Chapter 3

Disasters from 1948 to 2015 in Korea and Power-Law Distribution

Abstract The Korean peninsula is no stranger to disaster, experiencing natural disasters such as severe downpours, floods, and typhoons and human-caused disasters such as industrial accidents, building collapses, and infernos. Fortunately, for the purposes of learning from each event, it has well documented many aspects of each disaster, policy and law changes, institutional reforms, and future risk management alternatives. However, to take the almost 2000-year documented history of Korea in a more manageable period, we focus on the major disaster events, those that are quantifiable and that took place between 1948 and 2015 to see if the disaster trend in Korea is producing power-law distributed disasters. We specifically analyzed the statistical characteristics of these major disaster events and their functional relationship between frequency and magnitude to see if a change in one produces a proportional relative change in the other.

Keywords Major disasters in Korea • Power-law distribution • Statistical analysis

3.1 Major Disasters from 1948 to 2015 and Trend in Korea

This section will review major disasters from 1948 when the first Korean government was established to 2015 when the Middle East respiratory syndrome coronavirus (MERS-CoV) occurred in Korea. Among various disasters during the period, this paper will focus on disasters that caused a large number of casualties or economic loss. Disaster of which damage is hardly calculated quantitatively, such as drought or yellow dust, is excluded in the analysis.

The data used in the research mainly comes from the *Yearbook of Natural Disaster* (YND) (1979–2015), the *Yearbook of Social Disaster* (YSD) (1995–2015), and *60 Year History of Disaster Management* (NEMA 2009).[1]

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[1] Readers can also find useful photos about the disasters described in this book at the Web site of MPSS (http://www.mpss.go.kr/home/safetys/photobook/disasterPhotoGallery).

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3.1.1 Torrential Downpour in the Nakdong River Basin in 1957

A 40-day deluge in the Nakdong River Basin due to a typhoon (first moving over Jeju Island on August 21, 1957 then up over the peninsula) resulted in 247 deaths, 60,000 people homeless, and 54.2 billion Korean Won (KRW) (249.3 billion KRW of 2015) of property loss (Ministry of Culture, Sports and Tourism n.d.).

3.1.2 Typhoon Sarah in 1959

On September 11, 1959, Typhoon Sarah formed as tropical depression (TD) around Saipan and moved toward the west-northwest. The TD strengthened moving northwestward as it received a large amount of vapor from the sea, and moving northward, it transformed into a typhoon at 965 hpa central pressure on 13th. Then it moved northward to Jeju Island on September 15, moved along the sea, and reached almost southern Yeosu-si where it was 120 km apart from the typhoon. After, it moved northeastward and reached Chungmu-si[2] and moved along from Pohang-si to the southern sea of Ulleung Island. On the 18th, it passed the center of the East Sea and northern Hokkaido and headed to the Sea of Okhotsk where it damaged Jeju Island, Yeongdong area,[3] and southern region of Korea from the 15th to the 18th. Typhoon Sarah caused about 750 casualties and loss of 9329 ships, 12,366 houses, roads, bridges, telephone booths, and 216,325 ha of farmland; the total economic loss was estimated at 62.2 billion KRW (297.2 billion KRW of 2015).

3.1.3 Flood in Jeollabuk-do Namwon-eup[4] and Gyeongsangbuk-do Yeongju-gun[5] in 1961

Floods occurred in Yeongju-gun of Gyeongsangbuk-do and Namwon-eup of Jeollabuk-do in 1961. From 4 a.m. to 8 a.m. on July 11, 1961, in Yeongju-gun, 215 mm of rain fell causing the Seocheon Bank to burst at 5 a.m., which flooded two thirds of the downtown area. Also, a bank along the Hyogi Reservoir in Namwon-eup of Jeollabuk-do collapsed at 8 p.m. due to heavy rain. These events

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[2] Chungmu-si was changed into Tongyeong-si in 1994.

[3] Gangwon-do is divided into the Yeongdong (east of mountain range) and Yeongseo (west of mountain range) with the Taebaek Mountain ranges.

[4] Namwon-eup was upgraded to a city in 1981.

[5] Yeongju-gun was upgraded to a city in 1980.

caused 17.46 billion KRW (66.46 billion KRW of 2015) in property damage and 262 casualties (NEMA 2009).

3.1.4 Suncheon Flood in 1962

The "Suncheon Flood" was a disaster that occurred on August 28, 1962 due to a torrential downpour in the Suncheon-si area. The bank of the reservoir burst causing two thirds of Suncheon-si to be flooded, 229 deaths, 76 missing persons, 14,391 displaced people, and 161.8 million KRW (5.634 billion KRW of 2015) in property damage (NEMA 2009).

3.1.5 Torrential Downpour in Central Region in 1965

There was a torrential downpour in the central and southern regions from July 16 to 20 in 1965. The rain front, which moved northward to North Korea early in July, moved southward from 14th, and as the rain front stayed in the central region, there was torrential downpour on the 16th. As a result, there were around 600 mm rain in the North Han River and 100–200 mm in the neighboring regions, which caused the most severe flood since 1925. Also, the Nakdong River, downstream of the Geum River and the Seomjin River, was flooded. The torrent of rain in the central region caused 10.9 billion KRW of damage including 242 casualties, 220,000 displaced people, and 2.2 billion KRW (42.89 billion KRW of 2015) in property damage (NEMA 2009).

3.1.6 Wow Apartment Collapse in 1970

On April 8, 1970, 15 apartments within the Wow Apartment Complex collapsed around 6:30 a.m. in San-2, Changjeon-dong,[6] Mapo-gu, Seoul City. In December 1969, the Wow Citizen Apartments were built using substandard materials, inferior and defective support structures, and careless timescales. In cost-cutting measures, rebar and concrete were reduced, shoddy workmanship was employed, and safety measures were ignored to complete the construction of the project ahead of schedule. Additionally, the Mapo-gu Office and the police office received an emergency call but failed to act upon a notification of impending collapse. The combined failures resulted in the building crumbling just 5 months after the

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[6] The Changjeon-dong and Sangsu-dong were merged into Seogang-dong in 2007.

construction, taking 33 lives and injuring 44 (National Archives of Korea 1970; NEMA 2009).

3.1.7 Namyoung Ferry Sinking Accident in 1970

The Namyoung Ferry, which was heading from Seogwipo-si to Seongsanpo port toward Busan City, sank in the sea 28 miles away from the southeast of Yeosu-si, Jeollanam-do, around 1:25 a.m. on December 15, 1970. The cause of the accident was instability due to an overload. Its center of gravity became higher, which made the ship unstable, and there was a sinking followed by an overturn. The passenger capacity of the ferry was 302, but the actual number of passengers was 338. Moreover, the loading capacity was 150 tons, but the actual loading was almost 500 tons. Also, at the moment of the sinking accident, the belated response of the rescue agency on SOS was another factor leading to more damage and deaths. As a result, there were 326 deaths or missing persons, and the property damage was 170 million KRW (2.27 billion KRW of 2015) including the ship and the freight (NEMA 2009).

3.1.8 Seoul Daeyeongak Hotel Fire in 1971

Around 10 p.m. on December 25, 1971, a fire at the Seoul Daeyeongak Hotel on Chungmu Street broke out. The investigation team found that a gas pipe in the kitchen of the coffee shop on the first floor had succumbed to metal fatigue, leaking gas around the hotel. The hotel's nylon and silk carpets, the extensive wood interior, and a strong southwest wind exacerbated the ensuing inferno. 163 people died, 63 were injured, and a property loss of 838.2 million KRW (10.31 billion KRW of 2015) was incurred (NEMA 2009).

3.1.9 Gunpowder Freight Train Explosion at Iri Station in 1977

The Iksan Iri Station Explosion accident was an explosion accident identified as human error due to the deliverer while a freight train carrying 30 tons of gunpowder (ex. dynamite) was stoped at Iri Train Station at around 9:15 p.m. on November 11, 1977. An unattended candle left by a sleeping deliverer set off a box full of gunpowder. The National Railroad Administration's employment of lenient safety standards allowed the deliverer to delay the transit of the dangerous articles, prohibited by the principle of direct delivery. The accident caused 59 deaths, 185 seriously injured persons, 1158 slightly injured persons, and 7591 affected buildings. Additionally, there were 7873 displaced people from 1674 households, 1.09 billion KRW (5.01 billion KRW of 2015) damage of railway services, 1.06 billion KRW (4.87 billion KRW of 2015) damage of vehicles, 81 million KRW (372.1 million KRW of 2015) damage of electrics, 63 million KRW (289.4 million KRW of 2015) damage of machines, and 114.53 million KRW (526.1 million KRW of 2015) damage of freight (NEMA 2009).

3.1.10 Typhoon Agnes in 1981

Typhoon Agnes formed at sea 600 km in a southeastly direction from Guam on August 25, 1981 and moved northward. It affected all the cities and provinces on the Korean peninsula, including Jeollanam-do and Gyeongsangnam-do, from August 31 to September 4. Particularly, flood inundation aggravated the damage to the Mokpo-si, Jangheung-gun, Goheung-gun, and Haenam-gun regions since high tide and flow time overlapped while the daily amount of rainfall was 200–400 mm. Typhoon Agnes, which hit Jeollanam-do the hardest (60 casualties or missing persons and 13 injuries), left 114 dead, 25 missing, 14,346 displaced people, and 98.28 billion KRW (203.5 billion KRW of 2015) in property damage (Ministry of Construction 1982).

3.1.11 Great Flood in 1984

The torrential downpour from August 31 to September 3 in 1984 affected all major cities and provinces with the greatest damage occurring along the Han River. The torrent of rain caused 164 deaths, 25 missing persons, 150 injuries, 355,216 displaced, and 164.37 billion KRW (322.1 billion KRW of 2015) in property damage (Ministry of Construction 1985).

3.1.12 Typhoon Judy in 1989

Typhoon Judy which developed in the North Pacific, 250 km eastward of Okinawa on July 24, 1989, damaged the Gyeongsangnam-do including Busan City, Geoje-si, Masan-si,[7] Chungmu-si, and Namhae-gun on July 28. The damage from Typhoon Judy was intensified by the simultaneous high tide, volume of precipitation, and delay in draining the inner basin. The typhoon caused 20 deaths, 16 missing

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[7] The Masan-si was merged into the Changwon-si in 2010.

persons, and 119.19 billion KRW (224.5 billion KRW of 2015) in property damage (Ministry of Construction 1990).

3.1.13 Collapse of Levee in Ilsan Region in 1990

The collapse was due to the development of a rain front when a dry and cold continental air mass over Manchuria collided with a wet and hot maritime air mass over the southern part of the East Sea; the colliding masses stayed over the central region from September 9 to 12 (NEMA 2009). The downpour caused 126 deaths, 37 missing persons, 187,265 displaced people, and 520.31 billion KRW (993.3 billion KRW of 2015) in property damage (Ministry of Construction 1991).

3.1.14 Train Overturn Accident at Gupo Station in 1993

A railroad foundation, 200 m from the Deokcheon Stream Bridge, Deokcheon 2-dong, Buk-gu, Busan City, subsided, and it caused the 117th Mugunghwa train from Seoul City to Busan City to overturn at 5:30 a.m. on March 28, 1993. The slack reinforcement of walls and ceiling prior to explosive excavation work caused the ground the collapse that caused the Gupo Train to overturn, killing 78 people, injuring 198, and causing a 37.5 h delay in train service (NEMA 2009).

3.1.15 Asiana Airlines Boeing 737 Crash in 1993

Asiana Boeing 737 crash near Ungeo Mountain, Masan-ri, Hwawon-myeon, Mokpo-si, Jeollanam-do, at 3:50 p.m. on July 26, 1993. Even though there was bad weather conditions and low visibility, a reckless landing attempt was made but failed, resulting in 66 deaths and 40 injuries (NEMA 2009).

3.1.16 Seohae Ferry Sinking Accident in 1993

A West Sea Ferry boat met storms and sank near the coastal waters of Wido-myeon, Buan-gun, Jeollabuk-do, at 10:10 a.m. on October 10, 1993. When the boat tried to sail back as the weather got worse, its propeller got stuck on old fishing gear and the body of the boat lurched and sank. Baggage overload and an excessive embarkation of 362 people (capacity was 221) directly lead to the accident and 292 deaths and 70 injuries (NEMA 2009).

3.1.17 Seongsu Bridge Collapse in 1994

The collapse of Seongsu Bridge was caused by the 10th and 11th bridge piers collapsing on the north side of Seongsu Bridge at 7:38 a.m. on October 21, 1994. Seongsu Bridge was a bridge linking Seongsu 1-ga 1-dong, Seongdong-gu and Apgujeong-dong, Gangnam-gu. A multiple of reasons lead to the accident: poor construction techniques in welding, safety-related defects, inefficient regular checkups, diagnosis and repairs, and careless repairs of the heavy vehicle land and floor beams. The accident caused 49 casualties (32 deaths and 17 injuries) (NEMA 2009).

3.1.18 Gas Explosion in Daegu City in 1995

A gas explosion occurred at the new construction site for a new Daegu Department Store, which was located at the Sangin-dong, Dalseo-gu, Daegu City, Sangin crossing at 7:52 a.m. on April 28, 1995. During the grouting at the department store construction site, a worker broke a city gas pipeline that passed near the site. The subsequent action allowed gas to leak into a subway construction site about 77 m away where it ignited into an inferno. After the accident, poor response increased the damage: the construction company reported the break of the gas pipe 30 min after the fact and the Daegu City Gas did not take immediate action even after it was reported. The accident caused 101 deaths, 202 injures, and 2.7 billion KRW (4.18 billion KRW of 2015) in property damage (NEMA 2009).

3.1.19 Sampoong Department Store Collapse in 1995

The collapse of the Sampoong Department Store, located in Seocho-dong, Seocho-gu, Seoul City, took place at 05:55 p.m. on June 29, 1995. The frequent design changes, the irresponsible extension or reconstruction works after completion, the out of control maintenance office, and the callus regard to safety protocols were the direct and indirect causes of the accident. The accident caused a total of 1439 casualties (502 deaths and 937 injuries) and 34 billion KRW (52.6 billion KRW of 2015) in property damage (NEMA 2009).

3.1.20 Typhoon Janis in 1995

Typhoon Janis and heavy rainfall from August 19 to 30 in 1995 caused severe damage in 14 cities and provinces, including Chungcheongnam-do, Jeollabuk-do, and Gyeongsangbuk-do, and 142 towns and villages. Additionally, the heavy rain leads to a severe landslide and the flooding of a stream. The typhoon caused 65 casualties, 789 households damaged, 2493 homeless, and 456.3 billion KRW (706.3 billion KRW of 2015) in property damage (Ministry of Interior 1996).

3.1.21 Korean Air Boeing 747 Crash in 1997

A Korean Air Boeing 747 crashed into a mountainside 5 km from the Guam Hagåtña Airport as it was trying to make an approach at 12:55 a.m. on August 6, 1997 (at 01:55 a.m. local time). A software malfunction caused a Minimum Safe Altitude Warning (MSAW) from an approach control center to fail. The accident killed 231 Koreans and 16 non-Koreans and injured 25 (NEMA 2009).

3.1.22 Torrential Downpour in 1998

From July 31 to August 18, 1998, 10 torrential downpours occurred in a part of the Jiri Mountain Range, Seoul City, Gyunggi-do, and the south central region of Chungcheong-do. Deaths were exacerbated due to people camping overnight during the deluge and a landslide that destroyed many homes. There were 324 deaths (89 from the landslide, 189 from rapid streams and strong currents, 24 from building collapses, and 22 from other reasons), 26,818 homeless nationwide (24,531 in Gyunggi-do alone and 2287 in Seoul), and 1.248 trillion KRW (1.607 trillion KRW of 2015) in property damage (Ministry of Government Administration and Home Affairs 1999).

3.1.23 Typhoon Rusa in 2002

The 15th Typhoon Rusa formed near Guam at 9 a.m. on August 23, 2002, and grew to be a strong typhoon with 950 hpa central pressure and maximum instantaneous wind speed of 56.7 m/s, which broke the historical Korean weather observation records. Typhoon Rusa caused the most severe damage since Typhoon Sarah hit in 1959. It passed Goheung-gun, Jeollanam-do, Boeun-gun, Chungcheongbuk-do, and Inje-gun, Gangwon-do, at 6:00 p.m. on August 31 and disappeared 130 km away from Sokcho Sea at 3:00 p.m. September 1. This typhoon recorded the greatest daily rainfall since the Korean weather observation opened in 1904, recording 870.5 mm in Gangneung-si, Gangwon-do on August 31. The central pressure of Typhoon Rusa was 967 hpa (Typhoon Sarah in 1959 was 952 hpa), and the maximum wind speed recorded was 60.0 m/s (Typhoon Sarah was 46.9 m/s) at the Jeju Weather Observation Site. Typhoon Rusa damaged 16 cities, 16 provinces, 203 towns and villages, caused 213 deaths and 33 missing, and made 63,085 homeless from 21,318 households. Flooding inundated 27,562 homes and 31,280 ha of farmland, causing 5.148 trillion KRW (6.682 trillion KRW of 2015) in property damage. Approximately 7.145 trillion KRW (9.273 trillion KRW of 2015) was spent for the recovery (Ministry of Government Administration and Home Affairs 2003).

3.1.24 Daegu Subway Fire in 2003

The Daegu Subway fire occurred at Jungang St Station along the Daegu Subway line number 1. This accident was caused by a man with stroke disabilities Grade 2, who set fire to his clothes and upholstery sheets in the 1079 subway train. There was a total of 339 casualties (192 deaths and 146 injuries). The platform was in blackout and quickly filled with smoke; the 1080 Jungang St bound train entered the platform but could not reverse out of danger due to the power being cut; the fire from the 1079 train quickly spread to the subway station building. As a result, there were 142 bodies found in the 1080 train. The accident caused 557 thousand KRW (707.5 thousand KRW of 2015) in property damage, including underground platforms; a movable asset damage of 4.211 billion KRW (5.349 billion KRW of 2019) including trains, communication equipment, and platform equipment; and 51.6 billion KRW (65.542 billion KRW of 2015) of trains and historical facilities damage according to material damage standards in terms of recovery cost (Board of Audit and Inspection of Korea 2003).

3.1.25 Typhoon Maemi in 2003

The 14th Typhoon Maemi formed near the northwest area of Guam in September 2003. It landed near Sacheon-si, Gyeongsangnam-do, at 8 p.m. on the 12th, left the east sea at Uljin-gun at 2 a.m. on the 13th, and disappeared in the west east sea of Sapporo, Japan, on the 14th. The central pressure of Typhoon Maemi was 950 hpa (Typhoon Sarah in 1959 was 952 hpa and Typhoon Rusa in 2002 was 967 hpa) which was the lowest since the Korea weather observation stations began monitoring. Its maximum wind speed recorded 60.0 m/s (Typhoon Sarah was 46.9 m/s) at the Suwolbong Weather Station in Hankyung, north Jeju Island, at 4:10 p.m. in September 2 and at the Jeju Island Weather Station 2 h later at 6:11 p.m. The maximum rainfall was 453 mm in the south sea and the maximum hourly rainfall was 79 mm in the south sea from 8 to 9 p.m. in September 12. Typhoon Maemi damaged 14 provinces; 156 cities, counties, and districts; and 1657 eup, myeon, and dong. It caused 117 deaths (63 casualties occurred in the Gyeongsangnam-do region) and 13 missing and made 61,844 people from 19,851 households homeless. It caused 4.22 trillion KRW (5.36 trillion KRW of 2015) in property damage, including 1.28 trillion KRW (1.626 trillion KRW of 2015) of private facility damage and 2.94 trillion KRW (3.734 trillion KRW of 2015) of public facility damage (NEMA 2004).

3.1.26 Woo-myun Mountain Landslide in 2011

The Woo-myun landslide occurred between 7:40 a.m. and 8:40 a.m. on July 27, 2011, by torrential downpour at Umyeon Mountain, Umyeon-dong, Seocho-gu, Seoul City. Due to torrential downpours and weak geological features, there were 150 slope collapses and 33 avalanches of sand and stones in 12 areas (69,000 m^2). The landslide caused 67 casualties (16 deaths, 51 injuries), 11 houses destroyed (1 full destruction, 10 partial destructions), 76 vehicle damages, and flood damage (2103 houses, 1583 plants and stores). The media and NGOs criticized the government for a lack of disaster preparedness (Seoul Metropolitan Government 2014).

3.1.27 Typhoon Bolaven and Typhoon Tembin in 2012

The 14th Typhoon Tembin struck the southern coast of Korea 43 h after the 15th Typhoon Bolaven struck the Ongjin peninsula, August 25 to 30, 2012. The typhoon, which contained strong winds and heavy precipitation, caused the most damage in the Jeollanam-do and Jeollabuk-do. The typhoon resulted in 15 deaths, 34 injuries, 2902 displaced from 1458 households, and 636.6 billion KRW (603.6 billion KRW of 2015) in property damage (3665 private facilities, 2701 public facilities) (NEMA 2013).

3.1.28 Hydrofluoric Acid Leak in Gumi-si in 2012

The Hube Global Co., Ltd. chemical plant (324, Bongsan-ri, Sandong-myeon, Gumi-si, Gyeongsangbuk-do), located in Gumi 4th National Industrial Complex, experienced a chemical leak around 2:43 p.m. on September 27, 2012. The subsequently labeled accident, the Gumi hydrofluoric leak, occurred when employees of the company were extracting hydrogen fluoride (HF) from a tanker. A valve in the tanker that was not secured sprang open, allowing HF to escape and consequently ignite. The valve, which remained open from 3:43 p.m. to 11:40 p.m., allowed 8–12 tons of hydrogen fluoride to flow out as a gas (Joo et al. 2013). The ensuing fire and gas leak killed 5 people, injured 18, and polluted 212 ha of agricultural land farmed by 469 families (Gumi-si 2013).

3.1.29 Gyeongju Mauna Ocean Resort Gymnasium Collapse Accident in 2014

The Gyeongju Mauna Ocean Resort Gymnasium collapse accident occurred at around 9:05 p.m. on February 17, 2014. The accident was caused by various errors: poor planning, negligent supervision, and the failure to remove heavy snow from the roof in a timely manner. In addition, failure of cooperation between first responders and other agencies, such as blocked roads by media vehicles and delayed deployment of heavy rescue support equipment, intensified the disaster damage: 10 dead and 204 injured (Daegu District Public Prosecutor's Office Press Release 2014).

3.1.30 Sewol Ferry Sinking Accident in 2014

The Sewol Ferry sinking accident occurred on April 16, 2014, while the ship with 6825 ton was en route from Incheon City to Jeju Island. The ship went down carrying 476 people; 295 died and 9 still remain missing as of March 3, 2017. The 2014 audit report indicated several direct and indirect causes of the catastrophic events: the ship company's greed to overload the vessel only thinking about profit; the captain and his crew's negligence of duty, escaping without alarming the passengers of the danger of the situation; poor safety checks while in port; and improper response of emergency organizations during the crisis (Board of Audit and Inspection of Korea 2014).

3.1.31 Middle East Respiratory Syndrome in 2015

MERS-CoV,[8] a deadly viral respiratory infectious disease out of Saudi Arabia, first appeared in Korea in May 2015 and lasted in July 2015 (Daegu District Public Prosecutor's Office Press Release 2014). From the first appearance, the virus quickly spread to infect 186 and killed 36 people over the 2-month period with an estimated 2 billion US dollars in direct economic lose and a further 0.5 in indirect lose. The cause for the swiftness is because the first infected person did not seek treatment until 9 days after returning from the Middle East, and the Ministry of

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[8] MERS-CoV was first identified in a patient in early 2012 in Saudi Arabia and rapidly spread to London, England, later that same year. However, the syndrome was somewhat contained until a severe outbreak occurred in April 2014, in the Philippines. It quickly spread across 27 nations, resulting in 513 deaths; the majority of the deaths occurred in Saudi Arabia (452) and cost each nation effected by the virus an estimated 1–3 billion US dollars in direct or indirect losses (world estimate is 30 to 90 billion).

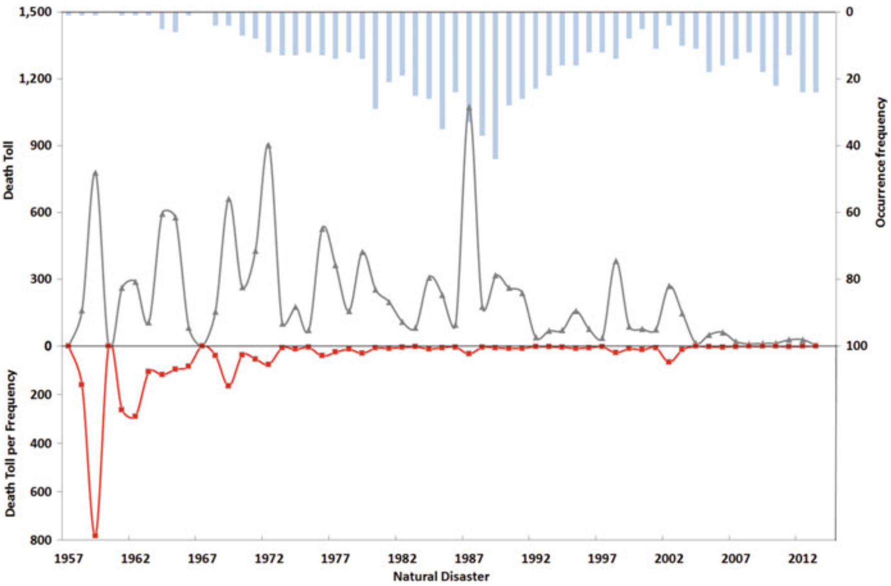

Fig. 3.1 Death toll due to natural disaster by year

Health and Welfare did not release pertinent information to the public in the onset of the disaster. Additionally, the inefficient national epidemic prevention systems and a lack of a substantial MERS-CoV response manual added to the escalation of the crisis (Ministry of Health and Welfare 2016).

Until now, we scrutinized the major disasters that occurred in Korea from 1948 to 2015. The next step is to analyze the pattern of disaster occurrence in Korea during the same period. The trend of death tolls due to natural and social disasters and economic loss due to natural disasters by year are shown in Figs. 3.1, 3.2, and 3.3. The trend of economic loss due to social disasters is not included because its criteria are in the process of being set up by the Korean government.

The analysis of the graph above indicates the following trend:

- Death toll due to natural disaster significantly decreased after 2004.
- Economic loss per occurrence frequency due to natural disaster after 2000 increased. It is caused by Typhoon Rusa in 2002 and Typhoon Maemi in 2003.
- The death toll due to social disaster after 1990 increased.

The analysis of death toll and economic loss due to natural disaster and social disaster by year can show the overall trend of disaster damage. However, it is not sufficient information for the development of an effective disaster response policy. Therefore, the analysis of the characteristic of each disaster will be conducted by using a statistical model.

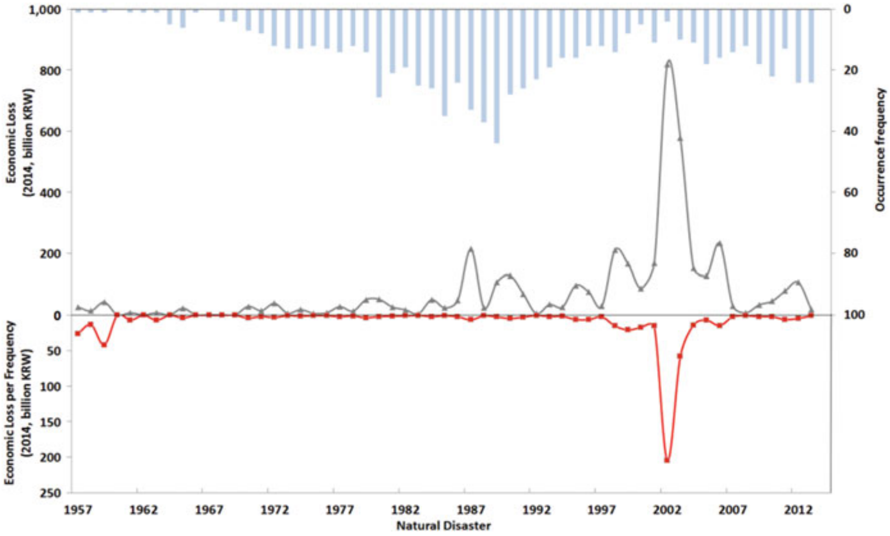

Fig. 3.2 Economic loss due to natural disaster by year

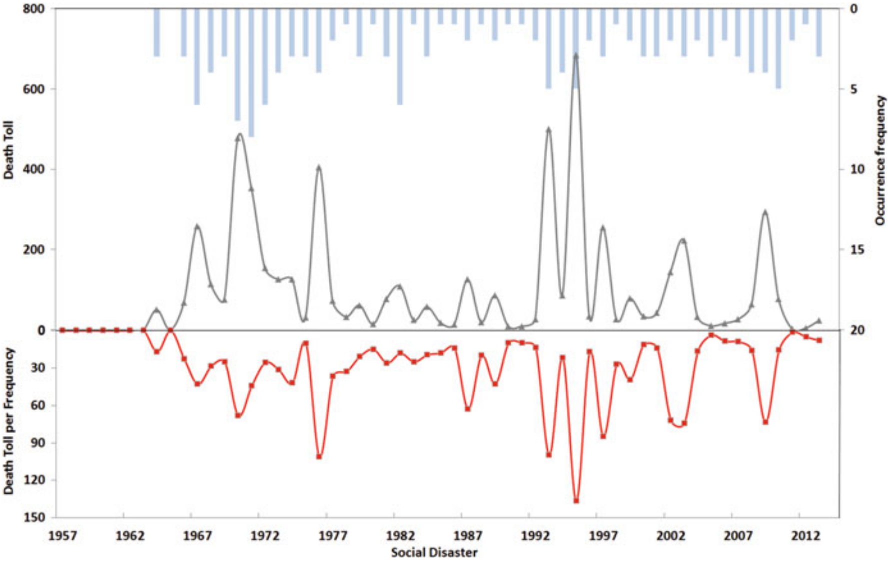

Fig. 3.3 Death toll due to social disaster by year

3.2 Power-Law Distribution

3.2.1 Theoretical Background

Normal distribution has been used as basic probability model since Gauss proposed a statistical probability model named Gaussian distribution. A normal distribution refers to a probability model that is decided by a mean and a standard deviation, as shown in (3.1). The distribution shows the greatest number of events around the average, and the probability of an event's occurrence drops as we move further away from the mean. Heights, weights, school grades, and other such diverse aspects of human life are known to follow this pattern of normal distribution. The model is thus used in various disciplines, including surveying, social sciences, the humanities, and medicine:

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \tag{3.1}$$

where μ is the mean and σ is the standard deviation.

However, not all natural phenomena occur with the greatest frequency at or around the mean level as the normal distribution would predict. The distribution of social wealth and the sizes of urban areas often show extreme polarizations, with events of smaller scales occurring with great probability and events of larger scales occurring seldom. Vilfredo Pareto, the Italian economist, revealed that the amounts and frequencies of personal wealth follow these polarized patterns in his study on the distribution of social wealth in 1896 (Pareto 1896). Auerbach (1913) also unveiled the fact that the sizes and frequencies of urban populations bear a linear relation on the log-log scale. The two variables that bear a linear relation on the log-log scale can be expressed like (3.2). Removing the logs from the linear equation, we obtain a power-law relation expressed in (3.3)

$$p(x) = -\alpha \ln x + C \tag{3.2}$$

$$p(x) = Cx^{-\alpha} \tag{3.3}$$

where $p(x)$ decreases as x increases and α is a coefficient indicating the level of decrease. Also, C is a constant to make the maximum value of cumulative probability function to be 1. $C =$ ec, and it can be expressed without the negative sign. However, the negative sign is used in general to indicate clearly that the graph has a decreasing shape toward the end.

Zipf (1949) observed the same phenomenon in the relation between the frequency and the rank of a book or document in which words are used. The power-law distribution is thus also known as the Pareto distribution or Zipf's law, after these two pioneering researchers.

Pareto also discovered that, while there are more people without much wealth than people with much wealth, almost 80% of the gross income of a society is concentrated in the top 20% of the wealth (known as Pareto's law or the 2080 law). In the power-law distribution, in other words, events with less frequency may still shape the long tails of the given graph, unlike the tendency of events to be concentrated around the mean in the normal distribution.

Researchers so far have found that the stock markets (Gabix et al. 2003), Internet networks (Faloutsos et al. 1999), the sizes of stars (Peebles 1974), the sizes of computer files (Crovella and Bestavros 1996), the citation frequencies of academic articles (Price 1965), the number of species of living organisms (Willis and Yule 1922), the number of visitors to Web pages (Adamic and Huberman 2000), and others follow the power-law distribution pattern.

To understand the ecosystem better, biologists used the Complexity Theory in conducting mathematical research on nonlinear dynamic systems. This complex system follows the power-law distribution rather than the bell-curve distribution (Farber 2003), and thus disasters occurring in such complex systems appear by power law with "fat tails" (Etkin 2015). Figure 3.4 shows that events occur most frequently around the average in the normal distribution, while events occur most frequently in the minimum value in the power-law distribution. For example, there are large numbers of small-scale earthquakes, compared to small number of large-scale earthquakes, and the pattern of the frequency and magnitude is consistent with the power-law distribution. The population of the city and intensity of the earthquake also follow the power-law distribution (Farber 2003). Such features are hardly characterized by general or average values, which are found in the phenomenon that follows the power-law distribution (Clauset et al. 2009).

Events following power-law distribution are independent from scale, and it is very hard to find a typical characteristic size. In general, power-law distribution includes many small events, slightly larger and bigger events, and extremely severe events in some cases (Farber 2003). Accordingly, power law has the characteristics of a fat tail; thus, for events that do not occur frequently, hazards explained by power law are more important than those explained by normal distribution in terms of risk analyses.

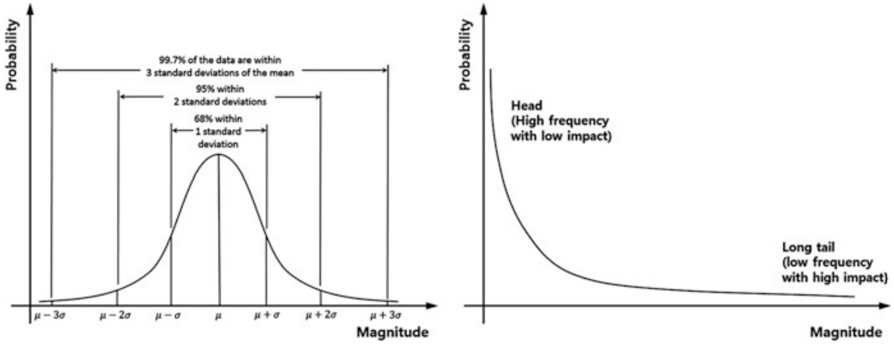

Fig. 3.4 Normal and power-law distribution

As disaster has been triggered by various causes and its aspect has been complicated, research on disaster using Complexity Theory has been conducted by several scholars. Through research by Barton et al. (1994), Becerra et al. (2006), Janczura and Weron (2012), and Jo and Ko (2014), the relation between event frequency and its magnitude about earthquake, hurricane, and flood follows the power law. Etkin (2015) insisted that more research should be conducted because disasters are better explained by power law having long tail.

3.2.2 Relation Between the Frequency and the Magnitude of Disasters in Korea

3.2.2.1 Data

The target disasters in this study include natural disaster and social disaster provided in Article 3 of the Disasters and Safety Act. The number of deaths and economic loss due to natural disaster and social disaster, provided by YND from 1979 to 2015, YSD from 1995 to 2015, and a book titled *60 Year History of Disaster Management* published in 2009 by the National Emergency Management Agency (NEMA), was used in order to examine the relation between the occurrence frequency of disasters and their damage (death toll and economic loss). The death toll and economic loss due to natural disaster provided by YND (1979–2015) include most natural disasters in Korea; however, YSD (1995–2015) does not provide detailed data about all types of social disaster. In addition, the data in the YSD is incomparable between disaster and minor accident. In addition, the ministry or agency that is mainly responsible for each type of social disaster does not have a database about death toll or economic loss due to social disaster. The most credible data source about social disaster that is available is the book titled *60 Year History of Disaster Management* published in 2009 by NEMA. Therefore, the *60 Year History of Disaster Management* is the primary data source of social disaster for this book, and the *YSD* will supplement it. The number of natural disasters, collected and analyzed through the method above, is 851 and that of social disasters is 172. As the data is collected based on the number of deaths, disaster of which relation with casualties does not appear in official records, such as drought or yellow dust, is excluded from this research.

In order to standardize the damage amount due to disasters into a value at a specific time point, it was converted based on the 2015 Price Index announced by the Bank of Korea. The equation for the conversion is as shown in (3.4):

$$\begin{aligned}&\text{Value equivalent index} = \text{Price index of reference year}/\text{Price index of relevant year}\\&\text{Converted amount} = \text{Value equivalent index} \times \text{Value in Won}\end{aligned} \tag{3.4}$$

All economic loss in this book was converted to 2015 values by using the 2015 Price Index announced by the Bank of Korea. For reference, we put the economic loss in the occurrence year in the footnote.

3.2.2.2 Analysis Methodology

The method suggested by Becerra et al. (2006) was used for the model to estimate the relation between the occurrence probability and scale of disaster. The occurrence probability of disaster can be expressed as shown in (3.5) as the probability function to scale:

$$p(x) = 1 - \frac{n(X \leq x)}{N} = \frac{n(X > x)}{N} \tag{3.5}$$

where X is the random variable of disaster, x is the damage scale of the relevant disaster, $n(X > x)$ is the number of disasters which scale exceeds x, and N is the total number of disasters. The disaster occurrence probability function used in (3.5) is not the occurrence probability of a disaster of a certain size but the occurrence probability of a disaster over a certain size, and this is the cumulative probability function that calculates the cumulative occurrence probability of a disaster over the relevant size. In this research, the relation between the occurrence probability and size of disaster calculated through (3.5) was assumed to be the power-law distribution, and therefore the probability density function in (3.5) can be estimated using the power law as shown in (3.6):

$$p(x) = Cx^{-\alpha} \tag{3.6}$$

where $p(x)$ decreases as x increases and α is a coefficient indicating the level of decrease. Also, C is a constant to make the maximum value of cumulative probability function to be 1. C is calculated differently as shown in (3.7) depending on whether the data used is continuous or discontinuous:

$$\begin{aligned} Cx &= (\alpha - 1)x_{\min}^{\alpha-1} && \text{(countinuous)} \\ &= 1/(\zeta(\alpha, x_{\min})) = 1/\sum_{n=0}^{\infty}(n + x_{\min})^{-\alpha} && \text{(discrete)} \end{aligned} \tag{3.7}$$

The values to estimate from the model in (3.7) are $x_{\min}$ and α indicating the minimum value of section which begins to follow the power law and the level of decrease, respectively. In order to estimate $x_{\min}$ and α at the same time, α was estimated by increasing the value of $x_{\min}$ gradually, and the conformance of estimated $x_{\min}$ and α was verified using the Kolmogorov-Smirnov statistic. Since the range of the minimum value and the maximum value for death toll and economic loss indicating the size of disaster was very wide, the values were displayed in a graph by taking log. At this time, it is also possible to convert (3.6) into a linear equation just as (3.8) by taking log for the disaster occurrence probability, and two variables following the power low show a linear relation on the log-log graph:

$$\log p(x) = C - \alpha \log x \tag{3.8}$$

3.2.2.3 Power-Law Distributed Disasters

This section will analyze the relation between occurrence frequency and disaster damage by using a statistical model. The data and analysis methodology was explained above. The relation between occurrence frequency and economic loss due to social disaster is excluded in the analysis because most economic loss due to social disaster are not available in official records.

Arranging the probability of the occurrence of disaster by disaster size, we can divide the number of disasters above a certain size by the number of total disasters observed, as shown in (3.9). Assuming that the magnitude of disaster damage and their probability of occurrence bear a power-law relation as shown in (3.10), we estimate the values of $x_{\min}$ and α. Here, the scale of the death toll consists of noncontinuous data in the form of integers that decrease toward the end. Property damage consists of continuous data with decimal points. We thus apply (3.11) to each to obtain the correction factor, C:

$$p(x) = 1 - \frac{n(X \leq x)}{N} = \frac{n(X > x)}{N} \tag{3.9}$$

$$p(x) = Cx^{-\alpha} \tag{3.10}$$

$$\begin{aligned} Cx &= (\alpha - 1)x_{\min}^{\alpha-1} && \text{(countinuous)} \\ &= 1/(\zeta(\alpha, x_{\min})) = 1/\sum_{n=0}^{\infty}(n + x_{\min})^{-\alpha} && \text{(discrete)} \end{aligned} \tag{3.11}$$

Through this process based on the power-law distribution, we estimate the relation between the magnitude of disaster damage, and the results are shown in Table 3.1 and Fig. 3.5.

Table 3.1 lists the values of $x_{\min}$, α, and C that have been estimated, while Fig. 3.5 charts the relation between the estimated probability and the actual probability of disasters of varying sizes using the estimated variables. The blue circle in Fig. 3.5 indicates the probability of actual disasters, while the blue dotted line represents the estimated probability of disasters. (a) and (b) of Fig. 3.5 indicate the probabilities of property damage and the death toll ensuing natural disaster, respectively, while (c) of Fig. 3.5 indicates the probabilities of death toll ensuing social disasters. In most cases, estimates and actual probabilities remained close to each other, affirming the law of power-law distribution. However, in the cases of property damage caused by natural disasters, the model in this research tended to

Table 3.1 Factors in power-law distributed disasters in Korea

	Natural disaster			Social disasters		
	$x_{\min}$	α	C	$x_{\min}$	α	C
Death toll	23	1.970	19.8819	10	2.040	10.8216
Economic loss	6,039,505	1.560	5.2525E-8			

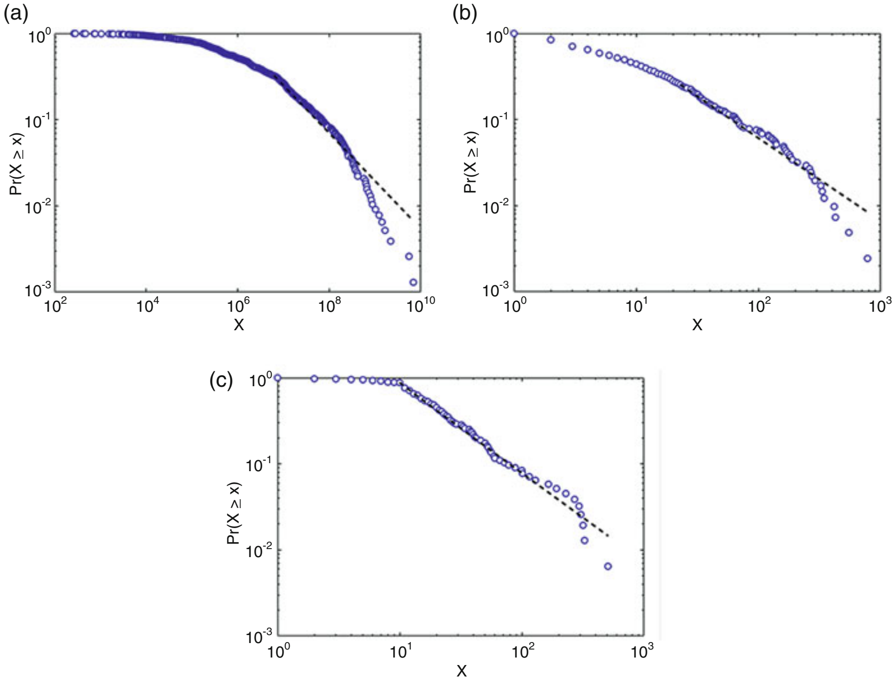

Fig. 3.5 Power-law distribution of natural disaster and social disaster in Korea. (**a**) Economic loss due to natural disaster. (**b**) Death toll due to natural disaster. (**c**) Death toll due to social disaster

overestimate the probability of a major-scale natural disasters' occurrence than that of the reality. The collections of overestimated events showed linear relations on two sections of the log-log graph, thus showing the pattern of a double power-law distribution.

The estimated α-value from the power-law distribution indicates the extent of inverse proportion between the probability of disaster occurrence and the magnitude of disaster damage. The larger the α-value, the less likely a disaster of a given size is to occur; it may suggest that the α-value shows how vulnerable a nation is to large scale disasters. In Korea, the α-value in the power-law function of the death toll and the probability of occurrence of natural disasters was 1.97. For future study, it is worthwhile to compare it to the α-values of other regions and countries listed in Becerra et al. (2006) (i.e., world average = 1.73, North America = 2.13, South America = 1.68, Asia-Oceania = 1.69, Africa = 1.66, and the European Union = 1.73).

According to Becerra and others' (2006) result, most of α-values lie between 1.6 and 1.75. The high α-value of 2.13 of North America are inferred to be due to the relatively low number of observations for North America or high incomes and low population density (Becerra et al. 2006). Korea has a relatively high α-value of 1.97, despite the fact that the population density is relatively high.[9]

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[9] Author's note: Although it is arguable that the higher value of Korea is caused by the more exact disaster data that Korea has than other countries, our indication is that this high value is caused by the fact that, since the 1990s, Korea has continued to invest in early warning systems and in strengthening disaster capabilities against natural disasters. As a result, the number of casualties due to natural disasters has been rapidly decreasing.

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