Preventing Wildfires, Mitigating Natural Disasters, and "Avoiding the Inevitable"

An STS Research Paper Presented to the

Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science in Computer Engineering

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Spring, 2021

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Approved ______________________________ Date 05/10/2021

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Preface/Introduction

“A sudden calamitous event bringing great damage, loss, or destruction” marks the Merriam-Webster definition of a disaster. Disasters are divided into two generic groups: natural or technological. While the latter is new to the stage and primarily human-made, the former is no stranger to human civilizations. For thousands of years, humanity not only withstood nature’s trials but has prospered into the modern societies we live in today. However, little did we realize that Earth’s climate has been changing, getting much warmer. In the past few decades, rapid industrialization and modernization have resulted in astounding growth in society and generated welfares beyond measure. But have we been developing in our best interests, in sustainable ways, or have we been exploiting the Earth irreversibly, and have our deeds been playing a part in mother nature’s disaster calls? These are all questions essential to us as natural disasters are the most devastating events in recorded history, more so than warfare.

Wildfires have become an increasingly trending topic in the news lately. Beyond their immediate devastation, the enormous amount of smoke and ashes buries the surrounding areas, and the desolation of the ecosystem takes years, if not decades, to revive. In response, my capstone project built a sensor system to monitor and detect hazardous conditions such as wildfires remotely using a distributed IoT network. We hope to help humans better respond to these significant threats, preventing large-scale fires and invaluable economic losses.

Meanwhile, this STS research delves into detail on wildfire’s causes and their ties to climate change and looks at other current and novel methodologies in wildfire detection and prevention. In the end, this research navigates to explore the toll of natural disasters on society from the past and how our communities can rise to the challenge of combating natural disasters in the social and technical aspects.

Literature Review

The 2019–2020 bushfire season in Australia destroyed an estimated 46 million acres of land and around 6000 buildings in a few months. The fires also affected approximately 143 million mammals, 2.46 billion reptiles, 180 million birds, and 51 million frogs ("2019–20 Australian Bushfire Season," 2021). Similarly, countless wildfires ravaged the California region across the Pacific, causing millions of dollars in damages while displacing numerous families and calling for massive evacuations. 2020 was California's worst wildfire season on record yet, as 9,639 fires burned 4,397,809 acres (1,779,730 ha), more than 4% of the state's roughly 100 million acres of land. ("2020 California Wildfires," 2021)

Yet recently, the danger of wildfires has only been on the rise. Since the 1980s, the wildfire season has lengthened across 25.3% of the world's vegetated surface (Jolly et al., 2015), and fire has become a year-round risk in places like California. "Hot and dry" are the usual catchwords for fires, and while every fire needs a spark to ignite and fuel to burn, hot and dry conditions in the atmosphere determine the likelihood of a fire's starting, its intensity, and the speed at which it spreads. However, though comprehensive data have shown that the global temperature has been rising and that this climate change aggravates natural disasters overall, global warming conspiracy theories condemn it as a "hoax." Governments and communities worldwide have come together in the past century to combat natural disasters and climate change, specifically the World Meteorological Organization (WMO) of the United Nations (UN). Nevertheless, there is still a long way ahead.

Methodology

To answer such a question of "how to prevent wildfires and mitigate natural disasters," we first need to understand the issue itself; what are these catastrophes, how, and why do they occur. We also need to survey the affected regions and study their geography, climate, and culture closely to assess situations better. Finally, we need knowledge across engineering fields to humanities, math, physics, economics, politics, sociology, and many more to construct a comprehensive answer. While understanding these contrasting areas' fundamental interactions is crucial, no individual expertise is needed. We need not start from "Ground Zero" and master every subject field, for we can build on humanity's "collective knowledge" more accessible than ever in today's Information Age. A thorough search solicited articles and researches from various magazines, Google Scholar, and UVA Virgo databases. Their bibliographies were then compiled into Zotero for references. This paper hopes to explore wildfire prevention, raise awareness of natural disasters and their social implications, and propose sustainable development approaches by evaluating and analyzing these materials.

Research Body

- **The Origin of Wildfires**

According to the National Geographic Society (2019) definition, a wildfire is an uncontrolled fire that burns in the wildland vegetation, often in, but not limited to, rural areas or a particular continent or environment. Craig Clements, an associate professor and director of the Fire Weather Research Laboratory at San Jose State University (SJSU), is currently researching how wildfires behave and create their weather. In an interview by Derouin (2018), Clements sat down with the EARTH magazine in his Fire Weather Lab to talk about his extreme fieldwork.

- *The Basic Conditions and Contributions*

According to Clements, a fire environment triangle, a fire's stage, is composed of the fuel (brushes, shrubs, grasses, and trees), the topography (flatland or mountain), and the most variable, weather. The vegetation of the land, on the other hand, is seasonal. Green grass in the spring can turn into brown grass, fire-prone fuel, by mid-autumn, depending on the conditions.

- *Fire Weather and Its Creation*

When a fire starts to burn, fire weathers are created. Clements uses the campfire as a vivid analogy. "When you warm yourself by a campfire, you put your hands up beside it… You don't put your hands directly above it, in the plume, because all the hot gases are rising vertically, and you could burn yourself. The heat you [actually] feel is the updraft of hot gases." This weather system that the fire has created is called "fire weather." A wildfire's big billowing smoke column is its plume with much dynamics inside, and the updrafts make the situation noteworthy. With stronger updraft, stronger surface wind feeds into the plume's base and carries the smoke upward. As a result, more air rushes into the plume's base and further fuels it. The rushing-running wind, the so-called fire-induced wind, comes from all directions and forms its wind system around the fire. In addition, strong updraft can also carry large embers high up the atmosphere, where they can start new blazes known as spot fires, while plumes can travel across the globe in the stratosphere.

Wildfires are generally divided into two types, wind-driven or plume-dominated. In wind-driven fires, wind from the ambiance drive and spread the fire. However, in plume-dominated fires, large flames release immense heat, drive air circulation by feeding back into the flame, and create their weather. Clements says that plumes are fascinating to study because, despite the academic classification, it’s often difficult to determine the difference between the two categories or when fires change domain.

- **The Climatological Flame**

Now that there is a technical understanding of wildfires, it’s time to delve into their root causes and effects. When the fallen branches and leaves’ moisture content reaches 0%, they are categorized as “dead fuel.” When the fuel moisture content is low, fires start more quickly and spread more rapidly, as all of the heat’s energy goes into the combustion. However, fires do not readily ignite when the fuel moisture content is high because most of the heat is first used up to evaporate water from the fuel. Although hotter air has a higher capacity to hold water, the higher temperature ultimately increases the fuel’s required heat to burn.

- *Hot and Dry*

“High temperatures and low humidity are two essential factors behind the rise in fire risk and activity, affecting fire behavior from its ignition to its spread,” said Jim Randerson, an Earth system scientist at the University of California, Irvine. Our ability to track fires with satellite data over the last 20 years had captured consistent large-scale global warming trends in places like the western US forests where fuels are abundant. In a research on the abundance of lightning strikes, the leading natural cause of fires, Randerson and colleagues found an unusually high number of lightning strikes occurred in the 2015 Alaskan fire season. It was later concluded that warmer temperatures created more convective systems, thunderstorms in the atmosphere, eventually adding to more burned areas that year. (Gary, 2019)

The hotter and drier conditions do not meddle with nature's temper alone, for they also set the stage for human-ignited fires. In 2018, sparks flying from hammering a concrete stake in 100-degree Fahrenheit and a flat-tired car's tire rim scraping against the asphalt turned into California's devastatingly destructive Ranch and Carr Fires, respectively. Died and dried-out vegetations quickly flared and grew out of control, similar to that of agricultural fires.

Higher nighttime temperature is another "contribution" made by the warming weather. "Warmer nighttime temperature allows fires to [not only] burn through the night [but also] more intensely, to spread over multiple days. Whereas previously, [it] might have weakened or extinguished the fire after only one day," Doug Morton, chief of the Biospheric Sciences Laboratory at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

- *Fire Feedbacks*

Fires can impact humans and the climate beyond the immediate loss of life and property. For example, smoke is a severe health hazard; long-term exposure to soot particles has links to higher rates of respiratory and heart problems. The smoke plumes can also affect air quality for people far downwind for thousands of miles. Additionally, the loss of vegetation can lead to erosion and mudslides afterward and affect local water supplies.

As for the climate, fires can, directly and indirectly, increase carbon emissions to the atmosphere. Fires release carbon stored in plants or the soil as they burn, and carbon is released as dead plants decompose, further shrinking the carbon sink. They also burn organic carbon from the Earth in the Arctic and boreal forest ecosystems, hastening permafrost's melting, releasing methane when thawed, another greenhouse gas. The mixed effect of aerosols produced by fire is another area of active research. Dark aerosols, also called black carbon, absorb heat from the sun and render the snow dark as they land, accelerating the melting of snow and raising local temperatures. And light aerosols, on the other hand, have the opposite cooling effect. Furthermore, these particles can also impede precipitations, altering the water cycle.

- *"Climate Change Is A Hoax"*

As Shaftel et al. (n.d.) noted, Earth's climate has changed throughout time, seven glacial cycles of advances and retreats in the past 650,000 years, with the abrupt end of the last ice age about 11,700 years ago marking the beginning of the modern climate era and human civilization. Most of these variations are attributed to minimal variations in Earth's orbit, which change our planet's solar energy amount.

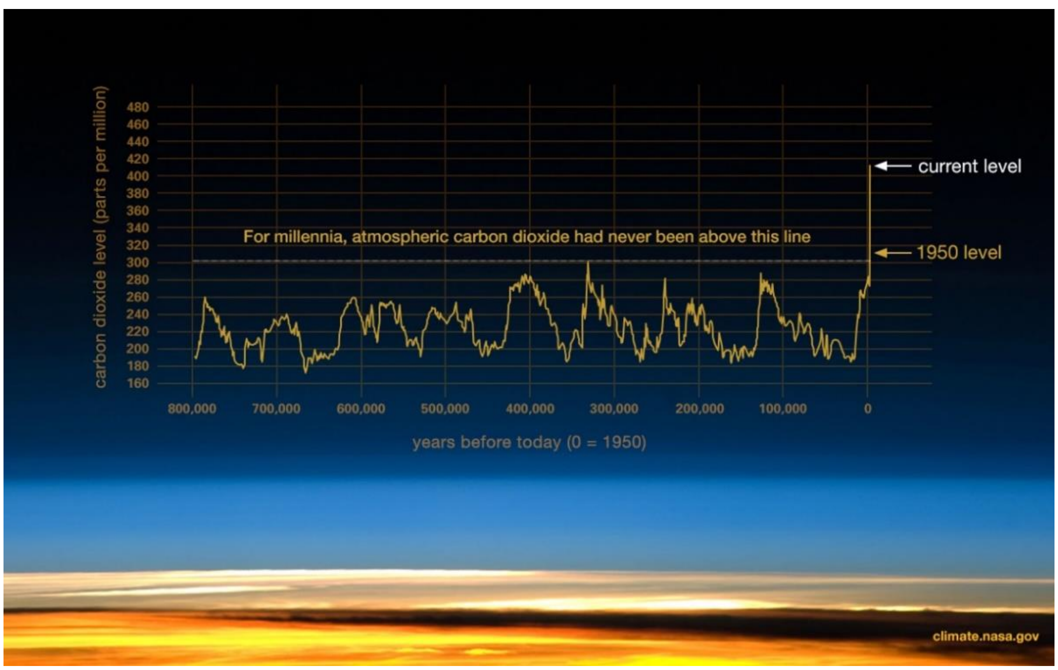

Figure #1: Earth's Carbon Dioxide Level Over the Past 800,00 Years

However, since 1880, the world has warmed by 1.9 degrees Fahrenheit (1.09 degrees Celsius), and carbon dioxide from human activity increased more than 250 times faster than from natural sources after the last Ice Age. This current warming trend is of particular significance because most of it is highly likely (greater than 95% probability) due to human activity since the mid-20th century proceeding unprecedentedly over decades to millennia.

Despite accruing data suggesting warming temperatures as a primary factor of the recently intensified wildfires, the battle against climate change presents political and social concerns. From "Global Warming Conspiracy Theory" (2021), alleged conspiracies ranged from faked scientific data, the corrupt peer review process, perpetration by the liberal extremist to green scam. The US's withdrawal from the Paris Agreement under the Trump administration aggravated the lack of action to mitigate the damage done by global warming. It has indubitably reinforced the 40% of Americans today who still believe that climate change is a hoax.

- **Early Mitigation, Detection, and Prevention**

Wildfires, like other disasters, bring tremendous losses to our society, but with appropriate early actions, much of the damage can be averted. From Fowler (2017), scholars and scientists have begun their venture in the relatively new computer fire modeling field to better combat the increasingly dangerous fires.

- *Measuring the Biomass*

Biomass, the total mass of organisms in a given area or volume produced by years of decaying vegetation, is often challenging to estimate and measure. In the San Francisco Bay area, after watching the destruction of the centuries-old Giant sequoias in California's 2017 wildfire season, naturalist Aditya Shah (2018) partnered with Sanjana Shah, a friend, and fellow student, to measure biomass. The duo developed a device to analyze biomass images, estimating their moisture level and size to determine the dead fuel level. Used in a network of sensors, this Smart Wildfire Sensor device could remove the need for physical forest visits to collect and classify dead fuel samples manually while predicting the wildfire at a 100 square-meter granularity level.

➢ *Watching the Fire*

At California State University Fullerton, the increasingly frequent destructive blazes sparked a novel idea for a team of mechanical engineering students. They developed a system called “Wildfire Aversion by Forecast and Early Response System (WAFERS).” The project utilizes smart drone technology to construct an orthomosaic map, an aerial photograph of a fire that accurately depicts the picture without distortion, through Pix4D software used for drone mapping. The WAFERS algorithm then analyzes the software to predict and visually represent the projected wildfire spread perimeter. WAFERS’s prototype test runs, using an alternative approach without using large amounts of computing power, obtained the results within a maximum of 10 minutes with its algorithm, contrasting with the others taking upwards of two to three days to finish. (Engineering Students Develop Smart Drone to Predict Wildfire Spread and Fight Climate Crisis, 2020)

➢ *Sensing the Atmosphere*

The many current satellite-system forest fire detection implementations are prone to limitations, such as the lack of “omniscient coverage,” leading to delay in detection speed and failure in quality. Meanwhile, other methods using automatic smoke detection usually run up maintenance and detection costs way too high (A. A. Alkhatib, 2017). Alternatively, Aeris and LADSensors have implemented a wireless sensor network measuring metrics such as temperature, ambient CO^2, humidity, etc., to detect wildfires early on and predict their potential spread (Fight Forest Fires with Tech, n.d.). Furthermore, wireless sensor networks have been used to monitor aquaculture plants (Xiaoman & Xia, 2016).

Back home at the University of Virginia, my capstone team built a robust and intelligent monitoring system for monitoring wildfires by creating an IoT wireless network that uses sensors to collect and transmit air metric data to existing web technologies. These web technologies, consisting of databases and data visualization dashboards, then visualize the data and provide meaningful feedback quickly and efficiently. Our team designed this device while prioritizing low-power and high efficiency. If economically viable, this system would alert to enact prompt and appropriate responses and lead to hazard prevention (A. A. A. Alkhatib, 2014).

- **Calamities of the Past**

Humankind has prevailed through natural disasters since the beginning of recorded history. Yet, we have only recently attained the ability to collect and analyze large amounts of data with information technologies. "Our World in Data" is a website that hosts thousands of researches with quality data to make progress against the world's most significant problems, and Ritchie & Roser (2014) presented one such on natural disasters.

- *Humanity's Struggle and Advancement*

In the visualization shown in *Figure #2*, we see the long-term declining global trend in natural disaster deaths, based on data from the EM-DAT International Disaster Database.

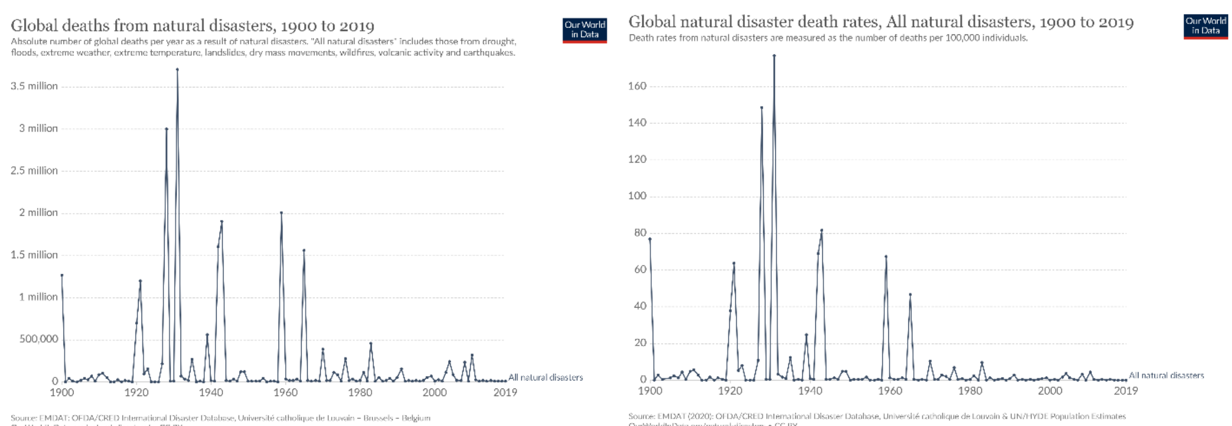

Figure #2: Estimated Global Deaths from Natural Disasters (1900–2019)

In the early to mid-20th century, the annual death toll from disasters was still high, reaching over one million per year. However, over the recent decades, we have seen a substantial decline, fewer than 20,000 in most years, while often less than 10,000 in the past decade. Most significantly, the death toll has not exceeded 500,000 since the mid-1960s, even with “high-impact events” in peak years. Such a declining trend became even more impressive when corrected for population growth (the right-hand chart) during this period.

Figure #3 shows the global number of deaths by type of disaster since 1900, where the bubble size represents the number. We can see that earthquakes, floods, and droughts result in extensive deaths historically, with significant earthquakes taking the lead.

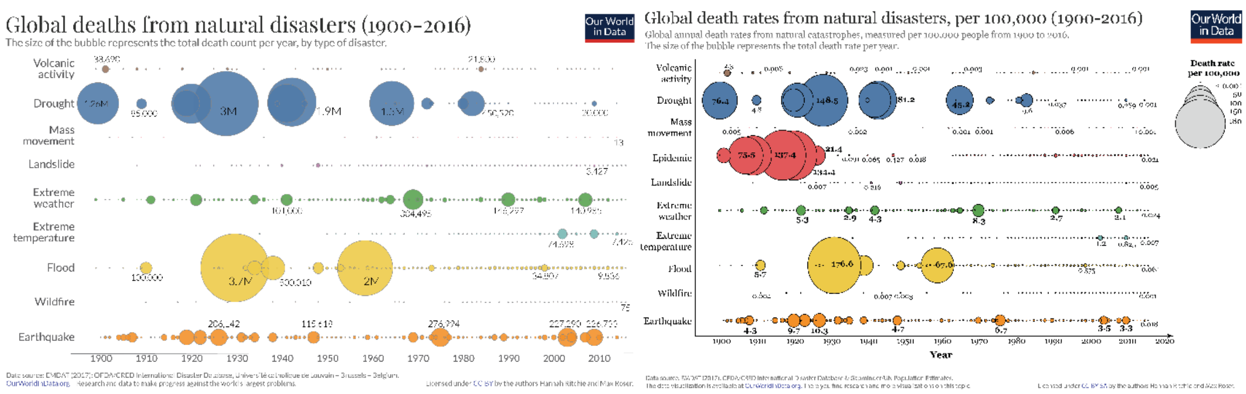

Figure #3: Global Deaths from Natural Disasters by Type (1900–2016)

We can also observe a significant decline in deaths from nearly all types of disasters except for earthquakes and extreme weather. Population growth adjustment magnifies such remarkable progress (the right-hand chart).

➢ *All Are Equal and Some More So Than Others*

The data from Ritchie & Roser’s (2014) research have also shown quite some disparity in natural disasters, namely, catastrophes in poverty. Although humanity has made monumental economic and population growth hallmarks, most low-income countries, those where a significant portion of the population still live in extreme poverty, are more susceptible to natural disasters.

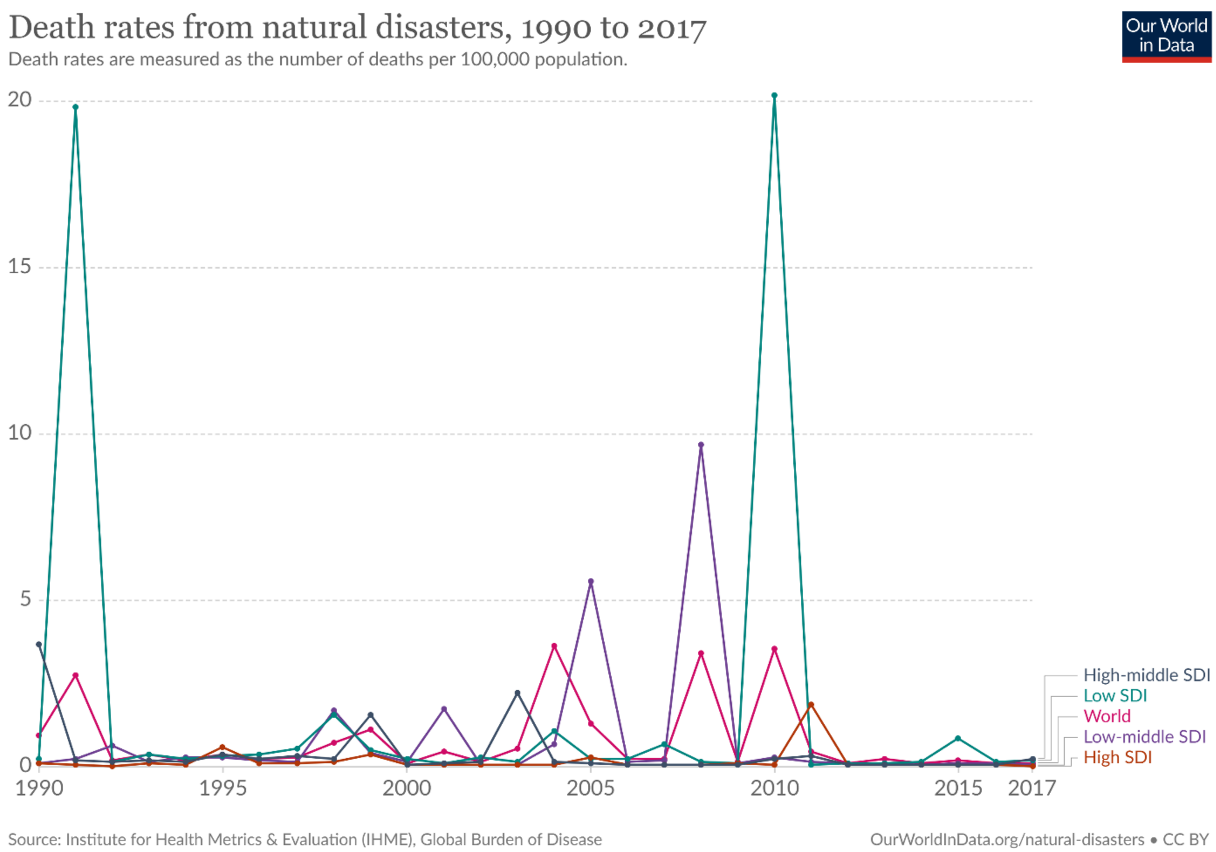

Figure #4: Global Death Rates from Natural Disasters by SDI (1900–2017)

This effect is shown in the chart above, the death rates from natural disasters per 100,000 people, of countries grouped by their socio-demographic index (SDI). As a metric of development, SDI corresponds to countries' standards of living. The large spikes in death rates occurred almost exclusively in low or low-middle SDI countries. Though the data do not suggest a high year-round risk of disasters in low-income countries, they propose that these countries are particularly susceptible to the albeit low-frequency, high-impact events.

Another inequality of natural disasters manifests in the news coverage. *Figure #5* considers more than 5,000 natural disasters and 700,000 news stories from the major US national broadcast networks (ABC, CBS, NBC, and CNN) between 1968 and 2002 and their corresponding coverage in major US networks while controlling for several factors. It became clear that "spectacular" disasters receive more coverage and sometimes do not reflect natural disasters' severity.

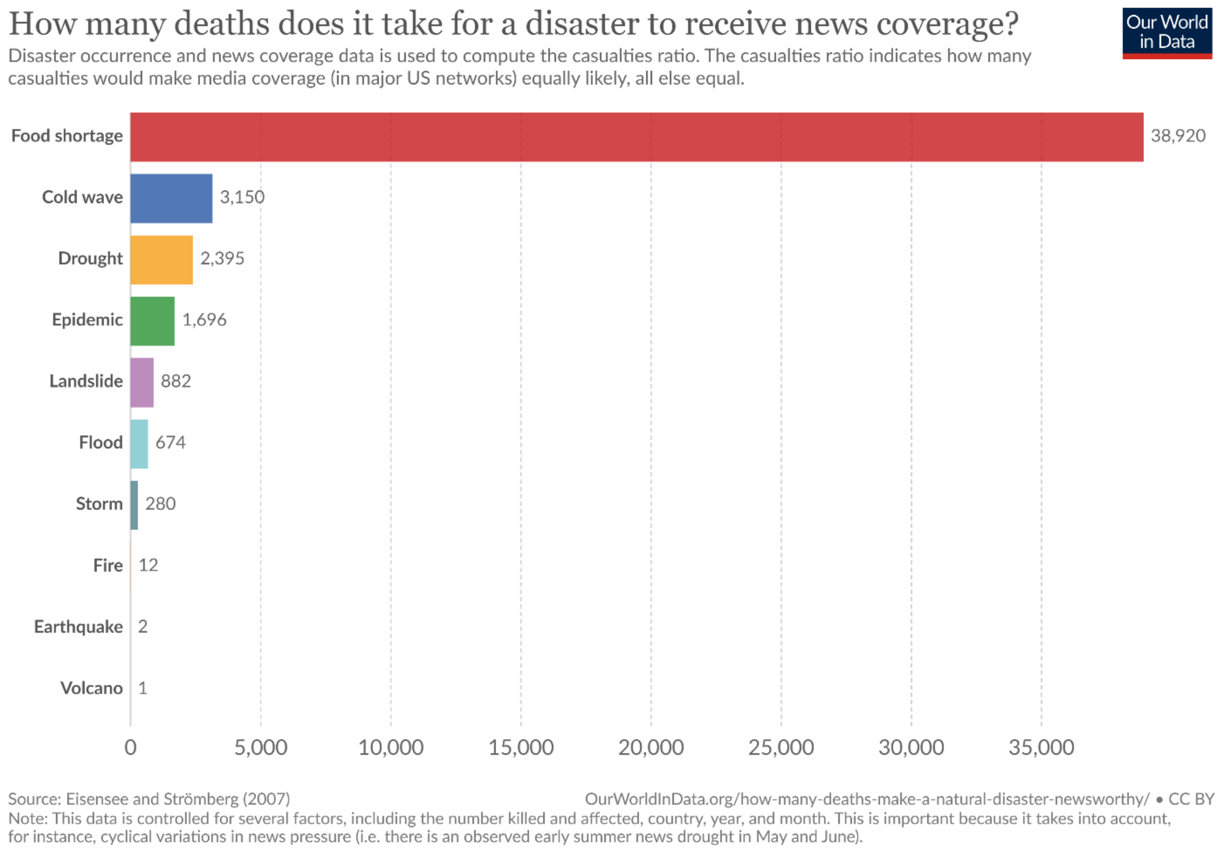

Figure #5: Proportion of News Coverages on Each Type of Natural Disaster (Casualty Ratio)

In terms of news coverages by region, there exists a very similar trend. After controlling for disaster type and other factors such as the number killed and the news's timing, a colossal difference emerged between coverage of Africa, Asia, and the Pacific, and Europe and South and Central America. *Figure #6* suggests that 45 times as many people "need to die" in an African disaster to garner the same media attention as a European one.

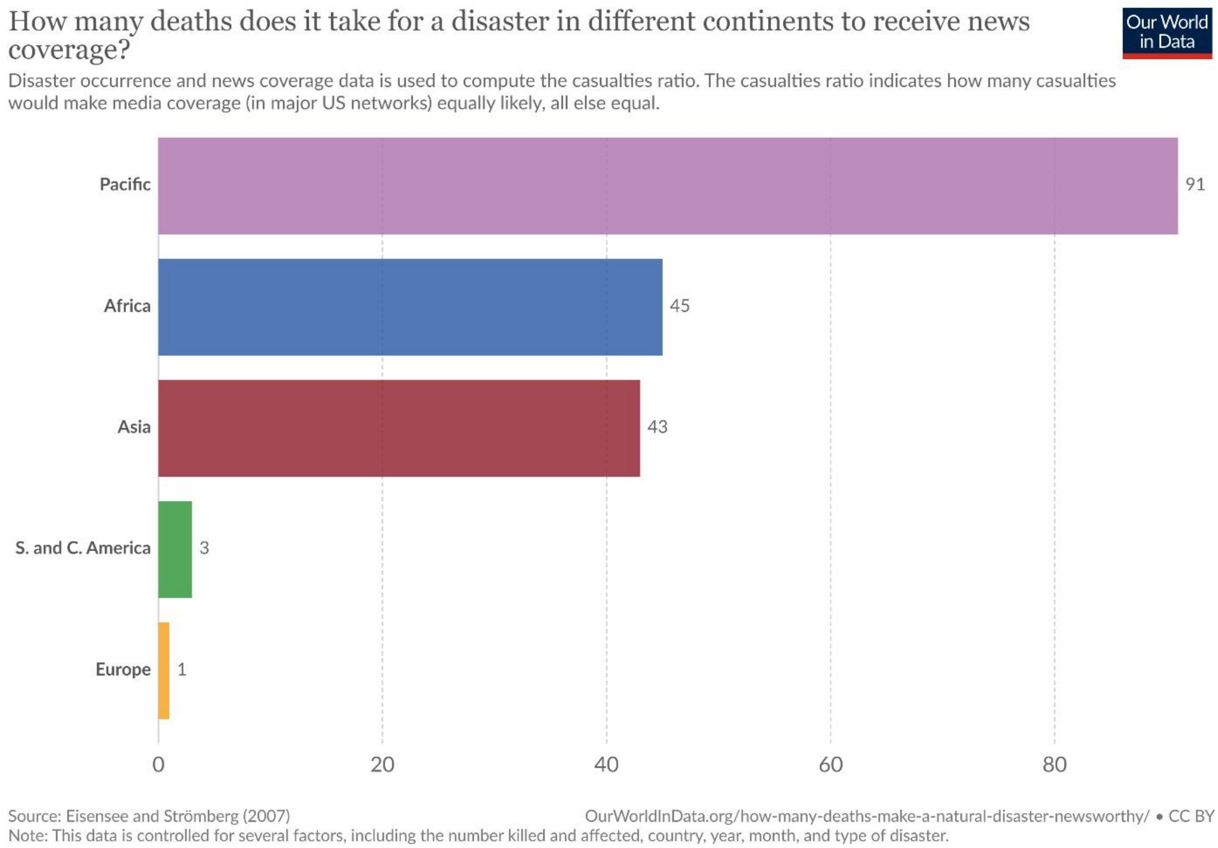

Figure #6: Proportion of News Coverages on Natural Disasters by Region (Casualty Ratio)

This bias is not only unfair, misleading but can misallocate attention and aid. It is essential to stay vigilant of the extent of the observed "news effect" on how newsworthy networks find different natural disasters. ABC News's slogan says, "See the whole picture," while CNN says, "Go there," but what exactly, and where, remain questions.

❖ A Road to Sustainability

Whether one likes to believe it or not, "scientific evidence for warming of the climate system is unequivocal," Intergovernmental Panel on Climate Change. We must seek sustainable development, revolved around the three pillars of economic, environmental, and social, informally known as the three P's, profit, planet, and people. Lone & Subramani (2016) suggested that the more liable low-income countries should foster sustainable developments in an organized manner from the start to build resilience in the face of disasters. They also advocated that local communities should, as the primary stakeholders and the "disaster front," incorporate risk management into the planning process. Participate in the educational and empowering approach to identify the problems and needs and assume responsibility to plan, manage, and assess the necessary collective action. Doing so can allow the most efficient external and local resource allocation in a well-structured people-centric, coordinated, and integrated effort during disasters without falling to mere "victims" of aids.

- *The Sendai Framework*

Policy-maker and disaster management experts from over 180 countries met in Cancun, Mexico, in May 2017 to pave the way towards reducing disaster losses "significantly" by 2030 based on the Sendai Framework for Disaster Risk Reduction 2015–2030 (DRR). The DRR, adopted in 2015, outlines seven targets and four priorities for action to prevent new and reduce existing disaster risks.

Studies conducted on the flood and landslide in Sri Lanka, which happened right in the middle of the summit, concluded that the root cause was social, widespread poverty, conflict-induced migration, and problematic land-use practices. More importantly, these characteristics are not homogeneous; different places and people are affected differently. However, while underdeveloped and developing nations and obvious socially disadvantaged receive significant focuses nowadays, little is known about the vulnerability of those who live in overall affluent societies. This problem, known as the "ecological fallacy," happens when making inferences based on aggregated economic characteristics and relationships on the macro-level do not hold on the micro-level. These examples from "the rich and the poor" point to the need to consider social vulnerability in more geographically and demographically nuanced ways when implementing DRR activities. Knowledge about socially vulnerable groups' nature and location is critical for effective DRR across all disaster cycle stages, preparedness, response, and recovery. (Eriksen et al., 2017)

- *Categorization and Standardization*

Limitation induced by the lack of clear standards and definitions is another significant ongoing challenge in disaster management, leading to inconsistent reliability and poor interoperability of different disaster data compilation initiatives. The Center for Research on the Epidemiology of Disasters (CRED) undertook an analytical review of selected data set on natural disasters and their impacts in 2006. The CRED and Munich RE led a collaborative initiative, agreed on, and implemented as a joint "Disaster Category Classification and Peril Terminology for Operational Databases" in 2007 with data from a 2002 CRED comparative study of three global data sets: EM-DAT (CRED), NatCatSERVICE (Munich RE), and Sigma (Swiss RE).

This new classification system distinguishes two generic disaster groups, natural and technological while dividing natural disasters into six disaster groups: Biological, Geophysical, Meteorological, Hydrological, Climatological, and Extra-Terrestrial. Each group covers different disaster main types, each having different disaster sub-types. The harmonization between two of the most critical global disaster databases NatCatSERVICE, EM-DAT and the definition of common standards made essential contributions to improving comparability and interoperability of the international disaster databases. (Sapir & Below, 2009)

Conclusion

Modern human civilization has wandered the Earth for thousands of years. Reminiscing in the 21st century, we have made extraordinary advances in our struggle against the wrath of nature. In retrospect, this research focused on unveiling wildfires' origin, discovering their ties to climate change, and analyzing the various approaches to early mitigation and detection. If our capstone team and the many other groups succeed in our efforts, wildfire prevention will become obtainable. Additionally, social vulnerability was identified as the primary concern in the aftermath of natural disasters, and micro-management is needed even when instrumenting macro-scale DRR initiatives. Future research should further investigate the target, priorities, and finally, the realization of The Sendai Framework. Sustainability is the only way out, and we, a community with a shared future, must "think and live ahead" shall we continue to flourish.

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