes." *The Daily Disaster*, <https://dailydisaster.wordpress.com/2009/04/03/april-3-1856-palace-of-the-grand-masters-explosion-rhodes/> (Jan. 1, 2013).

World Bank. (2015). "Population, total." *World Bank Open Data*, <http://data.worldbank.org/indicator/SP.POP.TOTL?end=2015&start=1960&view=chart>.

World Bank. (2016). "GDP (current US$)." *World Bank national accounts data*, <http://data.worldbank.org/indicator/NY.GDP.MKTP.CD> (Oct. 26, 2016).

Zhang, D., and Wang, G. (2007). "Study of the 1920 Haiyuan earthquake-induced landslides in loess (China)." *Engineering Geology*, 94(1–2), 76–88.