

Towards More Advanced, Equitable Natural Hazard Risk Metrics

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Abstract: With the aim of identifying gaps in the state of the art in natural hazard risk metrics, we performed a literature review on some of the risk metrics frequently employed in risk assessments of earthquakes, floods, and hurricanes. Academic researchers use risk metrics to develop risk models, new framework and explore new approaches to assess risks from natural hazards, while policy makers use risk metrics to make informed decisions. Reviewing risk metrics of natural hazards is crucial for understanding and ensuring the equitable distribution of resources and policies in natural hazard management. Direct economic loss, indirect economic loss, casualties, well-being loss, mental health loss, environmental loss, population displacement and recovery time are the risk metrics that will be examined in this research. The report is organised into sections each focusing on a different risk metrics. In each section, the risk metric will be introduced, defined, and discussed, followed by a review of how the risk metric is used theoretically and in practice. Theory papers include academic journal and practice papers include news articles and policy papers. Our review found that direct economic loss is the most prevalent risk metric used in risk assessments of the three natural hazards. This report concludes with discussions of the equity of the risk metrics reviewed, the limitations to our research and proposal of potential risk metrics that are more equitable for future use.

Keywords: Earthquake, Risk metrics, Costs.

1. Introduction

Natural hazards such as earthquakes, floods, hurricanes, and more can cause enormous amounts of property damage, injury, disruption to socioeconomic system, loss of livelihoods, environmental damage, and displaces people from their homes worldwide (Bankoff, 2003). A natural hazard can be defined as “environmental phenomena that have the potential to impact societies and the human environment” (Natural Hazards,2023) Some parts of the world are more at risk of certain types of natural hazards than others; for example, areas around the ‘ring of fire’ are more prone to earthquakes. It is important to understand the risk in

order to better prepare and mitigate the negative impact of natural disasters. According to the UNISDR (United Nations Office for Disaster Risk Reduction) terminology, the definition of "risk" is "the combination of the occurrence probability of an event and its negative consequences" (UNISDR Terminology on Disaster Risk Reduction, 2009) (refer to figure 1). A risk assessment is defined as “a qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential risk hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend”. Results from a risk assessment can be used to develop strategies to mitigate or manage those risks.

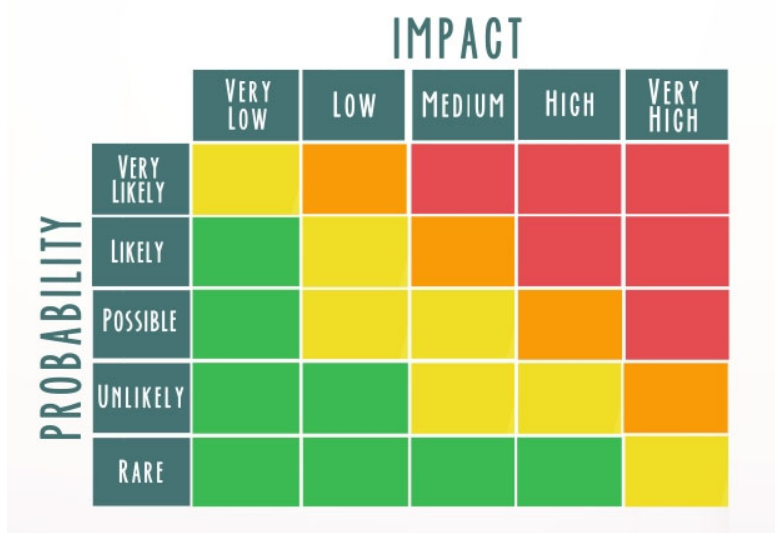


Figure 1. Visualisation of risk as a product of probability and impact with green representing low risk while red representing high risk

A risk metric is a method used to measure the risks of natural hazard and serve as an essential link between the

quantitative risk assessment and decision-making (Johansen and Rausand, 2014). Risk metrics are used in both theory and in practice. In theory, risk metrics serves as quantifiable indicators to examine the relationship between natural hazard events, human vulnerability, and resilience. In practice, risk metrics are used by policy makers to make informed decisions and to develop new polices or strategies to mitigate the risks posed by natural hazard. Furthermore, they are also used in news articles to provide readers with information on the impact of natural hazards (Vahdat et al.,2014). For example, a risk metric that quantifies the number of fatalities can be used to identify the type of natural hazard events that lead to the highest number of fatalities which will help in decision making on types of interventions and mitigation strategies to reduce casualties in similar future event.

This report aims to conduct a literature review of risk

metrics that have been used in natural hazard risk assessments with a view to identify gaps in the state of the art of the risk metrics, exploring the equity between risk metrics and proposing new metrics to fill the gaps (refer to figure 2). Reviewing risk metrics of natural hazards is crucial for understanding and ensuring the equitable distribution of resources and policies in natural hazard management. Academic researchers also use these metrics to develop risk models and explore new approaches to assess risks from natural hazards. Investigating equity of risk metrics will help us investigate if the metric can potentially distinguish the differences between the experiences of different social and economic groups in a natural hazard. Through this we can identify the metrics that are more equitable and use them to propose inclusive and equitable disaster preparedness and response strategies.



Figure 2. A flowchart visualising the process of natural hazard risk assessment and where risk metrics come in

This study will only focus on risk assessments of three natural hazards: earthquake, floods, and hurricane, as they are three of the most devastating and deadly natural hazards (Hannah et al., 2022). Earthquake can damage and even destroy homes through ground shaking, soil liquefaction, and landslides. The sudden influx of water from floods can cause damage to homes, infrastructure, disrupt transportation and communications systems, as well as spread diseases by contaminating drinking water. Hurricanes cause widespread damage and loss of life through strong winds, heavy rainfall, and storm surge.

The report will be organised into sections each focusing on different risk metrics. This report will focus on economic loss, casualties, mental health impact, wellbeing/welfare loss, environmental loss, population displacement and recovery time as these were found to be the most prevalent metrics used in earthquake risk assessments in a preliminary literature review. In each section, the risk metric will be introduced, defined, and discussed, followed by a review of how the risk metric is used theoretically and in practice.

To define a clear scope for this report, criteria will be set out for selecting both theory and practice papers. For theory, journal papers that uses the metrics mentioned above to measure risks of earthquake, floods or hurricane will be reviewed. To ensure the report is up to date, only journal papers that are published from the year 2000 onwards will be included, with the more recent studies with the most citations being prioritised. On the practice side, policy papers and news articles will be reviewed. In the context of this report policy papers are identified as documents that provide evidence-based information to policymakers who will make decisions on disaster risk mitigation policies. As for news articles only articles of the of major media outlets will be reviewed to maintain a level of credibility (Majid, 2023).

To keep the scope of our report clear we will focus on specific country for each hazard for practice papers. For earthquake we will be focusing on Turkey, for floods policy papers and news in the United Kingdom will be reviewed, and

finally for hurricane only United States will be reviewed.

2. Review of Risk Metrics

This following section will focus on the review of different current natural hazards risk metrics used in literature and in practice. They have been divided into the following categories: direct economic loss, indirect economic loss, mental health, casualties, environmental loss, population displacement and recovery time.

In each section, the risk metric will first be introduced and defined, followed by review of some its most cited academic literature, then review of the metric in practice which includes policy papers and news articles. Finally, the remaining academic journal and practice papers will be summarised in two separate tables.

2.1. Economic loss

Economic loss resulting from natural hazards such as earthquake, floods and hurricane can be defined as “a perturbation to the functioning of the economic system, with a significant negative impact on assets, production factors, output, employment, or consumption.” (Hallegatte et al. 2010). Several authors in the past including Pelling et al., (2002), Cochrane (2004), and Rose (2004), have discussed economic loss and generally the typologies can be distinguished into direct and indirect losses. Economic loss is a very common method to measure the impact of natural hazard as it provides an objective and quantitative way to assess the direct and indirect costs of the disaster. Economic loss estimates consider the damage to buildings, infrastructure, and other physical assets, as well as the economic impact of the disaster on businesses, tourism, and other sectors. In this literature review we are also dividing economic losses into direct economic losses and indirect economic losses as there are significant distinctions between them.

2.1.1. Direct economic loss

Direct economic loss is defined as “the monetary value of total or partial destruction of physical assets existing in the affected area. Direct economic loss is nearly equivalent to physical damage.” (UNISDR Terminology on Disaster Risk Reduction, 2009). Physical assets are the basis for calculating direct economic loss. Some examples of physical assets include buildings such as homes, hospitals, commercial buildings, office buildings, schools, factories, public transport systems, telecommunications infrastructures, etc. Since direct economic losses are calculated from damage to physical buildings, most of the direct economic loss from hazards happen throughout the duration of the hazard itself. Direct economic losses are assessed soon after the natural hazard has happened, cost of repair or reconstruction, and insurance payments are estimated. Hence, they are tangible and usually easy to measure. In this section of the literature review we are including studies that produced results of natural hazard risks in terms of direct economic loss where a specific or range of monetary value is given.

One example of measuring direct economic loss in earthquakes is a web-based seismic risk assessment platform known as OpenQuake which is an open-source development of software for seismic hazard and risk assessment launched as part of the Global Earthquake Model (GEM) (Pinho, 2012). OpenQuake consists of a set of calculators with the capability to compute economic losses for a group of assets caused by an earthquake. OpenQuake is then able to output data which includes loss curves, loss maps, and damage distributions.

Many published academic journals papers include direct economic loss as an earthquake risk metric. To begin with, Silva et al (2015) carried out an earthquake risk assessment of entire mainland Portugal using the OpenQuake engine and produced results of earthquake risk in terms of economic losses, including economic loss map and chart of economic loss in terms of construction material, design level, and number of storeys of a building. Corbane et al (2017) utilized Earthquake Loss Estimation Routine (ELER) which is a process of assessing potential damage and economic loss caused by earthquakes to calculate earthquake risk to produce economic loss maps and a chart of top 20 cities in EU in terms of expected economic losses.

Direct economic loss as a risk metric also features prominently in flood risk assessments. For instance, in Huang et al. (2008) the authors analysed the economic losses caused by floods in 1998 in the province of Hunan, China. Their study found that floods have caused significant direct economic loss to the province, particularly in terms of damage to the region’s infrastructure and agriculture. A total economic

loss of US\$ 8.925 million dollars was recorded from the 10,722 families investigated. The authors concluded that flood-related economic loss is closely linked to the severity and duration of the flood as well as the economic levels of the flood victims. The authors also suggested that policies aimed at preventing floods should prioritise measures to prevent river floods as this type of flood causes the most significant economic losses.

Hurricanes also cause direct economic loss mainly through property damage. Strong winds can damage roofs, windows, walls, and other parts of buildings, while heavy rain can cause flooding and water damage. All of these can result in direct economic losses for property owners, insurance companies, and the wider economy. As such, the economic impact of hurricanes can be significant and can have lasting effects on affected communities (After a Hurricane, 2023). Just like earthquake and floods, many journals also use direct economic loss to measure hurricane risk. For example, Pan (2015) estimated the direct economic loss caused by Hurricane Ike in the Greater Houston Region including economic losses from damages to houses and infrastructures. The author used a systematic approach that combines disaster models, a regional input/output model and a spatial allocation model to estimate the spatial distribution of property damage by census tract. The modelling results are reasonably close to the estimates from damage insurance claim after Hurricane Ike. The author also suggested that the modelling results can provide valuable insight for policymakers and planners in identifying cost-effective options for hazard mitigation and resource allocation for post hazard relief equitably.

Direct economic loss as a risk metric is also frequently used in practice. A few weeks after the devastating earthquake struck Turkey and Syria on 6th February 2023, the Financial Times reported that the main earthquake caused \$34 billion worth of damage and that rebuilding in all the provinces affected by the main quake and its aftershocks could cost upwards of \$68 billion (Samson, 2023b). In July 2020 the UK Department for Environment, Food & Rural Affairs published a policy statement which presented a plan for investment in flood and coastal defences from 2021 that will avoid £32 billion in future economic loss from floods (Eustice and Pow, 2020). More recently, CNBC reported that Hurricane Ian which struck Florida and South Carolina last year resulted in between \$50-65 billion of insured damages (Newburger, 2022).

The remaining academic and practice papers reviewed that includes direct economic losses as a natural hazard risk metric are summarized in the tables below:

2.1.1.1 Academic

Table 1. Academic journal papers that includes direct economic loss as a natural hazard risk metric

Titles and authors	Hazard	General note
Adapting Hazus for seismic risk assessment in Canada (Nastev, 2014)	Earthquake	This paper produced maps of probability of damage of educational facilities, highway/bridges, number of collapse buildings for a rural region in eastern Canada.
The risk component of the OpenQuake engine. (Silva et al., 2020)	Earthquake	This paper simulated a possible repeat of the destructive 1906 Magnitude 7.9 San Francisco earthquake on the San Andreas fault. Results include mean loss maps of the San Francisco area.
Seismic Risk Assessment for the Prioritization of High Seismic Risk Provinces in Turkey. (Erdik et al., 2012)	Earthquake	This paper utilized Hazus to produce maps of “Sub-province-based loss ratio corresponding to 475 years return period” and “Sub-province based average annualized loss ratio (AALR) distribution for Turkey”.
Development of the OpenQuake engine, the Global Earthquake Model’s open-source software for seismic risk	Earthquake	This paper produced earthquake risk maps of Turkey in terms of economic losses, including loss map, total economic loss exceedance curves for a portfolio of assets.

assessment. (Silva et al., 2013)		
Direct and indirect economic losses form earthquake damage. (Brookshire et al., 1997a)	Earthquake	This paper presented a case study on various earthquake scenario that might occur in the Boston Metropolitan area. Result includes breakdown of economic loss estimate in terms of monetary value in a table.
Urban seismic risk assessment by integrating direct economic loss and loss of statistical life: an empirical study in Xiamen (Zhou et al., 2020)	Earthquake	This paper measured earthquake risk of Xiamen in terms of direct economic loss and produced results in the form of direct economic loss maps with measurement in monetary value.
Seismic estimation of casualties and direct economic loss to Byblos city: a contribution to the ‘100 resilient cities’ strategy (Makhoul, Navarro and Lee, 2020)	Earthquake	This paper estimated the earthquake risk of Byblos in terms of direct economic loss for 6 different scenarios and summarized the result in a table. The economic loss is measured in US dollars and the results are also presented in an economic loss map of Byblos and a chart.
Incidences of waterborne and foodborne diseases after meteorologic disasters in South Korea (Na et al., 2017)	Floods	This paper built a comprehensive evaluation model of urban flood loss based on the combination of distributed hydrological model and distributed flood loss estimation model based on the basic loss curve model.
Estimating the impact of global change on flood and drought risks in Europe: A Continental, integrated analysis (Lehner et al., 2006)	Floods	This paper studied the influence of extreme rainfall events on river drainage and sediment transport in highly urbanized catchment by continuously monitoring the discharge and turbidity.
Prior experience as a moderator of disaster impact on anxiety symptoms in older adults (Norris and Murrell, 1988)	Floods	This paper established a dynamic rainfall-runoff model (SWMM) in the study area and used the optimization model and cost-benefit analysis to determine the adaptation scheme and disaster loss.
A local-scale analysis to understand differences in socioeconomic factors affecting economic loss due to floods among different communities. (Silva and Kawasaki, 2020)	Floods	This paper analysed the impact of socioeconomic factors on direct economic losses of different communities due to floods at a local scale. The study finds that households with lower education levels and income levels and people resident in rented homes experience higher economic losses due to floods.
Damage to residential buildings due to floodings of New Orleans after hurricane Katrina (Pistrika and Jonkman, 2010)	Floods	This paper analysed the direct economic loss from damages to residential buildings caused by flooding of New Orleans after Hurricane Katrina. The authors used a dataset that contains information on the level of economic damage for around 95,000 residential buildings in areas affected by the flood which was estimated at \$16 billion.
Long-term hurricane risk assessment and expected damage to residential structures (Huang, Rosowsky and Sparks, 2001)	Hurricane	This paper developed a probabilistic hurricane event model to evaluate long-term risks of hurricane. One of the two risks evaluated is “the expected insured losses from damage to residential structures”. Estimates of the expected losses can be provided using results from the event-based simulation analysis.
Hurricane Katrina: Preliminary Estimates of Commercial and Public Sector Damages (Hicks, 2005)	Hurricane	This paper provides preliminary estimates of economic loss from Hurricane Katrina in several infrastructure categories and residential and commercial structures, content, and equipment.
Methodology for Regional Multihazard Hurricane Damage and Risk Assessment (Yan et al., 2021)	Hurricane	This paper developed a model to calculate loss in terms of percentage damage to buildings instead of monetary value.
Normalized Hurricane Damage in the United States: 1900–2005 (Collins et al., 2008)	Hurricane	This paper normalised damage from hurricane in mainland US from 1900-2005 and used it to develop models to estimate that would occur if similar magnitude of hurricane strikes the US again.
Optimal location, capacity and timing of stockpiles for improved hurricane preparedness (Paul and MacDonald, 2016)	Hurricane	This paper created a stochastic optimization model with the aim of enhancing disaster preparedness in case of a hurricane by determining the ideal location and capacity of medical supplies stockpiles. The model considers the damage to facilities that may occur during the hurricane, based on their severity and the time left for their survival.
Economic damages from Hurricane Sandy attributable to sea level rise caused by anthropogenic climate change (Vinogradov et al., 2021)	Hurricane	This paper investigated the effect of rising sea level on the direct economic damage from hurricane using the 2012 Hurricane Sandy as the case study. They found that approximately \$8.1 billion out of Sandy’s total \$60 billion damages are attributable to climate-mediated sea level rise.

2.1.1.2 Practice

2.1.2. Indirect economic loss

Indirect economic loss is defined as “a decline in economic value added as a consequence of direct economic loss and/or human and environmental impacts”. (UNISDR Terminology on Disaster Risk Reduction, 2009). Indirect economic losses can be categorized into several distinct groups according to their impact. The first is microeconomic impacts which as an example is when the revenue of a business decline due to the business interruption caused by a natural hazard. Secondly, meso-economic impact is when the revenue of a business declines because of interruptions to the supply chain or

unemployment during the immediate days after the occurrence of a natural hazard. Lastly, macroeconomic impacts are impacts on a large scale, they may include increases in prices of products, downward stock market trend, and overall decline in GDP. Indirect economic losses aren’t restricted to the area where the natural hazard has occurred and could impact the surrounding areas, on country-wide level or even globally. Indirect economic losses could also continue to have an impact long after the natural hazard’s original occurrence, so they can be intangible and hard to estimate and measure. (UNISDR Terminology on Disaster Risk Reduction, 2009).

Table 2. Practice papers that uses direct economic loss as a natural hazard risk metric

Titles and authors	Type	Hazard	General note
Earthquake Damage in Türkiye Estimated to Exceed \$34 billion: World Bank Disaster Assessment Report	Policy paper	Earthquake	This report determined the two significant earthquakes that struck Turkey are predicted to have directly damaged the country for \$34.2 billion, which is equal to 4% of its 2021 GDP. The cost of recovery and restoration would likely double.
Turkey's earthquake caused \$34 billion in damage. It could cost Erdogan the election. (Lawati,2023)	News article	Earthquake	This article reported that one third of the nation's GDP was generated in the regions affected by the earthquake, according to the Organization of Economic Cooperation and Development (OECD).
Turkey earthquake damage set to exceed \$100 bln: UN agency (Farge,2023)	News article	Earthquake	This article reported that the damages caused by the 6th of February 2023 earthquake will exceed \$100 billion.
The costs of the summer 2007 floods in England	Policy paper	Floods	This report gave ranges of estimation of the direct economic loss of 2007 floods in UK, The cost of the summer 2007 floods as a whole range from £2.5 billion to £3.8 billion, the greatest impacts are acting on the household.
Floods of winter 2015 to 2016: estimating the costs	Policy paper	Floods	This report quantified the economic damages caused by flooding between 2015-2016, the total cost within a range between £1.3 billion to £1.9 billion.
Foresight Future Flooding: Executive Summary (King and Morley, 2004)	Policy paper	Floods	This report was produced by the Flood and Coastal Defence project of the Foresight programme. The report stated that the UK experiences an average of £1.4 billion of damages every year and that in England and Wales alone properties valued at more than £200 billion are at risk of floods.
Climate change: Warming could raise UK flood damage bill by 20%	News article	Floods	This article reported that a UK Environmental Agency has warned that climate change could raise the UK's flood damage cost by 20%. The report estimated that the annual flood damage in the UK could rise to £1.4 billion by 2050.
Hurricane Andrew (1992) (U.S. National Park Service)	Policy Paper	Hurricane	After Hurricane Andrew, the National Weather Service predicted that the damage to farms, beaches, and marinas would cost \$26.5 billion. Also, this would have a significant impact on the travel and tourism sector.
Katrina's Economic impact: One Year Later (Herman, 2023)	News article	Hurricane	This article stated Katrina caused direct losses of more than \$40 billion. That was almost twice as much damage as Hurricane Andrew in 1992.
Economic Impact of Hurricanes Harvey and Irma (Stupak and Jeffrey, 2017)	Policy paper	Hurricane	This report published by the Library of Congress: Congressional Research Service discussed that the economic impact of Hurricanes Harvey and Irma caused between \$42.5 billion to \$65 billion in property damage in the US.
Preliminary estimates put Hurricane Ian's economic impact to the ag industry between \$786 million and \$1.56 billion (Kiniry, 2022)	News article	Hurricane	This article reported that the value of the agricultural production in the storm's path during each calendar year was around 8.1 billion dollars. Citrus and vegetables are the most affected, with the economic impact on Florida's agriculture alone estimated to be between 786 million and 1.56 billion dollars.

One example of published articles that uses indirect economic loss as way to measure earthquake risk is by Wu et al (2012), they measured risk by estimating the indirect economic losses caused by the 2008 Wenchuan earthquake in Sichuan. The authors used a model that can reflect earthquake related changes in production capacity and ripple effects within the economic system in the region. The results estimated the indirect economic loss in the housing and production sector to be around 40% of the direct economic loss of the hazard, which is calculated to be approximately 300 billion Chinese Yuan.

Floods, especially river floods have far-reaching and long-lasting negative economic effects (Dottori et al., 2018). Therefore, indirect economic loss as a risk metric is also often used in papers regarding flood risk assessments. Tanoue et al. (2020) describes a global modelling framework developed to estimate the indirect economic loss from river floods. The authors applied the framework to the 2011 Thailand flood and found that the estimated economic loss due to business interruption in the industry and service sector was \$14.7

billion. The indirect economic losses reduced Thailand's GDP by 4.81% in 2011 and its impact will still be felt up until 2030.

Indirect economic loss as a risk metric is also frequently featured in journals on hurricane risks. In Tatyana Deryugina, Laura Kawano, and Steven Levitt (2018), the paper quantified indirect economic losses in terms of lost income, measured through differences in tax data before and after the hurricane. The results indicate that Hurricane Katrina had a significant negative impact on the incomes of those affected by the disaster, with particularly large losses in the year of the hurricane.

Indirect economic loss as a risk metric is also used in practice. Deutsche Welle reported that the Turkish Enterprise and Business Confederation has put the estimated economic loss from loss of national income to be at \$10.4 billion and an additional \$2.9 billion from loss of working days (Harper, 2023d). In the UK, the BBC reported at the end of 2022 that severe flooding in Scotland caused road closure and rail disruption. This leads to people not being able to travel to work and disruption to supply chain thus resulting in indirect

economic loss (BBC News, 2022). As for hurricane, in 2019 the Congressional Budget Office in the US reported the expected annual loss in the commercial sector including from revenue loss due to disruption of business is \$9 billion (Dinan and Wylie, 2019).

The remaining academic and practice papers reviewed that includes indirect economic losses as a natural hazard risk metric are summarized in the tables below:

2.1.2.1 Academic

Table 3. Academic journal papers that include indirect economic loss as a natural hazard risk metric

Titles and authors	Hazard	General note
Estimation of Earthquake Loss due to Bridge Damage in the St. Louis Metropolitan Area. II: Indirect Losses. (Enke, Tirasirichai and Luna, 2008)	Earthquake	This paper calculated earthquake risk by estimating the indirect economic loss that would result from damaged bridges in the St. Louis metropolitan area.
Indirect Economic Loss Estimation due to Seismic Highway Transportation System Disruption in “5.12” Wenchuan Earthquake. (Shi & Wang, 2013)	Earthquake	This paper investigates the indirect economic loss of earthquake due to damage to public transport system after the 2008 Wenchuan Earthquake.
Direct and indirect economic losses form earthquake damage. (Brookshire et al., 1997a)	Earthquake	This paper presents a case study on various earthquake scenario that might occur in the Boston Metropolitan area. Result includes breakdown of indirect economic loss estimated in terms of monetary value in a table.
A mathematical model for flood loss estimation (Dutta et al., 2003)	Floods	This paper conducted theoretical and empirical research on statistics of major natural disasters and evaluation methods of indirect economic losses.
The impact of a convectional summer rainfall event on river flow and fine sediment transport in a highly urbanised catchment: Bradford, West Yorkshire (OLD et al., 2003)	Floods	This paper modelled the loss rate by using Leontief input-output model. By using the modified linear input-output model and dynamic input-output model, this paper explains how to quantify and evaluate the impact of chain reaction on large-scale systems in theory.
The Economic Impact of Hurricane Katrina on Its Victims: Evidence from Individual Tax Returns (Deryugina, Kawano and Levitt, 2018)	Hurricane	This paper examined the long-term economic impact of Hurricane Katrina on individuals and households in affected areas using tax return data.
Risk-based input–output analysis of hurricane impacts on interdependent regional workforce systems (Akhtar and Santos, 2013)	Hurricane	This paper discusses how loss of workforce from the aftermath of a hurricane can adversely impact the economic productivity of the affected region.

2.1.2.2 Practice

Table 4. Practice papers that uses indirect economic loss as a natural hazard risk metric

Titles and authors	Type	Hazard	General note
What is the likely impact of the earthquakes on economic growth in Türkiye?	News article	Earthquake	This article reported that the indirect economic downturn was brought on by supply chain disruptions, destruction of industries, equipment, and food supplies (loss of physical capital and inventories), worker fatalities and injuries (loss of labour force), and decreased investment in the days and weeks after the earthquake.
Counting the cost of flood	Policy paper	Floods	This report stated that in addition to having a direct impact on economic activity, floods will force the appropriate authorities to invest more money on flood mitigation and flood-prevention technologies.
Hurricane Ian to have immediate & substantial impact on E&S property market: CRC (Wells, 2022)	New article	Hurricane	This article reported that the Florida property loss of Hurricane Ian is nearly estimated to \$1 billion. At the same time, it also greatly affected the normal operation of the company, causing employees' salaries to fluctuate to a certain extent.

2.2. Casualties

A casualty of a natural disaster can be defined as a person suffering a physical or psychological injury as a result natural hazards (Watt and Weinstein,2013). This section will only focus on physical injuries as there is a separate section for risk metric concerning psychological injuries titled under “Mental Health Impact”. People usually suffer injuries during earthquakes as a result of being trapped inside damaged or collapsed buildings, being hit by falling debris, or falling from high places (Watt and Weinstein,2013). Casualties from floods are often result from drowning, injuries caused by debris in floodwater, electrical injuries, and hypothermia (Fatalities associated with floods, 2022). Most casualties of hurricane are caused by indirect causes rather than the storm itself. Indirect casualties are injuries or deaths that cannot be directly attributed to the violent impact of the storm but would not have occurred if the storm hadn’t happened. These include carbon monoxide poisoning from using generators indoor, cardiovascular failure, and power outages (Visé, 2022) (Fox, 2016).

Casualties as a risk metric is commonly featured in academic journals regarding earthquakes. Taking Haiti earthquake as an example, the strong earthquake devastated much of Haiti’s capital city, Port-au-Prince, and its surrounding area. Many people became casualties of the disaster, around 220,000 people were reportedly killed and 300,000 people were injured because of the earthquake (Miks and Nesbitt, 2022). Majority of the fatalities were due to collapse of buildings with occupants still inside, stabilities of structures are heavily influenced by the stabilities of the ground they are built on, and many of the buildings in Haiti were built on unstable land (International Strategy for Disaster Reduction, 2010).

In Cousins et al (2008), researchers calculated the risk of an earthquake in New Zealand by estimating the number of casualties that result from a magnitude 7.5 earthquake. The result shows a relatively low casualty rate due to New Zealand’s long tradition of earthquake resistant building design and policies to remove or upgrade buildings that are at risk.

Flooding accounted for 47% of all weather-related disasters during the previous 20 years, affecting 2.3 billion people and resulting in 157,000 deaths (CRED& UNDRR,

2015). Casualties as a natural hazard risk metric is also often used in academic papers regarding flood risks. Diakakis et al., evaluated the temporal and geographic distribution of flood episodes and casualties during the last 130 years in Greece (Diakakis et al,2012). There were 545 distinct occurrences in total, 686 of which resulted in fatalities and widespread destruction across the nation. The findings revealed seasonality tendencies, with November having the highest concentration of incidents. They also demonstrated that, compared to mountainous and rural areas, metropolitan settings often exhibit greater rates of flood recurrence.

Casualties as a risk metric are also frequently used in hurricane risk assessments. In Brunkard, Namulanda and Ratard (2008), the authors analysed the mortality rate data after Hurricane Katrina. They found that Hurricane Katrina resulted in 1,170 direct deaths and 705 indirect deaths in Louisiana. Majority of the direct cases were caused by drowning, blunt force, and injuries from sharp objects. Meanwhile, indirect deaths were mostly due to lack of access of healthcare and medicines. The paper also highlights the disproportionate impact of Hurricane Katrina on populations that are more vulnerable, such as those with limited access to healthcare and other resources.

Casualties as a risk metric is commonly used in practice. Just four days after February 2023 Turkey-Syria earthquake the BBC reported that the death toll in both countries have exceeded 25,000 with majority of the casualties being from Turkey (Gahagan and Moloney, 2023). In December 2014 the UK Department for Environment Food and Rural Affairs published a report titled “The National Flood Emergency Framework for England” that outlines a set of guideline and procedures for responding to flood emergencies. The report highlights casualties and fatalities as a major risk of flooding (The National Flood Emergency Framework for England, 2014). The National Hurricane Center in the US published a tropical cyclone report of Hurricane Katrina which reported that it caused a total of 1392 fatalities with 520 direct deaths, 565 indirect deaths and 307 indeterminate causes (Knabb, Rhome and Brown, 2006).

The remaining academic journal papers and practice papers reviewed that includes causalities as a natural hazard risk metric are summarized in the tables below:

2.2.1. Academic

Table 5. Academic journal papers that include casualties as a natural hazard risk metric

Titles and authors	Hazard	General note
An empirical model for global earthquake fatality estimation (Jaiswal and Wald, 2010)	Earthquake	This paper studies models that would estimate the number of fatalities after an earthquake and gave an example of fatalities estimation of an earthquake in Java, Indonesia.
Urban seismic risk index for Medellín, Colombia, based on probabilistic loss and casualties’ estimations. (Salgado-Gálvez et al., 2016)	Earthquake	This paper estimated the earthquake risk of Medellín in terms of casualties and produced a map of ‘Physical risk index by county level for Medellín’ in an event of an earthquake.
An artificial neural network-based earthquake casualty estimation model for Istanbul city. (Gul and Guneri, 2016)	Earthquake	This paper estimated the earthquake risks of four regions in Istanbul in terms of casualties and produced casualties’ estimation chart for each of the region.
Seismic estimation of casualties and direct economic loss to Byblos city: a contribution to the ‘100 resilient cities’ strategy. (Makhoul,	Earthquake	This paper estimated the earthquake risk of Byblos in terms of casualties and summarized the result in a table. The results are also presented in a casualties’ severity map and chart.

Navarro and Lee, 2020)		
Unravelling the influence of human behaviour on reducing casualties during floods evacuation (Vicario et al., 2020)	Floods	This paper discussed that a flood warning system is essential because flooding has a high death rate. A case study in Orvieto (Italy) produced a model of the early warning system and the impact of casualties. The specialists discovered that a delay of 30 minutes in the warning's release can increase casualties by up to six times, and a successful early warning system can result in significantly reduced casualties.
A GIS for flood risk management in Flanders (Deckers et al., 2009)	Floods	This paper developed a risk-based technique to estimate the number of casualties using a Geographic Information System (GIS) to statistically evaluate flood risk using hydrologic models, land use data, and socio-economic data. This approach was used in the creation of LATIS, a GIS-based flood risk assessment tool, which provides the opportunity to execute risk assessments swiftly and efficiently by calculating the possible damage and number of casualties during a flood event.
Daily Variation in Natural Disaster Casualties: Information Flows, Safety, and Opportunity Costs in Tornado Versus Hurricane Strikes (Zahran, Tavani and Weiler, 2013)	Hurricane	This paper analysed the daily variation in hurricane and tornado casualties using data from the Spatial Hazard Events and Losses Database for the United States (SHELDUS). It finds that hurricanes are more lethal on weekdays. Hurricane forecasts provide more lead time, allowing strategic behaviour in choosing protective measures. The study's findings have important policy implications for managing the impacts of hurricane.
Tropical cyclone-tornado casualties (Moore and Dixon, 2012)	Hurricane	This paper examines the hazards of tornadoes produced by landfalling tropical cyclones in the United States from 1995 to 2009. Although most did not cause casualties, some extreme cases showed potential for significant harm. The majority of casualties occurred when and where the physical risk of tornadoes was higher.
Nonfatal injuries following Hurricane Katrina—New Orleans, Louisiana, 2005 (Sullivent et al., 2006)	Hurricane	This paper focused on non-fatal injuries that occurred in New Orleans, Louisiana following Hurricane Katrina. The authors analysed data from emergency department visits and hospital admissions related to injuries sustained in the aftermath of the hurricane. The injuries were found mostly to be lacerations, fractures, and sprains, and a significant number of carbon monoxide poisoning cases. The authors also highlighted the need for injury prevention efforts such as promoting public awareness through campaigns.
Injury Deaths Related to Hurricane Sandy, New York City, 2012 (Seil, Cohen and Marcum, 2016)	Hurricane	This paper investigates injury-related fatalities in New York City during Hurricane Sandy in 2012. The study aims to analyse the causes and circumstances of these deaths, which can inform future disaster preparedness and response strategies to minimize loss of life.
Prevalence and consequences of disaster-related illness and injury from hurricane ike (Norris, Sherrieb and Galea, 2010)	Hurricane	This paper conducted a population survey within months after Hurricane Ike hit Galveston Bay in 2008. The results showed that around 7,700 adults were injured, and 31,500 experienced household-level illness. Risk for injury or illness increased with area damage and decreased with evacuation.
Hurricane Isabel—Related Mortality—Virginia, 2003 (Jani et al., 2006)	Hurricane	This paper conducted an analysis of Hurricane Isabel's effect on Virginia, which experienced the highest death toll (32) out of all the affected states. The aim is to identify risk factors and injuries prevention measures to reduce future disaster-related casualties.

2.2.2. Practice

Table 6. Practice papers that include casualties as a natural hazard risk metric

Titles and authors	Type	Hazard	General note
Earthquake death toll in Turkey rises to 43,556, minister says, Reuters. (Butler, D. 2023)	News article	Earthquake	This article reported that the Interior Minister of Turkey announced that the death toll from the earthquake has risen to more than 43000.
Turkey earthquake: Erdogan seeks forgiveness over quake rescue delays: BBC News	News article	Earthquake	This article reported that more than 50000 people have been killed in the earthquake.

4 Turkish designers on the devastating aftermath of the earthquake, one month on : British Vogue (Chan, 2023)	News article	Earthquake	This article report that more than 50,000 people were killed in the 7.8-magnitude earthquake that struck Turkey and Syria last month, leaving the two nations in complete destruction.
Quake Updates: Toll in Turkey and Syria Surpasses 40,000 Dead (Jason Horowitz,2023)	News article	Earthquake	This article reported that as of 14th February 2023 the Turkey-Syria earthquake has claimed the lives of 35,418 in Turkey and the death toll is still rising.
Record number of deaths and injuries from flooding and water rescues across Yorkshire last year. (Beever, 2021)	News article	Floods	This article reported that there were 111 fatalities, 274 hospitalisations, and a total of 422 injuries in England, all of which were record-high numbers.
88% of U.S. Deaths From Hurricanes, Tropical Storms Are from Water, Not Wind (Erdman, 2021)	News article	Hurricane	This article reported that the majority of the 8,000 to 12,000 people who perished in the nation's deadliest hurricane, which hit Galveston, Texas, in 1900, were killed by a storm surge of up to 15 feet and pounding surf.
First Thing: Hurricane Ian death tolls climbs amid criticism over response (Slawson, 2022)	News article	Hurricane	This article report that the death toll from Hurricane Ian in Florida and South Carolina has surpasses 80 people.

2.3. Mental Health Impact

One of the most important challenges that natural hazards survivors have to face is the impact on their mental health. The wellbeing of a person's mind is known as "mental health," which speaks about the consistency of thinking and feeling at peace since everything is well. According to one study on the mental health of earthquake survivors, 42.6% of them had moderate to severe mental health problems (Yokoyama et al., 2014).

One of the common methods for studying people's post-disaster mental health is the PTSD (posttraumatic stress disorder) index to measure psychological trauma. Post-traumatic stress disorder (PTSD), an anxiety disorder that can develop after exposure to any incident that causes psychological trauma (Neria et al., 2007), is the post-disaster mental condition that has received the most research in recent years. "PTSD symptoms are broken down into three symptom clusters: five re-experiencing symptoms, seven numbing/avoidance symptoms, and five hyper-arousal symptoms (DSM-IV criteria B, C, and D, respectively)" (Dobie M.D. et al., 2002). Simply, it entails giving participants a questionnaire to fill out about a stressful experience they've had in the past. Adults with a score of 50 or higher are identified as having PTSD risk, and the total score ranges from 17 to 85 (Thepa&Hauff, 2005).

Mental health as a risk metric is also used in academic papers regarding earthquake risks. For instance, in Hong et al., 2009 the authors carried out the semi-structured diagnostic interview (CIDI) on survivors of the Zhangbei-Shangyi earthquake in 1998 based on DSM-IV diagnostic standard. It was found that the incidence of PTSD was 25.3% and 14.2% for 181 people in Duizhuang, two villages, three months after the earthquake, while the follow-up study nine months after the earthquake found that the incidence of PTSD was 30.3% and 30.3% respectively.

Floods also cause severe trauma for people who are impacted. Maltais and colleagues discovered that those afflicted two years after a flood in Canada had increased levels of depression, PTSD symptoms, psychological distress, and worse adjustment. South Korea was found to have a

considerable decline in health-related quality of life 18 months after the flood (Fernández et al., 2015). Other concerns include the necessity to restore emotional ties to one's home as well as the stress and worry brought on by the reconstruction and rebuilding efforts made in flooded homes (Springett et al, 2017c). Mental health impact can be also observed four years after a significant flood in Banbury, UK (Tapsell and Tunstall, 2008). In short, most in-depth research conducted in the years following the floods looked at how flooding affected people psychologically, including suicide, PTSD, sadness, and anxiety. After flooding, social support is a protective factor that can enhance long-term health results (Zhong et al, 2018).

Mental health as a risk metric is also prevalent academic journals regarding hurricane risk assessments. In Schwartz et al. (2018), the authors provided a preliminary assessment of Hurricane Harvey's impact on mental health in affected areas. A survey was conducted on individuals impacted by Hurricane Harvey, with questions regarding their exposure to the hurricane and its aftermath. The survey found that very high percentage of people reported experiencing negative mental health outcomes including depression, anxiety, and PTSD, which falls under the definition of mental health impact in this report. The authors also highlighted the need to address symptoms of PTSD in affected people as early as possible and to provide long-term support.

In practice, after the February 2023 Turkey-Syria earthquake Al Jazeera reported the emotional impact of the earthquake and emphasised on the importance of providing mental health and psychological support to the victims (Uras, 2023). USA Today also highlighted the potential long-term psychological impact of Hurricane Ian and the importance of for offering mental health support to victims of Hurricane Ian as they may have experienced tremendous trauma and stress (USA Today, 2022).

The remaining academic journals and practice papers reviewed that includes mental health impact as a natural hazard risk metric are summarized in the tables below:

2.3.1. Academic

Table 7. Academic journal papers that includes mental health impact as a natural hazard risk metric

Article reviewed	Hazard	General note
Emotional arousal to negative information after traumatic experiences: an event-related brain potential study (Wei et al., 2011)	Earthquake	This paper refers to the evaluation of the victim's self-experience, reaction, and perception to determine the degree of psychological trauma of the victim.
The performance of the Japanese version of the k6 and k10 in the mental health survey Japan (Furukawa et al., 2008)	Earthquake	This paper presented two psychological screening scales using the Japanese versions. The scales detect mood and disorders related to anxiety.
Are the elderly more vulnerable to the psychological impact of natural disasters (Jia et al., 2010)	Earthquake	The paper aims to determine the relationship between age and natural disasters. It seeks to establish whether elderly earthquake survivors would develop posttraumatic depression and psychiatric morbidity.
The effect of relocation and parental psychopathology on earthquake survivor children's mental health (Kilic et al., 2011)	Earthquake	This paper examines the effect of parents' psychopathologies on the earthquake survivor-children. Findings show that one can predict traumatic stress in a child by examining the father's traumatic stress.
A prospective study of the impact of floods on the mental and physical health of older adults (Bei et al., 2013)	Floods	This paper chose approximately 200 people who the age of 60 to participate in a survey to measure the value of PTSD index, that measured their levels of anxiety, depression, self-reported health, and life satisfaction in order to improve future service planning. It was found that maybe one in six people needed clinical observation because their PTSD index was higher than other observed people. But all the older had negative psychological repercussions as a result of the flood.
An exploration of factors affecting the long term psychological impact and deterioration of mental health in flooded households (Lamond et al., 2015)	Floods	This paper investigates the characteristics linked to psychological distress and long-term mental health decline. In the long-term study, household income and flood depth were the two most significant predictors, as tough financial requirements could cause strong mental issues. According to the study, implementing mitigation strategies may improve the mental health outcomes for communities who are at risk.
Psychological impact of the hurricane Mitch in Nicaragua in a one-year perspective (Caldera et al., 2001)	Hurricane	This paper assessed the prevalence of PTSD and its risk factors among people affected by Hurricane Mitch in Nicaragua. PTSD prevalence varied from 9% in worst-hit areas to 4.5% in less damaged areas. PTSD symptoms were significantly associated with death of relatives, destroyed home etc.
The Mental Health Impact of Hurricane Maria on Puerto Ricans in Puerto Rico and Florida (Scaramutti et al., 2019)	Hurricane	This paper analysed the mental health impact of Hurricane Maria on Puerto Ricans living in Puerto Rico and Florida. The authors found that rates of PTSD were high in both places. The study also highlights the challenge faced by Puerto Ricans residing in Florida who are separated from their families and communities.
Social Capital and the Mental Health Impacts of Hurricane Katrina: Assessing Long-Term Patterns of Psychosocial Distress (Adeola and Picou, 2014)	Hurricane	This paper analysed the long-term mental health impacts of Hurricane Katrina on individuals in New Orleans, Louisiana. The authors used data from a survey carried out on individuals impacted by the hurricane. They found that individuals with high level of social network and support experienced lower levels of psychosocial distress after the hurricane.

2.3.2. Practice

Table 8. Practice papers that use mental health impact as a natural hazard risk metric

Titles and authors	Type of paper	Hazard	General note
Turkey-Syria earthquake: The mental health impact of natural disaster (Osman, 2023)	News article	Earthquake	This article reported that both girls and boys in their nation had an early beginning of puberty and different level of PTSD following an earthquake, according to experts looking into the effects of earthquakes on youngsters.
Turkey earthquake: How the true costs calculated? (Harper, 2023)	News article	Earthquake	This article reported that after Turkey earthquake, the individuals are frightened to go back to work with poor mental state, unable to devote 100% to the

			original work.
Dealing with the psychological aftershocks of the Türkiye earthquakes: why mental health and psychosocial support are so desperately needed	News article	Earthquake	This article discussed the psychological impact of earthquake in Turkey and the importance of offering support to those affected by it. The psychological impact could include anxiety, depression, PTSD, and grief.
'We don't sleep when it's raining': the mental health impact of flooding (Murray, 2020)	News article	Floods	This article reported that the most commonly reported ailment, with a prevalence rate ranging from 7.06% to 43.7%, was PTSD. Depression and anxiety were also prevalent among the public. Also, some of the older think the rain as 'bloody nuisance'
Hurricane Ian devastation prompts concern about mental health struggles for those affected by the storm (CBS MIAMI team, 2022)	News article	Hurricane	This article reported that according to World Health Organization research, between one-third and fifty percent of those who are directly affected by natural disasters will experience emotional anguish. These can include depression, anxiety disorders, and post-traumatic stress disorder (PTSD). The suicide rate increased 26% the year after a hurricane Ian.
Impact of Hurricane Katrina on the Mental and Physical Health of Low-Income Parents in New Orleans (Rhodes et al., 2010)	Policy paper	Hurricane	This document published by the National Health Institutes of Health (U.S) investigated the change in mental and physical health among low-income parents exposed to Hurricane Katrina. The study found that the prevalence of probable serious mental health issues doubled and close to half of the respondents exhibited probable PTSD. The study also found that higher levels of hurricane related loss were closely linked to worse mental health outcomes.

2.4. Wellbeing/welfare loss

Wellbeing of a person has no single definition, but it generally includes positive emotions, satisfaction with life, and positive functioning. Some disciplines also include aspects such as economic wellbeing, personal development, and engaging work (Well-Being Concepts, 2018). Welfare of a person can also be defined similarly as “the general state of health or degree of success etc.” (Cambridge Dictionary, 2023). In the context of this report, wellbeing loss and welfare are defined as a negative impact on an individual’s quality of life due to loss of income or livelihood and loss of access to essential services such as water, electricity, and shelter as a result of natural hazards.

Several academic papers have used the well-being as a risk metric to assess earthquake risks. Traditionally, scholars used assets to assess risks. On the other hand, Walsh and Hallegatte (2019) simultaneously evaluate earthquake risks using two metrics: socioeconomic resilience and well-being losses. According to a case study in the Philippines, about half of Filipinos are thrown into poverty each year after a disaster, this study determines that low-income earners suffer about a 9% loss in assets but a 31% loss in their well-being. The benefits of interventions may be easily quantified thanks to the use of metrics that take poverty and well-being into account. Besides, when studying the earthquake shocks and well-being outcomes based on the Yogyakarta earthquake that rocked Indonesia in 2006, present well-being, people's hopes for the future, the style of life they lead, and happiness both before and after an earthquake are the main subjects of this study. According to the data, there is enough proof that seismic disasters caused a noticeable reduction in well-being. The investigation revealed that the poor health persisted for years after the earthquake had passed (De & Thamarapani,

2022).

Floods also have a certain impact on subjective well-being indexes. Hudson et al. (2019) explored the intangible effects of flood risk on the subjective well-being of inhabitants in central Vietnam, when a flood occurs, there will be a temporary decline in the general public's well-being. Based on an empirical analysis of 320 counties impacted by the 1993 Midwest flood, Xiao and Feser (2014) give large-sample evidence of the unemployment impact of catastrophes. They discovered that the flood caused unemployment rates to surge in severely damaged counties but that the impacts rapidly subsided. The average person's pay has decreased somewhat after the floods.

Hurricanes also have major impact on people’s welfare. Thompson et al (2005) examined how many individuals were unemployed following the natural hazard. In order to assess people's employment welfare levels following the hurricane, they discuss the impact of this windstorm on the period behaviour of the unemployment rate alongside recovery programmes implemented by the public and private sectors.

In practice, CNBC reported that thousands of people are left sleeping on the streets with no access to electricity and water after an earthquake struck Turkey in February 2023 (Khan, 2023). After Hurricane Ian struck Florida in October 2022 CNN reported that tens of thousands of people are likely to lose their jobs and file for unemployment benefit in the aftermath of the storm (White, 2022).

The remaining academic journal papers and practice papers reviewed that includes wellbeing/welfare loss as a natural hazard risk metric are summarized in the tables below:

2.4.1. Academic

Table 9. Academic journal papers that includes wellbeing/welfare loss as a natural hazard risk metric

Titles and authors	Hazard	General note
Changes in human well-being and rural livelihoods under natural disasters. (Yang et al., 2018)	Earthquake	This paper discussed that natural hazards hit rural areas more than they do in urban areas. Findings revealed that human well-being drastically changed after the Wulong earthquake in China.
Scenario-based earthquake risk assessment for Bucharest, Romania. (Pavel & Vacareanu, 2016)	Earthquake	This paper undertakes a risk analysis for an earthquake in Romania. They use the community-resilience metric defining it in terms of recovery and housing capacity.
An evaluation and monetary assessment of the impact of flooding on subjective well-being across genders in Vietnam (Hudson et al., 2019)	Floods	This paper hypothesised that gender differences in the impacts of floods on welfare could lead to an initial decline in welfare through subjective well-being when a flood occurs within five years. Men responders often recovered 80% of their welfare losses, while female responses were linked to a welfare recovery of about 70%. people need to utilise their own money to make up for the welfare they are missing.
Emergency preparedness and response to Ibadan Flood Disaster 2011: Implications for wellbeing (Adejuwon & Aina, 2014)	Floods	This paper analysed Nigeria's emergency preparedness situation and subsequent flood disaster response. Flood disasters can frequently lead to temporary disruptions of the family wellbeing and increase the risk of diseases, which could drastically alter the lives of family members and have a detrimental impact on their wellness.
Measuring Natural Risks in the Philippines: Socioeconomic Resilience and Wellbeing Losses (Walsh & Hallegatte, 2020)	Hurricane	This paper focused on measuring natural risks in the Philippines and the impact on socioeconomic resilience and well-being. The authors utilised data from a survey of victims of natural hazards, including their exposure to the hazard and their well-being outcome such as financial stability.
Hurricane Wilma, utility disruption, and household wellbeing (Chatterjee & Mozumder, 2015)	Hurricane	This paper analysed the impact of Hurricane Wilma and the subsequent disruption to utility on household well-being in Florida. The authors found that utility disruptions, particularly electricity outages had significant negative impact on household well-being.
Does hurricane risk affect individual well-being? Empirical evidence on the indirect effects of natural disasters (Berlemann, 2016)	Hurricane	This paper analysed the impact of hurricane risk on individual well-being in the United States. The author employed an approach that focuses on the indirect effects of natural hazards on individual well-being, such as through their impact on economic activity and job opportunities.

2.4.2. Practice

Table 10. Practice papers that use wellbeing/welfare loss as a natural hazard risk metric

Titles and authors	Type of paper	Hazard	General note
Hundreds of thousands lost their jobs in Turkey-Syria quake: UN	News article	Earthquake	This article reported that the earthquake had a terrible effect on employees and businesses. The hours wasted amounted to almost 657 000 employees' worth of labour. Thousands of workers lost their job, dividends, and fringe benefits.
Tens of thousands likely jobless after Hurricane Ian, economists say	News article	Hurricane	This article reported that to address the inflation brought on by Hurricane Harvey in Texas, which resulted in an increase of nearly 50,000 in August 2017, citizens must apply for employment subsidies in massive numbers.
UK floods: Environmental Agency job cuts 'on hold'	News article	Floods	This article reported that to ensure the budget is adequate for post-disaster reconstruction, employment was cut down around 1,550 due to a decrease in the amount of money received from the central government after the flood.

2.5. Environmental loss

Environmental losses relate to the negative effects that natural hazards have on the environment. The environment will undoubtedly be impacted by the occurrence of a natural hazard. For instance, the degradation of vegetation on both sides of rivers contributed to environmental damage by triggering landslides, debris flows, and erosion. The effects

on the air, such as CO_2 emissions due to the natural hazard, is also an example of environmental impact. (Chen et al., 2012).

Environmental loss as a risk metric is frequently featured in academic journal papers regarding earthquakes. An example of an environmental loss due to earthquake is clean water and air contamination. Environmental losses are a type of non-financial loss in natural hazards People's well-being is directly tied to these factors required for survival (Sangha et

al., 2020). Welsh-Huggins and Liel (2018) investigate the impacts of alternative structural concretes on the life-cycle sustainability and resilience of a reinforced concrete building in a high seismic region, and conduct a life-cycle environmental impact assessment, quantifying greenhouse gas emissions associated with building construction and seismic performance, accounting for potential earthquake damage and subsequent repairs.

Floods have a terrible effect on the ecosystem and the surrounding soil, as well as majority of animals (Istomina et al., 2004). Istomina et al. stated floods have an adverse effect on soils, cause fluvial morphological deformations, disrupt plant cover, and harm wildlife. The floods also change the chemical composition of water and dramatically worsen its quality; Hickey and Salas (1995) analyse the impacts of short- and long-term environment after extreme floods; Based on 835 instances of floods brought on by excessive rainfall in Hungary over the course of two decades, Czigány et al.(2009) examined the area's environmental effect and forecasted where flash floods will occur using GIS and other technologies.

Academic research papers also use environmental loss to measure hurricane risk. Mallin and Corbett (2006) stated that common adverse effects on water quality caused by hurricanes include excessive nutrient loading, increased biochemical oxygen demand and subsequent hypoxia and anoxia, fish and invertebrate deaths, aquatic animal scale

replacements, chemical pollutants and debris from damaged human structures, and pollution of water; Fran (1996) and Floyd (1999), the two greatest hurricanes, had effects on hydrology, nutrient loads, fish reproduction, soil erosion, and biotic composition that lasted from several months to many years (Paerl et al., 2006).

Environmental loss as a risk metric is also used in practice. Le Monde reported that the February 2023 Turkey-Syria earthquake may have an impact on the water quality nearby. The absence of access to bathrooms and drinking water for the survivors living in temporary camps is greatly increasing the risk of an epidemic. Moreover, poor sanitary may cause rapid transmission of diseases (Cazorla, 2023). The UK Environment Agency has warned that climate change will lead to more frequent and intense floods. The published document points out that floods caused by weather changes will greatly affect environment, such as the surrounding crops and ecological environment (Environment Agency, 2018). The Washington Post reported that because the hurricanes generated a lot of waste, people flouting laws governing gasoline use in car fuel tanks, plastic linings, and other contaminants, Hurricane Ian will leave behind a trail of environmental hazards (Mufson, 2022).

The remaining academic journal papers and practice papers reviewed that includes environmental loss as a natural hazard risk metric are summarized in the tables below:

2.5.1. Academic

Table 11. Academic journal papers that include environmental loss as a natural hazard risk metric

Article reviewed	Hazard	General note
Integrating Hazard-Induced Damage and Environmental Impacts in Building Life-Cycle Assessments. (Welsh-Huggins and Liel, 2018)	Earthquake	This paper presented an innovative building life-cycle assessment framework quantifying environmental metrics and economic indicators of building performance, while accounting for potential risk of hazard events. Preventive and essential maintenance strategies of bridges.
Reduce, Reuse, Resilient? Life-Cycle Seismic and Environmental Performance of Buildings with Alternative Concretes (Welsh-Huggins, Liel and Cook, 2020)	Earthquake	This paper investigated the impacts of alternative structural concretes on the life-cycle sustainability and resilience of a reinforced concrete building in a high seismic region. To conduct a life-cycle environmental impact assessment, quantifying greenhouse gas emissions associated with building construction and seismic performance, accounting for potential earthquake damage and subsequent repairs.
Evaluation of the environmental impacts of extreme floods in the Evros River basin using Contingent Valuation Method (Lehner et al., 2006)	Floods	This paper evaluated the environmental impacts of extreme floods in the Evros River basin using Contingent Valuation Method (CVM). The authors assessed the environmental damages caused by floods, including damage to agricultural lands, loss of biodiversity and contamination of water sources.
How hurricane attributes determine the extent of environmental effects: Multiple hurricanes and different coastal systems (Mallin & Corbett, 2006)	Hurricane	This paper discussed that excessive nutrient loading, algal blooms, increased biochemical oxygen demand and the resulting hypoxia and anoxia, fish and invertebrate deaths, aquatic animal displacement, large-scale releases of chemical pollutants and debris from damaged human structures, exacerbated spread of exotic species and pathogens, and contamination of water with fecal microbial pathogens are some of the common negative effects of hurricanes on water quality.
Effects of hurricane ivan on Water Quality in Pensacola Bay, Florida (Hagy et al., 2006)	Hurricane	This paper analysed the effect of Hurricane Ivan on water quality in Pensacola Bay, Florida. The authors assessed the quality of water using parameters such as dissolved oxygen, nutrients concentration and salinity.

2.5.2. Practice

Table 12. Practice papers that use environmental loss as a natural hazard risk metric

Titles and authors	Type of paper	Hazard	General note
Geological impact of Turkey-Syria earthquake slowly come into focus (Ravilious, 2023)	News article	Earthquake	This article reported that there are several landslides and rockfalls in the area where the earthquake occurred, it will have a significant impact on the future agricultural production in the region.
Flooding in UK: Ecological impacts and an ecosystem approach	News article	Floods	This article layout that humans gain several benefits from the freshwater system. Extreme weather conditions may harm the ecology permanently. Extreme flooding has been proven to significantly reduce plant biomass as well as fish and pearl mussel abundance.
Hurricane Ian damages homes and the environment (Penick, 2022)	News article	Hurricane	This article reported that Hurricane Ian caused environmental damage in Florida, including the release of thousands of gallons of diesel and water that "looks like root beer and stinks like dead fish rolled into compost."

2.6. Population displacement

Population displacement in the context of natural hazards means the forced removal of individuals or communities from their homes or places of residence due to the immediate or long-term impact of natural hazards (UNISDR Terminology on Disaster Risk Reduction, 2009). Natural hazards can lead to population displacement directly through damage to homes and infrastructures or indirectly through loss of livelihoods and disruption of essential supplies and services. Population displacement can be temporary or permanent, the duration depends on the extend of the damage and the ability of the displaced population to return and rebuild (Mallick and Vogt , 2014). People's choice to evacuate during a crisis is strongly influenced by how risky they perceive the situation to be. Other people perceive catastrophe danger strongly, while others perceive it weakly, and some people even perceive disaster risk indifferently (Lindell et al.2000). Therefore, some individuals who live in disaster risk zones will decide to evacuate in the face of prospective catastrophe hazards, whilst others are unwilling to relocate for a variety of reasons.

Natural hazards can severely damage the local infrastructure and has a great impact on the local social economy. A serious societal impact is that people may need to relocate their homes and assets following a natural disaster. According to a report released by the Japanese National Police Agency on October 9, 2015, the Tohoko Japan earthquake left 2567 people missing, over 400million people had to leave their homes due to the need to evacuate and about 400 000 properties sustained damage, more than half of which were irreparable (Tsuchiya et al., 2017); Notably, following the 2015 earthquake in Nepal, an estimated 390,000 more people than usual left the Kathmandu valley, with the majority migrating to nearby places and the densely populated regions in the country's central and southern areas (Wilson et al., 2016) ; Moreover, a significant earthquake that year rocked northwest Turkey in August. A needs assessment was

conducted to determine the population's urgent requirements. Interviews were conducted with 230 household representatives from the four earthquake-worst areas. 84% of families were uprooted from their homes and were living in temporary shelters (Daley, Karpati and Sheik, 2001).

Population displacement also features prominently in flood risk assessments. In Kakinuma et al. (2020b) the paper presents an analysis of flood-induced population displacement in the world. The authors highlighted that flood could result in significant population displacement of populations both temporary and permanent. Various data sources on flood-induced displacement were analysed and South Asia, Southeast Asia, and Sub-Saharan Africa were regions most vulnerable to that type of displacement.

Population displacement is also a major risk metric of hurricane and frequently used in academic research. In Acosta et al., 2020 the paper analysed data from mobile phones and social media to estimate the number of people at risk and the migration pattern in Puerto Rico after Hurricane Maria. The authors observed a population loss across all data sources throughout the study period. However, the number differed significantly across different data sources.

Population displacement is also featured prominently in practice. Al Jazeera reported that nearly 530,000 people have been evacuated from the disaster area after the February 2023 Turkey-Syria earthquake and many survivors have settled in tents, container homes and other government-sponsored accommodation (Jazeera, 2023). After Hurricane Ida in 2021, CNN reported that one region in Louisiana saw over 14,000 people left homeless after the hurricane damaged or destroyed 75% of the buildings there (Holcombe, Levenson and Selva, 2021).

The remaining academic journal papers and practice papers reviewed that includes population displacement as a natural hazard risk metric are summarized in the tables below:

2.6.1. Academic

Table 13. Academic journal papers that include population displacement as a natural hazard risk metric

Titles and authors	Hazard	General note
Agent-based model simulations of future changes in migration flows for Burkina Faso. <i>Global Environmental Change</i> . (Kniveton et al., 2011)	Earthquake	This paper states that there are two kinds of original site resettlement, one is to rebuild new houses in the destroyed houses; The other refers to the maintenance and reinforcement of houses on the premise that they are damaged by earthquakes but do not constitute dangerous houses.
Be proactive for better decisions: Predicting information seeking in the context of earthquake risk. <i>International Journal of Disaster Risk Reduction</i> . (Li & Guo, 2016)	Earthquake	This paper defined relocation as moving away from the current residence to build a new house in town. This way can grasp the opportunity to upgrade the infrastructure construction, and then improve the living environment of residents.
A generic decision model for developing concentrated rural settlement in post-disaster reconstruction: a China study. <i>Natural Hazards</i> . (Peng et al., 2013)	Earthquake	This paper discussed that the operation of decentralized resettlement is simple, but it is not conducive to sustainable development and infrastructure construction, which is of little significance to improving residents' quality of life.
The risk perception paradox--implications for governance and communication of natural hazards. (Wachinger et al., 2012)	Earthquake	This paper states that residents' satisfaction with the living environment also has an impact on residents' final mode choice. Studies show that people prefer to live in places with comfortable environment, harmonious neighbourhood and far away from disasters.
Migration and Displacement triggered by Floods in the Mekong Delta (Dun, 2011)	Floods	This paper aimed to ascertain whether flooding qualified as a factor in migration or displacement. Findings indicate that the effects of the Mekong Delta's recurrent floods can lead to independent household or individual relocation decisions and are a reason for government-initiated household resettlement.
A climate of control: flooding, displacement and planned resettlement in the Lower Zambezi River valley, Mozambique (Munro et al., 2017)	Floods	This paper states that in high-income countries like the UK, flood occurrences often result in few direct fatalities; instead, the rise in mental health impact brought on by constant relocation causes the most significant health impact. Relocation was linked to greater levels of anxiety and depressive symptoms.
Hurricane Events, Population Displacement, and Sheltering Provision in the United States (Mitchell, Esnard and Sapat, 2012)	Hurricane	This paper focused on the impact of hurricane events on population displacement in the United States. The authors studied the patterns of population displacement during hurricane events using data from the Federal Emergency Management Agency (FEMA) and the U.S. Census Bureau, the study found that hurricane events result in high population displacement especially for people in low-income households.
Population Displacement and Housing Dilemmas Due to Catastrophic Disasters (Levine, Esnard, and Sapat, 2016)	Hurricane	This paper analysed the impact of natural hazards on population displacement and housing dilemmas. The authors examined the patterns of population displacement and housing dilemmas during natural hazards using data from various sources. The authors also suggested that effective disaster response and recovery effort should focus on development of proactive housing strategies that account for the diverse needs of impacted communities.
The Long-Term Recovery of New Orleans' Population After Hurricane Katrina (Fussell, 2015)	Hurricane	This paper analysed the long-term recovery of New Orleans' population after Hurricane Katrina. The authors examined the change in population, demographic shifts, and housing market dynamic within the city after the hurricane. The paper also suggested that post hazard recovery plan should prioritize the development of affordable housing.

2.6.2. Practice

Table 14. Practice papers that use population displacement as a natural risk metric

Titles and authors	Type of paper	Hazard	General note
Global Rapid Post-Disaster Damage Estimation (GRADE) Report	Policy paper	Earthquake	This document focused on the physical damages for the people after Turkey earthquake, estimates that almost 42 percent of residential buildings are estimated to be damaged and collapsed, 1.25 million individuals are now temporarily homeless and need to look for new place to live.
Floods: Research shows millions more at risk of flooding	News article	Floods	This article reported that Hurricane Harvey hits Texas in 2017 and almost 80,000 were flooded, the families need to find new home.
Hurricane Ian causes high death toll, displacement. (Gappy, 2022)	News article	Hurricane	This article reported that it was estimated that at least 40,600 individuals are displaced and had to locate new houses within 10 days after the hurricane.

2.7. Recovery time

Recovery time in the context of natural hazards refers to the time needed for the affected region and population to return to a state of normalcy and stability after the occurrence of the natural hazard. There are many ways to define recovery from a natural hazard. Smith and Wenger (2007b) defined the recovery process as “the differential process of restoring, rebuilding, and reshaping the physical, social, economic, and natural environment through pre-event planning and post-event actions”. While the UN Office of Disaster Risk Reduction defined recovery as “decisions and actions aimed at restoring or improving livelihoods, health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development, including build back better to avoid or reduce future hazard risk” (Proposed Updated Terminology on Disaster Risk Reduction: A Technical Review, 2015). For the purpose of this report, the key point is that recovery time should only be measured in terms of time and not in terms of money or other unit of measurements.

Many foreign countries have conducted in-depth research on the problem of earthquake recovery and reconstruction, among which Japan has a relatively high frequency of earthquakes due to its geographical characteristics. In 1995, a 7.5-magnitude earthquake struck Hanshin. By making an effective reconstruction plan, the economy in the disaster area returned to normal within a month, and so did the residents' lives. Restoration and reconstruction and earthquake resistance of buildings are one of the key research issues in Japan. Itsuki (2017) has made a comparative study on the restoration and reconstruction procedures in Japan, Taiwan Province, and Turkey. Martinez and Hirayama introduced and studied the problems of post-disaster planning and housing construction in El Salvador and Kobe. From the research of American scholars on restoration and reconstruction, it can be found that the implementation and planning of restoration and reconstruction are the two main points in the study of rehabilitation and reconstruction in the United States. Olshansky believes that speed directly affects the reconstruction of disaster areas, so fast and efficient planning is the priority. Bryson introduced the operational research model into the reconstruction in order to optimize the reconstruction planning, which provided some reference for the decision-making department (Bryson, 2016).

Recovery time is also used as a risk metric in academic papers regarding flood risks. Asgary et al. conduct research about the effect of floods on small enterprises and the reasons for their recovery are examined six months after the 2010 floods in Pakistan. Small firms in disaster-prone areas of poor countries are less equipped to create and carry out business continuity plans because they lack the necessary personnel, funding, and awareness of their vulnerability. 90% of the sample firms (sample size=500) reopened six months after the flood, according to the findings, but the bulk of them were doing so at a loss, and only a few were operating at or above-average levels (Asgary et al, 2012). Besides, 8–9 months after the catastrophic floods in Central Europe in 2002. An investigation carried out by Thieken et al. (2007), over 2,000 homes were chosen at random and split up into several groups. During the study, it was discovered that those who were knowledgeable about flood management and self-defence were less negatively impacted by the floods and recovered more quickly.

The recovery of New Orleans following Hurricane Katrina has been the subject of numerous studies; this hurricane profoundly impacted people's lives and employment. Firstly, Zottarelli (2008) studied the post-disaster employment recovery process; the data in this article give a certificate to examine the short- and medium-term employment recovery roughly one month and one year after Hurricane Katrina. Secondly, Fussell also proposed a study of the problem of population displacement and environmental foundation recovery. The reconstruction of the city's businesses, homes, and infrastructure was completed in 2006, four years after the hurricane. Moreover, Kates predicted that the process of making the built environment functional after hurricane would take 60 weeks and that improving, replacing, or rebuilding the built environment would take between 8 and 11 years (Kates,2006).

Recovery time is also frequently used in practice. For instance, a news article by The Washing Post reported that one of the experts said rebounding from Hurricane Ian could take up to a decade, with one of the toughest hurdles being a shortage of affordable housing after the storm destroyed most of them (Sacks, 2023).

The remaining academic journal papers and practice papers reviewed that include recovery time as a natural hazard risk metric is summarized in the tables below:

2.7.1. Academic

Table 15. Academic journal papers that include recovery time as a natural hazard risk metric

Titles and authors	Hazard	General note
Community vulnerability and capacity in post-disaster recovery: The cases of Mano and Mikura neighborhoods in the wake of the 1995 Kobe earthquake. (Yasui, 1970)	Earthquake	This paper introduced and studied the problems of post-disaster planning and housing construction in El Salvador and Kobe. Hanes had an in-depth discussion on Tokyo's post-disaster planning.
Post-earthquake housing reconstruction programme. Open House International. (Martinez, 2005)	Earthquake	This paper introduced the operational research model into the reconstruction in order to optimize the reconstruction planning, which provided some reference for the decision-making department.
After the Rain – learning the lessons from flood recovery in Hull. (Whittle et al. 2010)	Floods	This paper examined the health, economic, and social aspects of the longer-term experience of flood impact and recovery along with the identification and documentation of essential factors. In-depth research that was conducted after the flood by interviewing a large number of families and recording how they eventually returned to their pre-disaster living arrangements.
Disaster recovery and business continuity after the 2010 flood in	Floods	This paper documented the recovery of Pakistani businesses six months after the flood. However, the findings indicate that 90% of the sample businesses were

Pakistan: Case of small businesses (Asgary et al., 2012)		operating at a loss when reopened, with only a small percentage doing at par or better. It will substantially improve the revival of the firm if relevant authorities can offer financial assistance to select small businesses.
Coping with floods: preparedness, response, and recovery of flood-affected residents in Germany in 2002 (THIEKEN et al., 2007)	Floods	This paper conducted post-disaster interviews with more than 1,000 homes following the devastating flood that struck Central Europe in 2002. Several regions' flood mitigation efforts, post-disaster losses, and reconstruction efforts were researched. In order for further improve readiness and reaction during future flood disasters.
Satellite-based assessment of electricity restoration efforts in Puerto Rico after Hurricane (Román et al., 2019)	Hurricane	This paper developed an approach to use satellites night-time lights data to create spatially disaggregated power outage estimates and tracking electricity restoration efforts after natural hazards. The authors applied the methodology in Puerto Rico following Hurricane Maria. The results shows that higher percentage of rural municipalities suffer long-duration power failures (>120 days) as compared to urban municipalities.
Impediments to recovery in New Orleans' Upper and Lower Ninth Ward: one year after Hurricane Katrina (Green, Bates and Smyth, 2007)	Hurricane	This paper examined the recovery process of Upper and Lower Ninth Ward in New Orleans one year after Hurricane Katrina. The authors used a survey to identify the extent of structural and flood damage, and post-storm recovery in the neighbourhood. The paper also identified impediments to recovery that may disproportionately affect the areas, including pre-existing inequalities and lack of resources.
Quantitative assessment of post-disaster housing recovery: a case study of Punta Gorda, Florida, after Hurricane Charley (Rathfon et al., 2013)	Hurricane	This paper presented a quantitative assessment of post natural hazard housing recovery in Punta Gorda, Florida after Hurricane Charley. The authors used multiple data sources including building permits, remotely sensed imagery and property appraiser data to evaluate the phases of housing recovery, incorporation of mitigation and effect of property sales.

2.7.2. Practice

Table 16. Practice papers that use recovery time as a natural hazard risk metric

Titles and authors	Type of paper	Hazard	General note
What the damage and recovery look like in Turkey a month after the earthquakes (Tanis,2023)	News article	Earthquake	This article reported that several people are still hunting for their families a month after the disaster, and many bodies are lying under the rubble. The basic water and power supply are still unsatisfactory, and people still required additional housing assistance.
Turkey and Syria face long road to recovery after earthquakes (Alsaafin, 2023)	News article	Earthquake	This article reported that destroying damaged buildings that can no longer be supported or have become a safety hazard and takes civil defence teams around five to six months.
Recovery from a flood	News article	Floods	This article reported that if flooding has seriously damaged a home, it might take up to a year or longer for the home to be rebuilt and liveable. The primary cause is the time needed to safely clean, dry out, and perform necessary repairs or restorations after a property has flooded.
After Hurricane Ian, Fort Myers Beach struggles to become 'a functional paradise' (Allen, 2023)	News article	Hurricane	This article reported that six months after Hurricane Ian, rebuilding is sluggishly progressing throughout Southwest Florida. In the second half of 2024, it's expected that several hotels and vacationers along the seaside would reopen.
Tourism recovery after Hurricane Ian in SWFL (Cifatte, 2023)	News article	Hurricane	This article reported that many people are closely monitoring how tourism recovers at Fort Myers Beach, and in an economy that depends on tourism, an early return to the original scene might hasten the recovery of the original economy. It is anticipated that this tourist sector would return within 18 to 24 months.
Locally Executed, State Managed, Federally Supported Recovery: Hurricane Irma Recovery in Florida	Policy paper	Hurricane	This document discusses the impacts of Hurricane Irma which struck Florida in 2017. The hurricane caused significant damage. After the hurricane the state officials recognised the importance of developing a recovery strategy to expedite critical recovery projects. The state had previously implemented capacity building recommendations and exercises after hurricanes in the past, therefore it is well-equipped to implement new recovery tactics.

3. Discussions of Results, Limitations, And More Equitable Risk Metrics

3.1. Discussions of results

This report reviewed eight different risk metrics that are used to measure earthquake, floods, and hurricane risks. These risk metrics cover virtually every element of life, from economic to behavioural factors. From our review it is evident that economic loss is the most prominent risk metric for measuring natural hazard risks (refer to figure 3). Out of all the risk metric reviewed economic loss dominates in terms of the number of academic journal papers it was featured in at 35. Casualties, mental health impact and population displacement are four risk metrics that are

also commonly featured in the literatures reviewed although at less than half the number of academic journal papers than economic loss. Risk metrics such as wellbeing loss and environmental loss are comparatively less represented and appear less frequently in the academic journal papers reviewed.

Moreover, even within economic loss itself the distribution between direct and indirect economic losses are not equal. Direct economic loss is noticeably featured much more frequently as a natural hazard risk metric than indirect economic loss (refer to figure 4). This is most likely due to the fact that direct economic loss is much easier to quantify and measure. On the other hand, indirect economic loss is often not tangible and not as easily identifiable, making it more difficult to calculate.

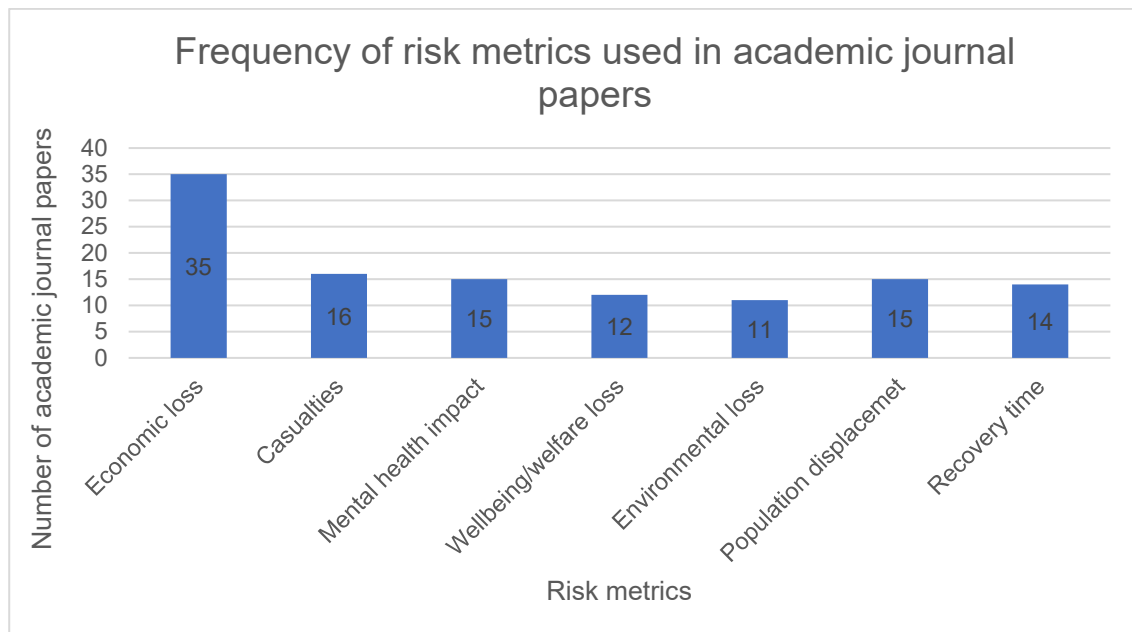


Figure 3. A chart summarising the number of academic journal papers reviewed for each risk metric

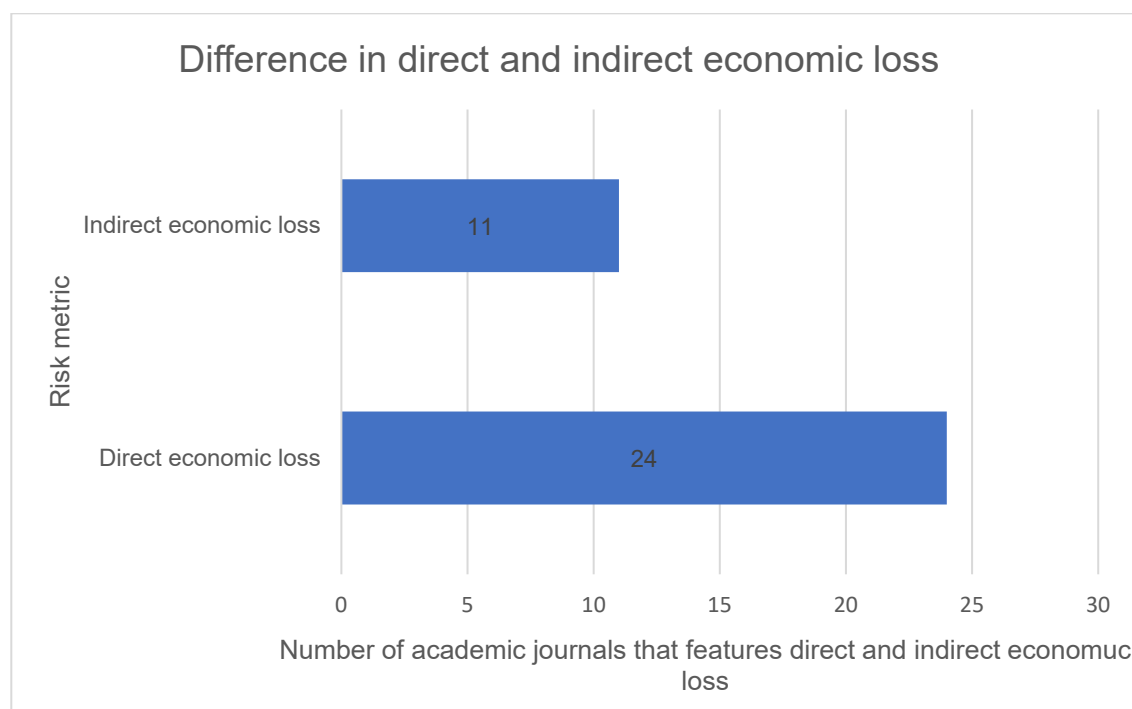


Figure 4. Number of academic journals that feature direct and indirect economic loss as a risk metric

Risk metrics used in practice tells a similar story. Economic loss is again the most used natural hazard risk metric in practice (refer to figure 5). Economic loss is featured prominently in both news articles and policy papers. However, for the rest of the risk metrics they are all more commonly found in news article than policy papers. For wellbeing/welfare loss not mention of it was found in policy papers. This could be due to the fact that it is much harder to define and measure than other metrics such as economic loss. Moreover, it can be seen that the number of news articles that

featured casualties is close to the number that featured economic loss as a risk metric. In fact, direct economic loss and casualties are often presented together in many news articles regarding natural hazards. The number of casualties is also found to be much high in earthquake and comparatively much lower in floods and hurricane. This is most likely due to the fact that floods and hurricanes usually can be predicted and warned early so that the population can make preparations for it while earthquake often strike with little to no warning.

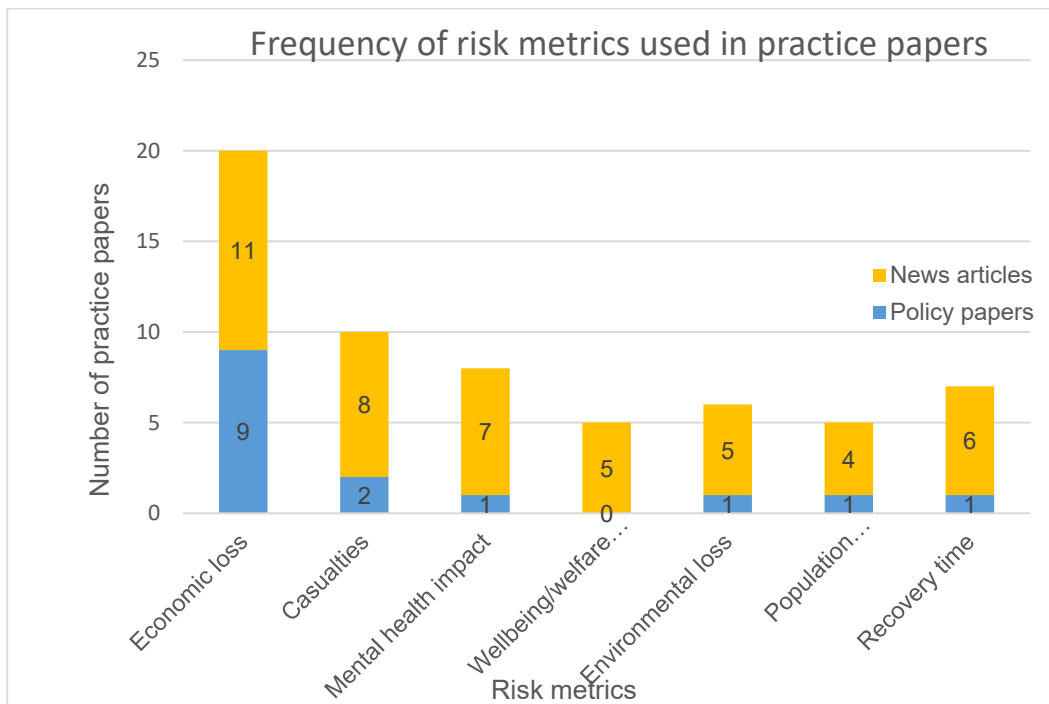


Figure 5. A chart summarising the number of practice papers found for each risk metric

In practice, direct economic loss is again more used than indirect economic loss within economic loss (refer to figure 6). Factors contributing to indirect economic loss such as business interruption and loss of revenue are often mentioned

in practice papers but rarely quantified. This can also be explained by the fact that indirect economic loss is intangible and difficult to measure.

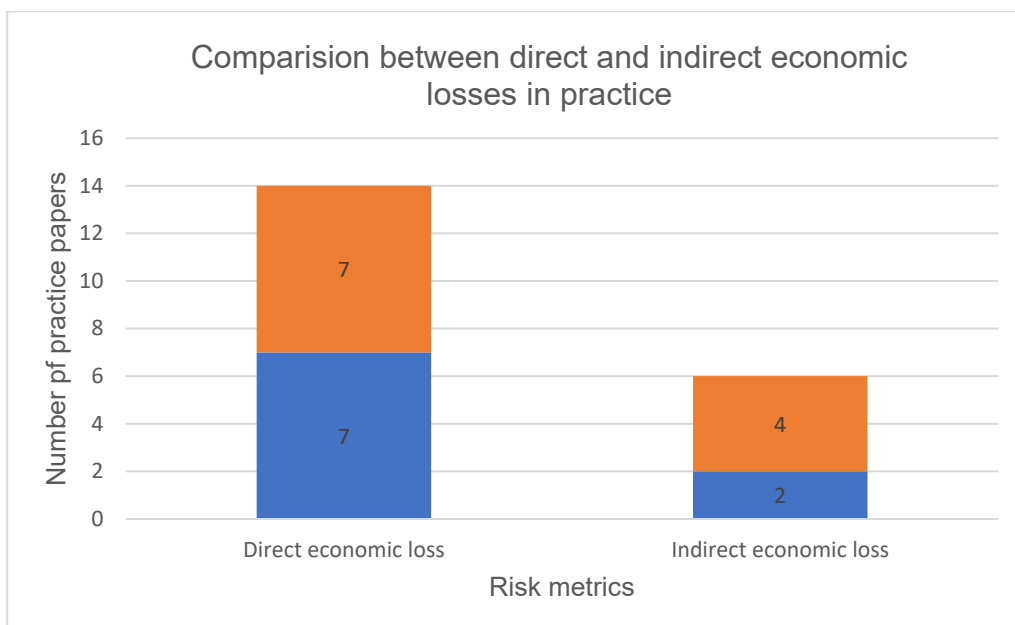


Figure 6. Comparison between direct and indirect economic loss in practice

Economic losses are not an equitable risk metric since they do not measure equal impact on all people or organisations. In fact, Individuals who are already poor or marginalised in society are frequently more adversely affected by economic losses. It can create a misleading representation of the hazard's impact since high-income individuals may incur larger monetary losses, but these losses often only represent a small proportion of their overall wealth, and they often have higher income and savings which means they are able to recover from their losses quickly. Conversely, low-income individuals may suffer much less monetary losses, but they could be significant portion of their wealth. People such as low-income individuals, small enterprises, and areas with limited infrastructure, are likely to suffer the smaller economic losses in terms of monetary loss from a natural hazard. These individuals and organizations might not have the means and abilities to recover from the financial losses brought on by the hazard, which further increase their unpredictability and vulnerability. As a result, using absolute monetary figures often overlook the difficulties and hardship suffered by more vulnerable individuals who will have a much harder time trying to recover from the hazard.

Comparatively, casualty as a natural hazard risk metric is more equitable. Casualties consider the impact of natural hazards on human life which do not disproportionately benefit wealthier individuals or regions. By measuring natural hazards in terms of injuries and deaths policy makers can more accurately assess the impact of those hazards on more vulnerable populations and take steps to mitigate the adverse effects. However, casualties as a risk metric does not take long-term impacts such as loss of livelihoods, displacement and mental health impact into account. Moreover, wealthier individuals are more likely to receive faster and better healthcare as they have the money to pay for it.

Mental health impact as a natural hazard risk metric considers the psychological well-being of individuals affected by the natural hazard. Mental health may not affect everyone equally as similar to economic loss, individuals or communities who have pre-existing vulnerabilities and limited access to mental health resources may be affected more by the hazard. However, this means that people who are more affected will be represented as so thus more help and resource can be allocated to them, making the risk metric more equitable than economic loss.

Wellbeing and welfare loss is another natural hazard risk metric that is potentially more equitable. Contrary to asset losses, which only take monetary value loss into account, well-being losses take the utility of consumption into account as it varies over the course of the recovery process (Boakye et al. 2020). The San Francisco Bay Area earthquake serves as an illustration of how well-being losses following a disaster impact the poor three times more severely than the wealthy (Hallegatte, 2021).

Environmental loss as a risk metric measures the impact of the natural hazard on the environment rather than humans. Environmental loss affects different individuals and communities differently, depending on their reliance on the natural resources and the environment. However, the relationship between different aspects and consequences of environmental loss can be complex and difficult to measure.

Population displacement is an equitable risk metric as it measures the number of people who are forced to relocate either short-term or long-term from their homes due to a

natural hazard regardless of their financial standings. However, wealthier individuals or families could move to other properties elsewhere that they own while poorer people who don't have anywhere else to go are forced to stay in shelters or even on the streets. To ensure that it is equitable the risk metric should take into account the places where displaced population end up and the length of time they are displaced for.

Recover time is a risk metric that is potentially more equitable than economic loss. Recovery time can measure the time it takes for different individuals or communities to recover from the impact of the natural hazard. From this vulnerable individuals or communities which are taking much longer to recover can be identified and resources can be allocated to those that are more in need. Moreover, recovery time can measure the length of time of business closure which is more equitable as measuring revenue loss will always show larger business as losing more than small business but larger business could probably sustain itself longer during closure.

All of the risk metrics above are used by many professionals, companies, and organisations both private and governmental all over the world. They are valuable assets to policy makers to make informed decisions and thus able to develop policies that address risks posed by different natural hazards. Some examples include risk assessment, land use planning, community engagement, and recovery planning. Insurance companies also make use of these risk metrics in the pricing of their insurance premiums regarding losses due to natural hazards. Vulnerable populations sometimes do not receive they aid and resources they require due to data skewed by inequitable risk metrics. It is therefore important for policy makers to use equitable risk metrics for their decision making to ensure that policies and strategies for natural hazard risk reduction are fair and just for every member of society.

3.2. Limitations

This report has two major limitations:

- 1) Due to limited time, only a finite of risk metrics and academic and practice papers can be reviewed.
- 2) This report also doesn't cover all types of natural hazards and only include earthquake, floods, and hurricane.

Both of those limitation means there may be other equitable risk metrics that are used in other risk assessments but have not been identified and included in this report.

There could also be many more policy papers that utilised the risk metrics discussed above but could not be found due to the lack to public access. Each of the natural hazard is only focusing on one country in this report, if more countries are explored for each hazard there could potentially be more policy papers that can be accessed and reviewed.

Economic losses both direct and indirect and casualties as a natural hazard risk metrics are also used frequently by professional assessors hired by insurance companies for their insurance pricing strategies. This is another example of risk metrics being used in practice. However, we could not review those documents as they are most often not readily available to the public.

The limitations discussed above could serve as a guide for the planning of future work.

3.3. Proposal of more equitable risk metrics

While carrying out literature review, we came across some risk metrics that could potentially be more equitable than

economic loss but are rarely used. These metrics could offer more equitable insight into victims of natural hazards.

For instance, in Nofal et al. (2021) the paper calculated losses for impacted buildings in North Carolina in terms of percentage structural, contents, and total losses after Hurricane Florence in 2018. Measuring economic loss in terms of percentage of a person's assets after a natural hazard offers a more equitable perspective as it accounts for the varying financial capacities of the victims. Through focusing on the proportion of person's total wealth, we can gain more accurate understanding of the relative losses experienced by victims of the natural hazard regardless of their financial standings. Measuring economic loss as a percentage of a person's wealth can enable policymakers to organise a more equitable distribution of resources and support following a natural hazard, prioritizing those who have been most affected by it.

Another potential equitable risk metric is loss of education. Education is an important factor in life. Children losing access to education can have detrimental impact the community, disruption to community development and have long term consequences which could include reduced earning potential, reduced quality of life and lower social mobility. It is therefore important to quantify the impact of education loss. The metric can be measured in terms of damage or destruction of educational facilities leading to interruption of education for a period of time measured in days or months etc. due to natural hazards. For example, a hurricane could force a school to close for days, and a devastating earthquake could lead to complete destruction of school facilities leading to the school being closed for months, years or even permanently. All of these could potentially result in children being delayed and missing out on valuable education.

4. Conclusion

In conclusion, this report reviewed eight earthquake, floods, and hurricane risk metrics one by one in both academic and in practice. The result analysis found that direct economic loss is the most dominant risk metric used in both academic and practice while other metrics such as casualties, mental health impact and population displacement are comparatively much less represented in both academic and practice with the exception of casualties also being used as much as economic loss in news articles. The discussion found economic loss to be not an equitable risk metrics while the rest of the metrics are also discussed, and their level of equity discussed. The two major limitations of this report are found to be the limit in time and the exclusion of other natural hazards. Finally, two risk metrics which are rarely used but could be equitable are identified and their potential evaluated.

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