AI AND ML IN EARLY WARNING SYSTEMS FOR NATURAL DISASTERS

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AI and ML in Early Warning Systems for Natural Disasters

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FOREWORD

The book *AI and ML in Early Warning Systems for Natural Disasters* is a timely publication by distinguished scholars in the field. Its twelve chapters are contributed by renowned experts in AI and ML, disaster science and management, extreme climate events, and early warning systems. Early warning is a critical phase of disaster management, with investments proving to be over ten times more cost-effective in reducing deaths and losses caused by disasters. This book comprehensively addresses various aspects of early warning systems for disaster management, focusing on the most pressing natural hazards facing the world today. This book will be an indispensable resource for students, researchers, educators, and practitioners eager to explore the transformative role of AI and ML in disaster preparedness and response. It will also serve as a vital guide for organizations and agencies working at the forefront of disaster risk reduction, offering insights into innovative strategies that can be scaled and adapted globally. In an era where the stakes of inaction are higher than ever, this book stands as a critical contribution to building a safer, more resilient world.

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FOREWORD II

In an era marked by escalating climate crises and the increasing frequency of natural disasters, the need for innovative solutions has never been more urgent. The book *AI and ML in Early Warning Systems for Natural Disasters* arrives at a critical juncture, offering a transformative perspective on the use of cutting-edge technology to address one of humanity's most pressing challenges.

Early warning systems are a cornerstone of disaster risk reduction, providing invaluable time to prepare and respond, thereby saving lives and reducing economic losses. However, the traditional approaches to early warning often struggle to keep pace with the complexities of modern disasters, characterized by rapid onset, evolving patterns, and compounding effects. This is where Artificial Intelligence (AI) and Machine Learning (ML) can revolutionize the field.

This book, meticulously compiled by some of the most distinguished minds in the disciplines of AI, ML, and disaster management, bridges the gap between technological advancements and practical applications in disaster risk reduction. It provides an in-depth exploration of how AI and ML can enhance predictive accuracy, optimize data processing, and deliver timely insights to improve preparedness and response.

The twelve chapters in this book address diverse aspects of early warning systems, from forecasting extreme climate events and monitoring geological hazards to integrating ethical frameworks and ensuring equitable access to technology. Importantly, it highlights the potential of AI and ML to support vulnerable populations and improve decision-making in resource-constrained environments, demonstrating a commitment to inclusive and sustainable development.

As a scholar and practitioner deeply engaged in disaster risk reduction, I am heartened by the emphasis on interdisciplinary collaboration presented in this volume. The integration of AI and ML with traditional knowledge, policy frameworks, and community-based approaches represents a holistic and forward-thinking strategy for mitigating disaster risks.

This book is not only a testament to the remarkable progress we have made in technological innovation but also a clarion call for action. It challenges researchers, practitioners, and policymakers to harness the power of AI and ML responsibly, ensuring that these technologies serve as tools for resilience and empowerment.

I am confident that this book will serve as an indispensable resource for academics, professionals, and organizations striving to create a safer, more resilient world. It is a vital contribution to the global discourse on disaster risk reduction and an inspiring roadmap for the integration of technology into one of humanity's most critical endeavors.

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PREFACE

In an era marked by escalating natural disasters, the integration of advanced technologies like Artificial Intelligence (AI) and Machine Learning (ML) has emerged as a transformative force in disaster management. The increasing frequency and intensity of calamities such as floods, earthquakes, and wildfires demand innovative solutions that go beyond traditional methods of detection and mitigation. This compilation of chapters explores the critical role of AI and ML in addressing these challenges, focusing on their potential to revolutionize disaster detection, management, and prevention. By delving into cutting-edge research, tools, and methodologies, the book aims to provide a comprehensive understanding of how technology is shaping the future of disaster resilience.

The first few chapters underscore the **importance of AI and ML in disaster detection**, offering a foundational perspective on their transformative capabilities. Traditional approaches often struggle to provide accurate, real-time data, whereas AI-driven models leverage large datasets, remote sensing, and predictive analytics to improve accuracy and timeliness. By examining the evolution of these technologies, readers will gain insights into their ability to anticipate disasters and reduce human and economic losses significantly.

Moving forward, the text explores **recent advances in AI and ML techniques**, emphasizing innovative applications across various natural disasters. From leveraging satellite imagery and IoT-based sensors for real-time monitoring to deploying sophisticated machine learning algorithms for pattern recognition, these chapters showcase the dynamic interplay between technology and disaster management. Real-world case studies further illustrate how these advancements are being implemented to save lives and protect communities worldwide.

The book also delves into the **integration of AI and ML into early warning systems**, a critical component of modern disaster preparedness. These systems not only enhance the predictive accuracy of traditional methods but also enable more effective communication and coordination among stakeholders. A dedicated section examines the challenges of implementing such systems in the context of climate change, highlighting the urgent need for scalable and adaptive solutions.

Finally, the book addresses the broader implications of AI and ML in disaster management, including **legal frameworks and ethical considerations**. With technology advancing at an unprecedented pace, ensuring responsible development and deployment is paramount. Additionally, specialized chapters focus on unique topics such as the use of fuzzy artificial intelligence for earthquake prediction and the potential of these technologies to mitigate the long-term impacts of climate change.

By presenting a holistic view of the field, this book aims to inspire researchers, policymakers, and practitioners to harness the full potential of AI and ML for disaster management. The insights and strategies offered within these pages underscore the transformative power of technology, emphasizing its critical role in creating a safer, more resilient world.

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CHAPTER 1

Importance of Artificial Intelligence and Machine Learning in Disaster Detection

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Abstract: The rapid progress of Artificial Intelligence (AI) and Machine Learning (ML) has raised hopes that these technologies could transform the way we detect and manage disasters. Nevertheless, this chapter contends that the current abilities of AI and ML are exaggerated and face inherent constraints in effectively identifying and responding to the intricacies inherent in disasters. AI and ML systems, despite their computational power, struggle to understand the complex nature of disasters due to their reliance on historical data and susceptibility to biases and noise in training data, potentially causing inaccurate predictions and worsening disaster impacts. Moreover, AI and ML currently lack contextual understanding and adaptability for real-world crises, requiring human judgement, intuition, and improvisation to navigate dynamic environments. This chapter delves into the ethical and societal consequences of relying too heavily on AI and ML for disaster detection and management. It highlights the dangers of perpetuating biases, compromising privacy and accountability, and potentially causing harm through flawed decision-making processes. The chapter also stresses the importance of human oversight, interdisciplinary collaboration, and a holistic approach that integrates AI and ML capabilities with local knowledge, robust emergency response plans, and effective communication strategies. The chapter highlights the limitations of AI and ML in disaster detection, advocating for a balanced approach that balances their strengths while acknowledging their limitations. Recognizing the complexities of disasters enables policymakers and disaster management professionals to make informed decisions and develop more resilient strategies for mitigating and responding to these critical events.

Keywords: Artificial intelligence, Decision support systems, Deep learning, Disaster detection, Disaster risk management, Early warning system, Internet of things, Machine learning, Remote sensing, Seismology.

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INTRODUCTION

Natural and man-made crises upset an organization's stability, goals, and operations. It can cause tension and emotional reactions, upend the existing quo, and delegitimize policies. Crises, however, can speed up the political learning and transformation processes and provide public organisations with an opportunity to learn how government institutions function under duress. These situations could put people under stress and jeopardise an organization's capacity to continue operating [1].

Catastrophes and emergencies are unpredictable occurrences that have substantial effects on the environment and society. Their intricately linked social amenities and ecological contexts make it difficult to forecast their path and mitigate their adverse effects [2, 3]. Global warming and environmental pollution increase natural disasters, particularly in developing nations. Studying these disasters using raw smartphone data and anomaly detection algorithms can improve community and catastrophe management [4]. There is an immediate need for strategic disaster risk management (DRM), and artificial intelligence could enhance decision-making. Disasters are now a bigger global concern due to factors like climate change, urbanisation, population growth, and environmental degradation. These incidents result in fatalities, economic upheaval, and long-term system and infrastructure damage [5]. Fig. (**1**) shows factors contributing to global disaster.

The advancements in artificial intelligence (AI) and machine learning (ML) have improved disaster detection by analysing data from various sources, enabling accurate prediction and management of events, thereby reducing damage to infrastructure and human life from natural and artificial disasters [6].

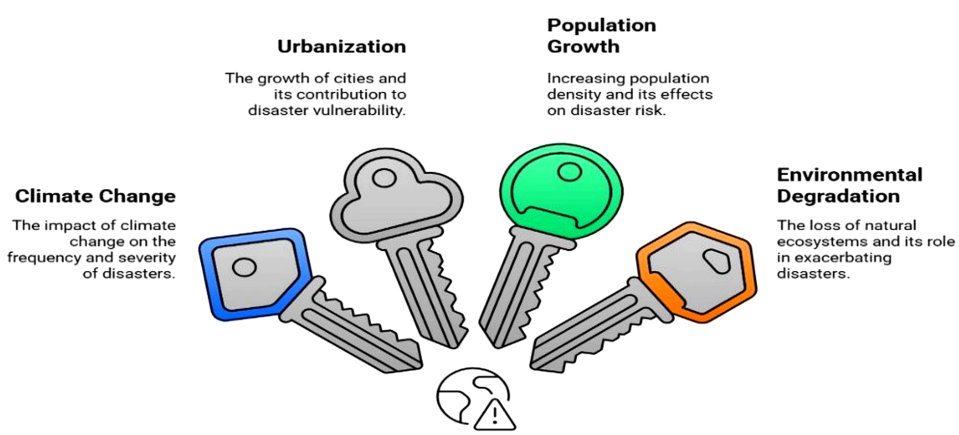

Fig. (1). Factors contributing to global disaster.

According to the United Nations Office for Disaster Risk Reduction (UNISDR), a disaster is an important disturbance to a community's normal operations that results in severe losses to people, property, the economy, or the environment that are greater than what the community is able to handle [7, 8].

Disaster Risk Management (DRM) involves assessing and mitigating risks from crises and disasters. Accurate information is essential, and stakeholders must work together to achieve it. The increasing volume of data being used from several sources, including social media and the Internet of Things, presents opportunities to employ AI and ML to enhance DRM decision-making [5].

The goals of disaster management operations are to minimise casualties, safeguard people and property, lessen the effects on the economy, and restore normalcy. They are carried out before, during, and afterwards. Disaster management requires robust decision-making due to the complexity of catastrophes and the criticality of operations, with AI and ML advancements enabling informed and effective management [8, 9]. Disaster management involves the systematic management of disaster prevention, preparedness, response, and recovery, with four stages: preparedness, response, mitigation, and recovery [10]. While preparedness and response involve preparing the community for emergency planning, mitigation concentrates on preventing or lessening the effects of disasters, and recovery is taking long-term measures to return things to normal. Resilience can be promoted by local communities' active participation in catastrophe management. Success or failure in disaster management depends on the use of effective practices. Resilience in emergency aid can be improved by utilising AI and GIS technologies. Planning for disaster response is impacted by morphology, weather, ecology, and resource availability, among other things. Disaster management relies heavily on preparedness, resilience, vulnerability, and preventive efforts to lessen the effects of disaster [8, 9, 11].

The Centre for Research on the Epidemiology of Disasters reports that the United States, China, Japan, and India have the highest GDP losses due to disasters, with the Asia-Pacific region being the most vulnerable since 1995 [12]. Real-time earthquake early warning systems are vital due to the global threat posed by seismic hotspots. Conventional models could result in more expenses and false alarms. The use of specialised instruments is lessened in major cities when people acquire smartphones, and mobile sensors provide better spatial resolution [4]. Fig. (**2**) illustrates the various stages involved in disaster management.

Artificial Intelligence

The idea of artificial intelligence was first proposed in the 1930s. They year 1950 and the 1956 meeting at Dartmouth College, where it was formally introduced,

CHAPTER 2

Harnessing AI and Machine Learning for Natural Disaster Management

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Abstract: Being exposed to natural disasters poses a significant risk to humans, their property, and the environment. This risk is very difficult to manage. These incidents are happening with increased frequency and severity as a consequence of variables such as climate change, population growth, and a rise in the number of people living in urban areas. These factors are contributing to the growing number of urban areas. It is because of these problems that a unique strategy for dealing with disasters has evolved, and that is the integration of technologies that make use of artificial intelligence (AI) and machine learning (ML). This article's objective is to investigate several ways in which artificial intelligence and machine learning may be used in the area of natural disaster management. The purpose of this article is to investigate the different ways in which they may be used throughout the life cycle of a disaster, including the stages of preparing for it, responding to it, recovering from it, and making it stronger for future catastrophes. The purpose of artificial intelligence algorithms is to analyze huge amounts of data in order to make informed estimates about when and how severe events will occur. These algorithms use prediction analytics and early warning systems to get this information. Because of this, individuals are able to move quickly while simultaneously defending themselves. During the period of response, AI-driven systems make the most effective use of available resources, simplify the process of cooperation between a large number of stakeholders, and raise awareness of the situation by monitoring and providing assistance with decision-making in real time. Artificial intelligence technologies make it easier to determine the extent of the damage during the immediate aftermath of a disaster. These technologies also offer assistance with the planning of recovery and supply communities with the resources they require to become more resilient through the utilization of data-driven approaches and community engagement initiatives. On the other hand, the extensive use of artificial intelligence in disaster management raises issues around the privacy of data, the bias of algorithms, and the fair access to technology. In order to ensure that AI-driven solutions are successful and that they are accessible to all users, it is vital to properly address these problems. Those who are involved in disaster management may be able to improve their ability to anticipate natural disasters, respond to them, and recover from them by working together with one another and using technology that is based on

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artificial intelligence and machine learning in addition to more traditional methods. In a world that is becoming more unstable, this will result in the preservation of lives, the safeguarding of livelihoods, and the fortification of communities.

Keywords: Artificial intelligence (AI), Community resilience, Damage assessment, Data analysis, Decision support, Disaster management, Early warning systems, Emergency response, Infrastructure optimization, Machine learning (ML), Natural disasters, Predictive analytics, Recovery planning, Remote sensing, Risk reduction.

INTRODUCTION

There is always a chance of a natural disaster happening, which can have terrible effects on communities, businesses, and ecosystems. From the damage caused by storms and earthquakes to the broad damage from floods and wildfires, these events show how important it is to have good emergency management plans right away. Natural disasters are happening more often and with more force because of climate change, development, and population growth. This makes things harder for governments, first responders, and communities all over the world.

Because these risks are getting worse, using AI and ML has become a revolutionary way to improve emergency preparation, reaction, and recovery. AI and machine learning technologies make it possible to look at huge amounts of data, find trends, and get useful information in real time. This helps people predict dangers, lower risks, and plan quick actions [1].

How we think about disaster resilience and risk reduction has changed a lot since AI and ML are being used in all parts of the disaster management process. Predictive analytics, early warning systems, damage evaluation, recovery planning, and community development programs are just some of the AI-driven solutions that could change how we understand, prepare for, and react to natural disasters.

But to get the most out of AI in emergency management, we need to take a multifaceted approach that takes into account scientific, moral, and economic factors. Data quality and availability issues, algorithm bias, privacy concerns, and fair access to technology are some of the problems that need to be carefully solved before AI solutions can help everyone and make communities stronger [2].

We have a once-in-a-lifetime chance to use AI and ML technologies to lessen the effects of natural disasters, save lives, and protect people's ways of making a living by working together on research, new ideas, and building up people's skills. We can build a more secure future in the face of growing environmental risks and uncertainties by taking a whole-person approach that includes new technologies, community involvement, policy support, and investments in infrastructure. This chapter looks at how AI and ML could completely change emergency management. It does this by showing possible uses, best practices, and possible future directions for using technology to solve one of the world's most important problems.

Understanding Natural Disasters

In order to effectively manage disasters, it is crucial to possess a thorough understanding of natural catastrophes, encompassing their origins, impacts, and intricacies. Extreme weather events like earthquakes, hurricanes, floods, and tsunamis are outcomes of both natural and human-induced processes. Urbanization and climate change can worsen the impacts of natural disasters. Researchers from various fields are conducting studies on environmental, meteorological, and geological factors to gain a deeper understanding of these phenomena and find ways to prevent or minimize their impact. Having a comprehensive understanding of the geographical and temporal patterns of natural disasters is crucial for effectively reducing the number of victims and minimizing property damage. Furthermore, this valuable information can be utilized to enhance the creation of early warning systems, evacuation procedures, and robust infrastructure. Understanding the social and environmental consequences of disasters is crucial for developing effective strategies for recovery, rehabilitation, and long-term risk reduction. These strategies are informed by social and environmental observations. Expanding knowledge about natural disasters can help stakeholders enhance the resilience of society and the safety of communities against future disasters. This will enable them to enhance their readiness, response, and reduction of the impacts of devastating disasters. Fig. (**1**) presents the natural disaster and artificial intelligence.

Role of AI and Machine Learning in Natural Disaster Management

Machine learning and artificial intelligence offer innovative methods to improve disaster preparedness, response, and recovery simultaneously, highlighting their indispensable role in disaster management. Machine learning and artificial intelligence play a crucial role in accurately predicting and forecasting natural disasters. Utilizing advanced algorithms, these technologies analyze vast amounts of data from satellite photos, weather patterns, and geological data, among other sources. To ensure the safety of vulnerable groups, these systems can analyze trends and patterns and issue early warnings. This enables the implementation of proactive measures to mitigate the effects of catastrophes. Thanks to advancements in technology, machine learning and artificial intelligence have

CHAPTER 3

Recent Advances in Techniques and Applications for Machine Learning in Disaster Management

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Abstract: With the exception of the COVID-19 pandemic, climate-related disasters have been the predominant feature of recent years, based on information gathered. The hottest year on record was one of those years. In addition to taking lives, disasters cause enormous and frequently disastrous societal costs, such as financial losses. An overview of research projects on disaster management systems developed have been published presented since 2017 is the goal of this study. Catastrophe and risk estimation, risk and vulnerability examination, systems for early warning, monitoring, damage evaluation, after-disaster response, and case reports have all received special attention. Additionally, a few newly created Machine Learning (ML) and distributed disaster management applications have been examined. The results were examined, and suggestions for additional studies were made. In addition to complicated science, developing dynamic urban exposure assessments, breaking earthquake fault lines, and weather models all necessitate gathering a lot of data from multiple sources. There are several methods for using AI to determine asset accessibility and demands on sites like Twitter, but it's still unclear which are the most accurate and extensively used. Machine learning tools for resource allocation are required in the event of a disaster in order to deliver aid to those in need right away. With accidents of all kinds becoming more frequent, these gadgets could enhance crisis management in real time for the duration of a disaster. This study aims to provide readers, especially data scientists, with a clear and short overview of the benefits of machine learning for disaster risk management

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systems. To understand more about this intricate and constantly changing collection of technologies, there are numerous resources available.

Keywords: Damage assessment, Disaster prediction, Early warning systems, Machine learning, Resource allocation.

INTRODUCTION

Natural catastrophes and man-made calamities affect millions of people worldwide each year [1]. It frequently happens that these incidents result in the loss of human life. Disasters entail substantial damage to buildings and infrastructure in addition to human casualties. Before, during, and after a disaster strikes, disaster management activities are carried out with the goals of preventing fatalities, safeguarding people and property, lessening the effects on the economy, and returning things to normal [2]. Strong decision-making is necessary due to the intricacy of catastrophes; this is made possible by information technology, especially artificial intelligence. The magnitude and consequences of calamities necessitate the use of effective and knowledgeable disaster management techniques, which have since been improved by developments in deep learning and machine learning [3].

Disasters, including landslides, hurricanes, earthquakes, floods, and wildfires, are examples of application fields. Recent technical advancements can also help handle man-made calamities like refugee crises [4, 5]. A calamity, however, has no special definition. A disaster is described as a "serious disruption of the functioning of a community or a society involving widespread human, material, economic, or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" by the United Nations Office for Disaster Risk Reduction (UNISDR) [6]. Natural and technical disasters are the two primary categories under which disasters fall according to the EM-DAT nomenclature [7]. Disasters have been divided into natural and man-made categories using a distinct classification system [8]. In addition to the human casualties, the numbers showed that 2020 had more reported catastrophes than normal, 26 percent more storms, and 23 percent more floods and higher economic losses than the average for the year.

Disaster management deals with disasters throughout time. Four distinct phases, preparation, response, recuperation, and mitigation, have been widely employed. Mitigation is the term used to describe actions that will either prevent a disaster from occurring or mitigate its impact. Emergency planning, storing goods, and imparting knowledge to the public to assist them in reacting better in the case of a disaster or decreasing its effects are all actions that prepare communities for dealing with a disaster.

The operations that carry out the plans created to safeguard the lives and assets of individuals, the surroundings, and the community's economic and social makeup are referred to as response. Because infrastructure and people require the most urgent support at this phase, it has been one of the areas of greatest interest. Time is crucial throughout this stage; therefore, strategies emphasise not only highly accurate outcomes but also efficient and quick processes. The long-term measures intended to restore stability to the community are included in recovery (reconstruction). This phase's activities include rebuilding and reconstruction (*e.g.*, of structures and vital infrastructure) as well as financial aid. Furthermore, communal resilience might result from local communities' active participation in dealing with disasters.

Artificial Intelligence (AI) applications in disaster management at all stages rely heavily on a variety of Machine Learning (ML) and Deep Learning (DL) techniques. The K-Nearest Neighbour (KNN) algorithm, Logistic Regression (LR), Decision Trees (DT), Random Forests (RF), Support Vector Machines (SVM), and Naïve Bayes (NB) are examples of common machine learning algorithms. Convolutional Neural Networks (CNNs), transformers, Generative Adversarial Networks (GANs), Recurrent Neural Networks (RNNs), Long Short-Term Memory networks (LSTM), and Multi-Layer Perceptrons (MLPs) are some of the sophisticated neural network topologies used in DL techniques [9, 10]. Complex and large-scale datasets can be analysed using ML and DL to create systems that forecast disasters, facilitate efficient response and recovery activities, and provide strong decision-making capabilities. To find patterns and insights that would otherwise be hard to find, these methods use data from a variety of sources, such as satellite photos, Unmanned Aerial Vehicles (UAVs), social media platforms, crowdfunding campaigns, Geographic Information Systems (GIS), and wireless sensor networks. Recent disaster management research has focused on the potential and use of big data in catastrophic event management and the applications of artificial intelligence in disaster management. Sun *et al.* gave an overview of sample AI applications in several disaster management application areas, such as hazard risk assessment, vulnerability assessment, early warning systems, catastrophe identification, incident visualisation, harm assessment, rescue and relief, and allocation of resources. AI is increasingly being used to handle and analyse large amounts of data from several sources in order to make well-informed decisions on catastrophe management. A total of 26 AI techniques were applied across 17 disaster management application areas in the studies contained. A comprehensive analysis of the function of massive data sets in disaster management was presented by Yu *et al.* Journal articles published

CHAPTER 4

Current Landscape of Early Warning Systems and Traditional Approaches to Disaster Detection

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Abstract: Advances in technology and the desire for more efficient disaster mitigation have led to a considerable change in the current state of Early Warning Systems (EWS) and traditional approaches to disaster detection. Cutting-edge technology, including Internet of Things (IoT) devices, real-time data analytics, and satellite remote sensing, is used by modern EWS to provide timely alerts and useful knowledge. These systems use artificial intelligence and machine learning algorithms to evaluate large datasets from social media feeds, geological surveys, and meteorological sensors. This allows for accurate predictions of natural disasters, including hurricanes, earthquakes, floods, and wildfires. AI-powered models, for instance, can forecast storm paths and intensities using satellite images, while machine learning algorithms can predict earthquakes and assess the chance of aftershocks by analysing seismic data. Modern Early Warning Systems (EWS) update their models on a regular basis with new data, increasing accuracy and reliability. These systems leverage technologies like AI, sensor networks, and high-performance computing for real-time data analysis and accurate disaster prediction, offering significant improvements in timeliness and coverage compared to traditional methods. However, challenges include data gaps, communication barriers, and system sustainability.

Modern EWS enhance detection precision while promoting enhanced public-government, emergency response, and communication coordination. Real-time alert distribution is made possible through IoT devices and mobile technology, guaranteeing that communities are informed in a timely manner. Rapid information dissemination and the detection of new dangers are further important functions of social media analytics. The success of these systems depends on making sure vulnerable populations can access them and that they take into account a variety of environmental and socioeconomic conditions. Resilience and inclusivity in disaster detection and response

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can be further improved by fusing traditional knowledge and community-based methods with contemporary technologies. In summary, technical advancements and the availability of real-time data have led to a significant advancement in early warning systems compared to more conventional methods of disaster detection. These developments have improved the accuracy and promptness of disaster forecasts considerably, enabling preventative actions and better-coordinated responses. To fully utilize these systems' potential in shielding communities from the destructive effects of disasters, it will be imperative to address current issues and guarantee equal access.

Keywords: AI and ML-based detection techniques, Disaster management, Disaster response, Early warning systems, Prediction model, Real-time data analytics.

INTRODUCTION

The environment, infrastructure, and human life are all seriously threatened by natural disasters, which can range from hurricanes and wildfires to earthquakes and floods. In a study by Munawar [1], an image processing and machine learning-based flood management method has been presented. In order to present a solid and trustworthy model for early flood detection and management, the system is designed to address the shortcomings of the available technologies.

Recent techniques like AI, ML, and DL [2, 3] have been used at a large scale in many sectors. Recent developments in these techniques have changed the disaster detection environment by providing more proactive, data-driven methods. Massive amounts of real-time data can be processed thanks to AI and ML from a variety of sources, including sensors, social media, satellite imaging, and historical records. These technologies improve prediction accuracy and make it possible to see intricate patterns that conventional algorithms might miss. AI-powered algorithms, for instance, can evaluate meteorological data to produce more precise forecasts of extreme weather events like storms and floods, or they can analyse seismic data to predict earthquakes [4 - 7]. Furthermore, when machine learning models process more data, they get better over time, improving their predictions. Early Warning Systems (EWS) utilize technology, from sensor networks to AI, to detect and predict impending disasters like earthquakes, floods, and wildfires. These systems disseminate timely warnings, enabling communities to prepare, evacuate, and minimize the impact of hazardous events, ultimately saving lives and reducing damage. The development of Early Warning Systems (EWS) for disaster detection, which provide timely information that can decrease economic damage and avoid loss of life, is a vital step in reducing the risk of natural and man-made disasters [8, 9]. These systems are intended to identify early warning indicators of impending natural disasters, including hurricanes, floods, tsunamis, earthquakes, and other extreme weather phenomena, as well as to promptly notify the public and pertinent authorities of these dangers. The rising frequency and intensity of disasters worldwide highlight the significance of EWS. A new framework for early warning and monitoring systems that shifts the traditional perspective toward participation was put forward in a study by Joshi *et al.* [10]. Moreover, with the help of examples from a few Nordic and other European nations, a new framework for flood risks (from numerous flood threats) was created.

The Centre for Research on the Epidemiology of Disasters (CRED) reports that between 2000 and 2019, there were 7,348 large disaster occurrences that affected 4.2 billion people, claiming over 1.23 million lives, and causing economic losses totaling close to $2.97 trillion. Compared to the preceding two decades, when 4,212 disaster events were reported, affecting 3.25 billion people and resulting in $1.63 trillion in economic damages, this is a notable increase. Reducing the amount of time that passes between the identification of a possible disaster and the release of alerts is one of the main objectives of an Early Warning System (EWS). This allows communities and emergency responders enough time to take precautionary action. For example, the Great East Japan Earthquake of 2011 illustrated how early warning systems can save lives. Seconds before the shaking reached populated areas, Japan's sophisticated earthquake early warning system sensed the activity and sent out signals, allowing people to seek cover and automating the shutdown of vital infrastructure to reduce casualties and damage. Comparably, the region's capacity to recognize and react to tsunamis has been greatly enhanced by the establishment of the Indian Ocean Tsunami Warning System in the wake of the catastrophic 2004 tsunami that claimed over 230,000 lives. Modern environmental monitoring systems use a variety of technical innovations, such as satellite images, big data, remote sensing, deep learning algorithms, and Internet of Things (IoT) devices, to monitor environmental conditions in real-time. In order to analyze massive volumes of data and more accurately predict disastrous events, machine learning algorithms and artificial intelligence are essential. Global disaster detection and response efforts, for example, are aided by a wealth of data from NASA's Earth Observing System Data and Information System (EOSDIS). Utilizing satellite data, weather radars, and ocean buoys, the National Oceanic and Atmospheric Administration (NOAA) monitors storm developments and issues warnings for hurricanes. An EWS's ability to guarantee that alerts are promptly received by the intended recipients depends on its ability to communicate effectively. Initiatives in public awareness and education are essential to ensure that communities are aware of the alerts and know how to respond appropriately. Table **1** shows the advantages and disadvantages of traditional EWS and AI-driven Early Warning Systems.

CHAPTER 5

Revolutionizing Early Warning Systems for Natural Disasters: Integrating AI and ML-driven Models, Tools, and Platforms

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Abstract: This chapter explores how AI is revolutionizing early warning systems for natural disasters, addressing the critical need for more effective predictive capabilities in the face of increasing disaster frequency and severity. It examines the integration of cutting-edge AI technologies, particularly Large Language Models (LLMs) and Visual Language Models (VLMs), with modern tools such as remote sensing, IoT sensors, and social media analytics for enhanced early warning and risk assessment. The chapter demonstrates how these technologies improve disaster prediction and detection through advanced data analysis, pattern recognition, and real-time monitoring, showcasing their effectiveness through platforms like NVIDIA's Earth-2, MOBILISE, and Google Flood Hub. While highlighting AI's transformative potential in early warning systems, the chapter also addresses critical challenges, including data privacy, algorithmic bias, and the need for transparent, explainable AI systems. Through comprehensive analysis and real-world case studies, this chapter contributes valuable insights for developing more robust and adaptive early warning systems, ultimately enhancing disaster preparedness and community resilience.

Keywords: Artificial intelligence, Big data analytics, Computer vision, Deep learning, Disaster management, Disaster preparedness, Ethical AI, Explainable AI, Internet of Things, Large language models, Machine learning, Natural disaster management, Natural language processing, Predictive modeling, Remote sensing, Visual language models.

INTRODUCTION

The twenty-first century has seen technology revolutionizing many aspects of life, including disaster management. As natural disasters become more frequent and

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severe, traditional approaches prove inadequate, necessitating proactive, efficient, and data-driven solutions. Artificial Intelligence (AI) offers transformative potential in this critical field.

The Growing Impact of Natural Disasters in the 21st Century

Natural disasters have intensified globally, with dire consequences for communities, economies, and ecosystems. The International Federation of Red Cross and Red Crescent Societies (IFRC) reports a nearly 35% increase in climate-related disasters since the 1990s [1] as illustrated in Fig. (**1**).

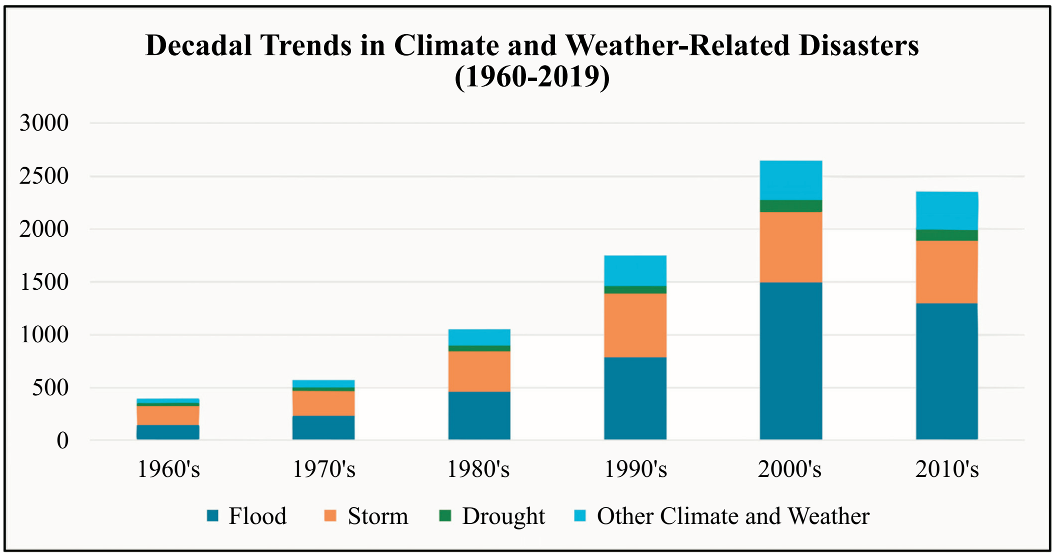

Fig. (1). Decadal trends in climate and weather-related disasters (1960-2019). Source: data from [1].

Recent events highlight this trend:

- **India Floods (2023):** Over 150,000 people were affected, 10,000 families were displaced, and significant infrastructure damage occurred [2].
- **Heatwaves:** India experienced its hottest July in 50 years in 2023 [3]. Uttar Pradesh and Bihar reported 54 and 42 heat-related deaths in June 2023 alone [4, 5]. As per data collected by the Union health ministry, this year the death toll due to confirmed heatstroke is 110, and 40,272 cases of heatstroke this summer until 17th June 2024 [6].
- **Wildfires:** Canada's worst wildfire season in 2023 released over 290 million tons of carbon [7].

These statistics reveal the limitations of current infrastructure and response capabilities. Natural disasters not only claim lives but also have far-reaching economic impacts, disrupt critical infrastructure, and threaten ecosystems. The traditional reactive approach, often constrained by resources, is insufficient to address these escalating challenges.

Given these escalating challenges and the limitations of traditional approaches, there is an urgent need for innovative solutions in disaster management. This chapter argues that the integration of AI, particularly Visual Language Models (VLMs) and Large Language Models (LLMs), with emerging technologies and data-driven approaches has the potential to revolutionize natural disaster management by enhancing prediction, detection, and response capabilities.

The Need for a Paradigm Shift: From Reactive to Proactive Disaster Management

Traditional disaster management approaches have shown significant limitations in recent years. These systems, often relying on manual processes and limited data, lead to inaccuracies, delays, and inefficiencies in disaster response. The focus on post-disaster response rather than proactive prevention results in higher economic losses, increased casualties, and longer recovery times.

A brief comparison of traditional and AI-driven approaches to Disaster Management is presented in Table **1**, which highlights AI's transformative potential in disaster management, resulting in a shift from reactive to proactive approaches. AI-driven systems offer improved accuracy, speed, scalability, and cost-effectiveness, leveraging real-time data for enhanced prediction, resource allocation, and stakeholder engagement.

Table 1. Comparison of traditional and AI-driven approaches to disaster management [8].

Aspect	Traditional Systems	AI-driven, Data-driven Approach
Approach	Reactive	Proactive
Data Analysis	Manual, limited	Automated, large-scale
Prediction Accuracy	Lower	Higher, real-time
Response Time	Slower	Faster, automated
Resource Allocation	Often inefficient	Optimized, data-based
Scalability	Limited	Highly scalable
Adaptability	Slow	Rapid
Cost-effectiveness	Higher long-term costs	Lower long-term costs
Communication	Fragmented, delayed	Integrated, real-time
Risk Assessment	Periodic, subjective	Continuous, objective

CHAPTER 6

Harnessing Satellite Imagery, Remote Sensing, and IoT for Real-time Disaster Detection and Monitoring – Floods, Earthquake and Wildlife

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Abstract: The effectiveness of applying satellite imagery, remote sensing platforms, sensors, and Internet of Things (IoT) devices for identification and early monitoring of natural disasters like floods, earthquakes, and wildfires is discussed in this paper. High-resolution data, including satellite imagery and remote sensing, provide real-time monitoring and analysis for prediction. Physical level demands the use of things in the IoT and sensor networks to improve data acquisition locally on an early warning system basis, as well as a physical intelligence basis. Interfacing these technologies, there is evidence illustrating how they can enhance the effectiveness of disaster preparedness, reduce response time and reduce the negative effects on the affected populations. Importance is therefore given to the combinational effect of technology and sustainable development for robust disaster management systems.

Keywords: Disaster management, IoT, Remote sensing, Satellite imagery, Warning system.

INTRODUCTION

Natural disasters are devastating occurrences that arise from the inherent processes of the Earth. They present substantial risks to human life, property, and the environment. Some of the most significant natural disasters include floods, earthquakes, and wildfires. Floods commonly arise from intense precipitation, river surges, coastal tempests, or breaches in dams. Hurricanes can cause extensive destruction to residential properties, infrastructure, and agricultural sectors, and can also result in fatalities. Flash floods are characterised by their abrupt and unpredictable nature, which makes them particularly hazardous. Regions susceptible to flooding frequently endure recurring harm, resulting in financial burden and the forced relocation of inhabitants. Earthquakes occur when

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there is a sudden release of energy in the Earth's crust, resulting in the generation of seismic waves. Earthquakes can occur suddenly and range in intensity from mild tremors to catastrophic shocks. Earthquakes have the potential to result in the destruction of buildings, bridges, and other infrastructure, leading to substantial human casualties and financial losses [1]. Additional consequences, such as tsunamis and landslides, might intensify the level of devastation. Wildfires are uncontrollable conflagrations that swiftly propagate through vegetation. Wildfires are frequently ignited by natural phenomena such as lightning strikes or human actions such as leaving campfires unattended. Wildfires can result in substantial destruction to forests, residences, and habitats for wildlife, and provide notable health hazards as a result of inhaling smoke. Climate change has been linked to the frequency and intensity of wildfires, creating a growing worldwide concern. Each of these disasters has different qualities and consequences, yet shares similar challenges in prediction, detection, and mitigation. Early and accurate identification is critical in minimising their impact, saving lives and reducing economic losses. The advancement of technology, like satellite images, remote sensing, sensor networks, and IoT devices, offers hopeful tools to improve disaster preparedness and response. These technologies serve the purpose of real-time tracking and provide decision-makers with essential data that will enhance our ability to more effectively predict, detect, and manage natural disasters [2].

IMPORTANCE OF PROMPT DETECTION AND EFFICIENT MONITORING

Early detection and effective monitoring of natural disasters are crucial to minimising their impact and saving lives and property. Floods, earthquakes, and wildfires are among the deadliest natural disasters, and early detection is a vital part of reducing the damage caused by them. When detection is early enough, alerts can be issued quickly to at-risk populations, giving them time to evacuate and take precautions. Early flood warning can allow communities to move and relocate to higher ground, which saves lives and reduces damage to property and infrastructure. Similarly, earthquake early warning systems can provide critical seconds to minutes of advance notice for both individuals to find shelter and for automated systems to shut down vital infrastructure (*e.g.*, gas pipelines and transportation systems) to prevent further hazards [3]. Surveillance is fundamental to unraveling the complexity of natural disasters and improving predictive models. Routine monitoring of aspects of the environment, including rainfall, earthquake activity and plant dryness, helps identify patterns and potential triggers for disasters. Such data is imperative for the construction of accurate forecast models and risk assessments that can help filter the knowledge from infectious diseases to support disaster preparedness plans and resource mobilization decisions. To manage floods, we need to monitor the river levels, rain, and weather fluctuations. This enables the prediction of potential flooding events. Utilizing state-of-the-art satellite imaging and remote sensing technologies, timely information about the size and progress of floods is provided to ensure prompt dispatch of response teams and allocation of resources [4].

Seismic monitoring networks are used to detect geological shifts and to collect the data needed for early warning systems when earthquakes occur. This data also helps scientists understand the fault lines and how earthquakes function, contributing to better building codes and construction methods that make structures more resilient. Wildfire monitoring involves systematic observation and assessment of meteorological conditions, status of vegetation and fire dynamics. Techniques for fire detection in their early stages, such as thermal imaging and ground sensors, are used to identify hot spots and monitor areas of fire spread [5]. This information is critical to deploying firefighting resources effectively and organising attempts to evacuate people. Timely identification and rapid surveillance also play a key role in the recovery process of a disaster. Knowing exactly how much destruction a certain area suffers, and what exactly is the current status, ensures that resources and aid can be deployed more effectively, making sure affected groups can receive support as soon as possible.

We cannot overstate the importance of quickly identifying and effectively managing natural disasters. These actions not only save lives and reduce financial losses, but also enhance our understanding of such events, leading to better preparedness and response in the future. It is critical to improve our capacity to respond to disasters and build safer, more resilient communities by leveraging innovative technologies in detection and monitoring. Technological advancements in disaster management are defined as the development and application of new and emerging technologies to improve the sequence of disaster risk reduction, preparedness, response, and recovery [6]. Technological advancements have tremendously changed the domain of disaster management, bringing new tools and methods of predicting, detecting and preventing natural disasters such as earthquakes, floods and even wildfires. These developments extend our ability to mitigate the impact of such events and improve the effectiveness of emergency response efforts.

Satellite imagery and remote sensing are now indispensable in disaster management. Satellites equipped with various sensors provide real-time information about environmental conditions and the progression of disasters. Synthetic aperture radar (SAR) is one example, which can penetrate cloud cover and offer detailed photos of areas at risk of flooding during storms. Optical & thermal imaging from satellites assist in identifying & monitoring wildfire hot spots. It is being used to study ground deformation and seismic activity in the

CHAPTER 7

Artificial Intelligence Applications in Disaster Management

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Abstract: The predictive algorithms of Artificial Intelligence (AI), which can analyse vast datasets, spot trends, and foresee future disasters, have the potential to greatly improve natural disaster management. The primary issues caused by natural disasters are addressed by these models, which support proactive measures including the creation of Early Warning Systems (EWSs), effective resource allocation, and careful evacuation planning. In-depth analysis of trustworthy AI applications related to natural disasters is given in this chapter, which covers topics including risk assessment, disaster prediction, and disaster management. A summary of the most recent methods and advancements in disaster management is provided, including data fusion, machine learning, deep learning, fuzzy logic, explainable AI, and multicriteria decision-making. This thorough work addresses seven significant issues and provides important insights, laying the groundwork for future studies in trustworthy AI-based natural disaster management. Although there may be benefits to utilizing AI for disaster management, there are still barriers to adoption. The chapter also offers a thorough examination of the bias, moral dilemmas, and results associated with AI in the context of natural disasters. In these frameworks, it identifies several underutilized and utilized domains in the theory of artificial intelligence based on natural disasters, summarise disaster datasets and machine learning techniques, and offers a practical AI method to grasp the complex dynamics and relationships at work, as well as the use of data fusion techniques in decision-making processes related to natural disasters. Finally, bias, ethical concerns, and AI results based on natural disasters are thoroughly examined.

Keywords: Applications, Artificial intelligence, Management, Natural disasters.

INTRODUCTION

The term Artificial Intelligence (AI) refers to the cognitive processes that are typically carried out by intelligent people using digital computers or computer-controlled robots [1]. AI is growing more and more important in many fields

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because of its numerous uses that are transforming businesses and enhancing people's lives [2]. Several industries have benefited greatly from this powerful technology [3, 4].

According to previous studies [5, 6], Artificial intelligence (AI) has changed how we detect diseases, make decisions in autonomous vehicles, manage financial risks, process and analyse language, optimize manufacturing processes, boost e-commerce capabilities, strengthen cyber-security, and assist in addressing environmental and climate change issues. One important context in which artificial intelligence can be effectively used is natural disasters. Around the world, natural disasters and their aftermath are becoming a greater hazard to property and human life. These increasing risks, often linked to climate change, align with AI's rapid progress and diverse applications [7, 8].

Artificial intelligence (AI) is being used more and more in the field of disaster management as researchers search for innovative and useful solutions to reduce the effects of disasters and human suffering [9]. Natural disasters, including heat waves, droughts, floods, storms, and wildfires, have become more often and intense throughout time, and the areas they impact are continuing to grow as a result of human activity and climate change. As a result, these disasters have posed significant challenges to the sustainability of economic growth as well as the safety of people's lives and their properties. Due to the increasing availability of large datasets and more powerful computing power, AI models have been utilized more frequently to analyse and interpret data more accurately [10]. The use of AI in Natural Disaster Management (NDM) has expanded concurrently. Due to their accuracy, speed, and ease of use, AI models have been progressively employed in a number of NDM sectors to lessen the effects of natural disasters [11]. Applications for this include locating and saving lives [12], gathering and combining data on disasters, and doing loss analysis following a calamity [13]. Several empirical studies have looked into the use of AI models in NDM, but the results have not been compared or thoroughly analysed. To the best of our knowledge, no comprehensive analysis of AI applications in NDM currently exists.

Initially, this chapter offers a multidisciplinary summary of the ways in which NDM research is carried out using AI models for various kinds ofdisasters and stages. Second, it analyses the patterns and applicability of earlier research by critically identifying and examining research gaps. Finally, it provides important information for both academics and catastrophe managers by summarizing the difficulties and outlining potential future paths. The primary contributions of this chapter are as follows:

- By thoroughly assessing AI applications in natural disasters, including crucial components like design, development, risk assessment, disaster management, and prediction, this study sets new standards in the industry.
- It provides a thorough review of the literature that closely looks at the latest research trends, challenges, motivations, recommendations, and limitations of artificial intelligence in connection with natural disasters.
- A range of AI techniques are mentioned, with an emphasis on the use of fuzzy logic and data fusion techniques in gaining a comprehensive understanding of disaster-related data.

NATURAL DISASTER MANAGEMENT (NDM) WITH ARTIFICIAL INTELLIGENCE (AI) ANALYSIS

Artificial Intelligence (AI)

The multidisciplinary field of Artificial Intelligence (AI) weaves together computer science, mathematics, philosophy, neurology, psychology, cybernetics, linguistics, and other specialist disciplines. Though it has drawn a lot of interest from both scientists and governments, artificial intelligence currently lacks a widely accepted definition. It has been explained that artificial intelligence (AI) is defined as "computational agents that act intelligently," emphasizing the technology's ability to analyze its environment and make decisions that improve its chances of success [14]. AI has also been described as a system of cognitive abilities connected to human traits, such as learning, speech generation, problem-solving, and the ability to monitor and act within an environment to achieve goals or maximize performance metrics [15].

As seen in Fig. (**1**) artificial intelligence has numerous applications in a variety of fields, including planning, robotics, machine learning, natural language processing, vision, and neural networks.

Natural Disasters

Though natural hazards are naturally occurring events, natural hazards turn devastating when they cause large numbers of deaths and property damage, impeding social and economic advancement. Natural catastrophes claim millions of lives every year, and they are happening more often. Human lives, infrastructure, and society are all significantly impacted by this. Therefore, investigating the geographical and temporal patterns, processes, and causes of these occurrences, together with devising plans for risk reduction and emergency response, are the core areas of study in the fields of natural hazards and disaster risk science. An overview of natural catastrophes is given in this section, along with an investigation of how Artificial Intelligence (AI) may be used to improve

CHAPTER 8

Machine Learning Algorithms for Disaster Detection

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Abstract: Machine Learning (ML) is one of the most popular subsets of Artificial Intelligence and is generally applied in situations where predictions based on huge datasets are of importance. Mainly concerned with developing as well as improving upon pre-existing techniques and algorithms, Machine Learning helps computers to learn and improve from the given data without the need for explicit coding by humans. Thus, Machine Learning can resemble human-like intelligence. It can be mainly categorized into three types: supervised learning (training a model based on a labeled dataset), unsupervised learning (training a model on an unlabeled dataset), and reinforcement learning (guiding the actions and rewards the model receives for optimal choices). Disasters can be natural or man-made, and when they are detected prior to their occurrence, a lot of damage to infrastructure can be minimized and the loss of human lives can be mitigated by effectively strategizing the countermeasures and evacuation. ML is a powerful tool that can be used for early detection of disasters due to its ability to recognize patterns across large datasets consisting of satellite images, temporal weather data acquired from sensors, as well as historical records and produce an effective result for predicting future occurrences since time is of the essence for disaster management. For example, the meteorological data can be leveraged by the ML model to predict the occurrence and the path of a cyclone, or the seismic data received from the sensors can be used to predict the occurrence and scale of an upcoming earthquake. By training models on labeled data, such as past disaster events and their characteristics, supervised ML algorithms can learn to recognize patterns and anomalies associated with different types of disasters. For example, in wildfire detection, ML models can be trained to classify satellite images into fire-affected areas and non-affected regions, enabling rapid response and containment efforts. Moreover, unsupervised learning techniques like clustering and anomaly detection play a vital role in disaster management. Clustering algorithms can identify spatial patterns and hotspots of disaster events, aiding in resource allocation and evacuation planning. Anomaly detection algorithms can check for unusual patterns in data, such as sudden or

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abrupt changes in temperature or air quality, alerting authorities to potential disaster risks. This chapter explores ML techniques proposed and used currently for disaster detection in today's scenario.

Keywords: Cyclones, Disaster detection, Earthquakes, Floods, Machine learning, Wildfires.

INTRODUCTION

Human-made/natural disasters are an inevitable part of our lives. If they are detected before their occurrence, it can help in mitigating massive destruction and the loss of human life by effectively strategizing countermeasures and evacuation. Machine Learning (ML) is a powerful tool for early disaster detection because it can recognize patterns across large data sets consisting of satellite images, weather trends, data acquired from sensors, social media, as well as historical records. Once the data is acquired, it can be used to generate effective predictions of future occurrences, which is crucial in disaster management, where time is of the essence. The early detection and response to disasters are critical components in lessening the devastating effects of natural and man-made calamities. The ability to identify and react to potential threats promptly can significantly reduce loss of life, property damage, and long-term socio-economic impacts.

The major types of ML are Supervised and Unsupervised learning, while Deep learning is considered a subset. Supervised learning algorithms train on labelled data to make predictions or classifications. The data is split into training, validation, and testing sets, upon which the model is trained and improved. This process is referred to as 'supervised learning' because it requires human supervision in the form of labeled datasets.

Unlike supervised learning algorithms, unsupervised learning algorithms do not require externally labeled datasets, as they analyze the data independently to extract insights without human intervention.

Unlike Machine learning, Deep learning (DL) models are used for mimicking neuron-like behaviour through layer-based neural networks, which automatically extract features from large datasets, unlike ML algorithms, which require explicit feature selection and engineering. DL models are usually chosen for larger amounts of data and when the premise is already complicated enough for traditional ML. However, this comes with the cost of heavy computational power. Supervised learning models are used when the data is clearly labelled for classification or prediction purposes. On the other hand, Unsupervised models are used when labelled data is not easily available or the dataset is too large to be manually labelled under a certain budget, and there is not much to analyse manually.

A few reasons highlighting the importance of early detection and response are listed below [1, 2]:

Saving Lives

Early detection allows us to inform people about the approaching hazards, followed up with an evacuation plan or protective measures to prevent injuries and fatalities. Early detection systems can provide the crucial minutes or hours needed for individuals to seek safety and for emergency services to mobilize.

Reducing Economic Losses

Disasters often cause extensive damage to infrastructure, homes, and businesses. Early detection allows for the implementation of protective measures, such as reinforcing structures or shutting down critical operations like fishing in coastal areas during cyclones, thereby reducing the overall financial impact and speeding up recovery efforts.

Enhancing Preparedness and Mitigation

With early detection, authorities can remain well prepared for disaster response by remaining on high alert. This includes deploying resources, setting up emergency shelters, and coordinating with various agencies to ensure a swift and effective response. It also allows for better planning and implementation of long-term mitigation strategies.

Improving Response Efficiency

Emergency response teams can be alerted and dispatched more efficiently when disasters are detected early. This enhances the coordination and effectiveness of rescue and relief operations, ensuring that help reaches those in need more quickly.

Minimizing Environmental Impact

Man-made disasters like oil spills or chemical leaks pose significant environmental risks. Early detection can prevent these hazards from escalating, allowing for rapid containment efforts to protect the flora and the fauna.

CHAPTER 9

The Role of Law in Shaping AI Development for Effective Natural Disaster Warning Systems

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Abstract: Integrating artificial intelligence and machine learning technologies into natural disaster warning systems represents a monumental leap forward in bolstering global disaster preparedness and response capabilities. This chapter discusses the pivotal role that law and legal frameworks play in shaping the intricate development and deployment processes of disaster warning systems, examining various facets ranging from regulatory compliance and ethical considerations to liability frameworks, international cooperation, and funding incentives. At the forefront of this discussion are regulatory compliance and standards. Governments and regulatory bodies assume a pivotal role in establishing comprehensive guidelines that govern data collection, processing, and sharing within algorithmic intelligence used for disaster warning. These regulations are paramount in ensuring data privacy, transparency in decision-making processes, and accountability mechanisms in case of system failures or errors. By setting clear standards, legal frameworks lay the groundwork for ethical development and responsible deployment. Ethical considerations emerge as a central and pressing focus in the context of computational intelligence-driven disaster warning systems. This chapter underscores the imperative to address fairness, bias mitigation, and equitable resource distribution throughout the machine intelligence advancement lifecycle. It advocates for proactive measures, such as regular audits and ethical reviews, to rectify biases that may disproportionately impact vulnerable communities. This approach aligns with the ethical principles that underpin algorithmic intelligence development, emphasizing the importance of responsible innovation and equitable outcomes. Liability and accountability take center stage during the developmental phase of artificial intelligence-driven disaster warning systems. Legal frameworks delineate clear responsibilities for stakeholders, ensuring the accuracy and safety of systems. Protocols are established to address liabilities effectively in cases of errors or failures, thereby upholding accountability and trust within the machine intelligence ecosystem. Given the global nature of natural disasters, international cooperation and data sharing are imperative. Legal agreements that encompass data protection and intellectual property rights facilitate seamless collaboration, enhancing disaster response capabilities by fostering information exchange and leveraging computational intelligence technologies across borders. These collaborative efforts bolster the effectiveness and reach of disaster warning systems powered by artificial intelligence,

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ensuring timely and accurate alerts to at-risk communities worldwide. Moreover, the chapter emphasizes the critical role of funding and incentives in driving the advancement of artificial intelligence for disaster warning systems. Governments are encouraged to provide robust financial support and foster public-private partnerships to stimulate innovation, collaboration, and responsible use of computational intelligence. These initiatives not only fuel technological advancements but also promote equitable access to lifesaving information and resources, ultimately enhancing disaster resilience on a global scale. In conclusion, the multifaceted role of law in shaping development for natural disaster warning systems cannot be overstated. Through clear guidelines, ethical considerations, robust liability frameworks, international cooperation, and strategic funding incentives, legal frameworks play a pivotal role in ensuring their responsible use, harnessing their full potential, mitigating risks, and safeguarding communities against the impacts of natural disasters.

Keywords: Artificial intelligence, Disaster warning systems, Ethical considerations, Funding incentives, Regulatory compliance.

INTRODUCTION

In recent years, the integration of AI and ML technologies into natural disaster warning systems has revolutionized disaster preparedness and response efforts. AI is the simulation of human intelligence processes by machines, resulting in their ability to think and act like humans, and ML is a branch of AI that uses algorithms that enable systems to learn from data and get better with every iteration without being programmed explicitly. These technologies depend on big data, neural networks, and predictive analysis to analyze real-time information and predict patterns leading to disasters. In the area of disaster management, AI-based models utilize satellite images, sensors, and historical data to identify the signs of disasters, including earthquakes, hurricanes, and floods. The successor ML algorithms improve these forecasts by updating themselves with the help of data from previous disasters to improve the accuracy of the alerts and response plans. The main difference between AI and ML is that while AI includes all forms of intelligent systems, ML is only a part of AI that supports the data-driven learning of AI. The integration of AI and ML in disaster warning systems enhances the risk analysis, increases the speed of emergency measures, and improves the management of resources. This technological leap holds the promise of significantly reducing the impact of natural disasters on human lives and property. However, alongside these technological advancements, the role of law and legal frameworks in shaping the development and deployment of the Disaster Warning System (DWS) based on artificial intelligence is becoming increasingly critical.

Natural disasters, such as earthquakes, hurricanes, floods, and wildfires, have devastating effects, often causing significant loss of life and economic damage. Traditional methods of disaster prediction and response, which rely heavily on historical data and human judgment, have limitations in accuracy and timeliness. The advent of AI and ML technologies has introduced new possibilities for enhancing these methods. By leveraging large datasets from various sources, such as satellite imagery, weather sensors, social media feeds, and historical records, algorithmic intelligence can identify patterns and anomalies that may indicate an impending disaster. This capability allows for more accurate and timely predictions, enabling authorities to take proactive measures to mitigate the effects of disasters [1].

The development and deployment of DWS based on artificial intelligence, however, are not without challenges. One of the foremost issues is ensuring that these systems operate within a robust legal and regulatory framework. Legal frameworks must address several critical aspects, including data privacy, transparency in algorithmic decision-making, accountability for system failures, and the ethical implications of AI use [2]. Without appropriate legal oversight, the deployment of artificial intelligence technologies could lead to unintended consequences, such as biased predictions that disproportionately affect certain communities or the misuse of sensitive data.

Regulatory compliance and standards are foundational to the successful implementation of DWS based on artificial intelligence. Authorities and regulators need to develop well-defined policies for how data is collected, processed, and shared by these systems. These regulations need to ensure that data privacy is protected, that the algorithms used are transparent and explainable, and that there is accountability in the event of system failures. Ensuring regulatory compliance helps build public trust in these technologies and promotes their widespread adoption.

Ethical considerations are another vital component in the deployment of disaster warning systems. Legal frameworks must ensure that these systems are designed and operated in a manner that is fair and equitable. This includes addressing issues of bias in algorithmic intelligence, ensuring that vulnerable communities are not disproportionately affected, and promoting the equitable distribution of resources and support. Regular audits and ethical reviews can help to identify and rectify biases, ensuring that the systems operate ethically.

Liability and accountability are critical aspects that must be addressed in the development of disaster warning systems based on artificial intelligence. Legal frameworks need to define the responsibilities of various stakeholders, including developers, operators, and government agencies. This ensures that there is clear accountability in the event of system failures or inaccuracies. Establishing protocols for addressing liabilities and providing compensation for affected

CHAPTER 10

Application of Fuzzy Artificial Intelligence as a Technique to Find The Relative Desirability of Earthquake

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Abstract: This chapter explores a new approach to applying fuzzy Artificial Intelligence (Fuzzy AI) to seismic risk assessment. Traditional seismic risk assessment methods often use rigorous probabilistic models to predict the probability of an earthquake occurring. However, it is difficult for these models to reflect the complex and uncertain nature of earthquakes. In this study, we respond to this problem by proposing a method to find the relative desirability of seismic hazards using fuzzy AI techniques. Fuzzy AI approaches demonstrate excellent ability in handling uncertainty and ambiguity in seismic data. This technique evaluates the relative desirability of an earthquake by taking into account various variables, such as earthquake magnitude, depth, and local characteristics such as population density. These assessments help communities and policymakers enhance earthquake preparedness and develop risk reduction strategies. The findings demonstrate the potential of fuzzy AI as an important tool in earthquake risk assessment. By using this technology, we can conduct more accurate and reliable earthquake risk assessments, which can ultimately contribute to reducing damage from earthquakes. This study gives a new dimension to earthquake risk assessment techniques using fuzzy AI.

Keywords: Artificial neural networks, Decision making system, Earthquake detection, Fuzzy system, Parameterized fuzzy measures.

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INTRODUCTION

Fuzzy Artificial Intelligence for Assessing the Relative Desirability of Earthquake

Earthquakes are one of the most destructive natural disasters for human beings. Assessing the relative desirability of earthquake-prone areas is a critical task that requires a comprehensive and nuanced approach [1]. FAI emerges as a powerful tool to tackle this complex challenge, combining the strengths of Fuzzy Logic and Artificial Intelligence. Fuzzy Logic with its ability to handle vague and imprecise information is particularly well-suited for the assessment of earthquake desirability. The factors that contribute to the desirability of an earthquake-prone area are often subjective and difficult to quantify, such as perceived risk, economic impact, and community resilience. Fuzzy Logic allows for the incorporation of these linguistic variables, enabling a more realistic and holistic evaluation.

Artificial Intelligence, on the other hand, offers the computational power and pattern recognition capabilities to process vast amounts of data and uncover hidden relationships [2]. When integrated with Fuzzy Logic, Artificial Intelligence can learn from historical earthquake data, expert knowledge, and other relevant information to develop predictive models and decision-support systems. The Fuzzy Artificial Intelligence approach to assessing the relative desirability of earthquake-prone areas typically involves several key steps. First, the relevant factors that contribute to desirability are identified and defined using fuzzy linguistic variables. These factors may include seismic activity, infrastructure resilience, emergency response capabilities, and socioeconomic considerations.

Next, the FAI system is trained on a comprehensive dataset, which may include historical earthquake records, geological surveys, infrastructure assessments, and socioeconomic indicators. The system learns to recognize the complex relationships between these factors and their impact on the overall desirability of a given area [3]. Once the FAI system has been trained, it can be used to evaluate and rank the relative desirability of different earthquake-prone regions. The system's outputs can provide valuable insights to decision-makers, urban planners, and emergency management authorities, enabling them to make informed decisions about resource allocation, disaster preparedness, and long-term development strategies.

One of the main benefits of the Fuzzy Artificial Intelligence approach is its ability to adapt to changing circumstances and evolving knowledge [4]. As new data becomes available or decision-making criteria shift, the FAI system can be updated and retrained, ensuring that the assessment of relative desirability remains relevant and responsive to the dynamic nature of earthquakes and their impacts. Moreover, the transparency and interpretability of the Fuzzy Artificial Intelligence approach can be enhanced through the use of explainable AI (XAI) methods. By providing insights into the decision-making process and the underlying reasoning behind the decisions made by AI, this approach can foster trust and facilitate better understanding among stakeholders, ultimately leading to more informed and effective decisions.

As the frequency and intensity of earthquakes continue to pose a major threat to communities around the world, the integration of Fuzzy Logic and Artificial Intelligence offers a promising solution for measuring the relative desirability of earthquake-prone areas [5]. By leveraging the strengths of both techniques, the Fuzzy Artificial Intelligence approach can contribute to more resilient and sustainable urban planning, disaster management, and community development strategies. The Fuzzy Artificial Intelligence framework for assessing the relative desirability of earthquake-prone areas characterizes a major step in the field of natural disaster management. By embracing the flexibility and adaptability of Fuzzy Logic and the computational power of Artificial Intelligence, this approach can help decision-makers navigate the complex and ever-evolving challenges posed by earthquakes, ultimately enhancing the resilience and well-being of communities worldwide.

Use of Deep Neural Network to Get Suggestions

Accurate and timely detection of earthquakes is crucial for implementing effective emergency response measures and reducing its impact on affected people. Deep Neural Networks (DNNs) are used as a powerful tool in the field of earthquake detection, giving advanced capabilities in pattern recognition, data analysis, and predictive modeling [6]. DNNs are a type of artificial intelligence that is based on the structure and function of the human brain. These deep learning models are good at learning complicated patterns and relations from large datasets, making them well-suited for the task of earthquake detection. By using the power of DNNs, researchers and practitioners can develop sophisticated systems that can analyze seismic data, identify precursory signals, and provide early warning alerts.

The main advantage of using DNNs for earthquake detection is their capability to process and interpret vast amounts of data from different sources, like seismometers, satellite imagery, and environmental sensors. This multidimensional approach allows the DNN models to capture the intricate patterns and subtle indicators that may precede an earthquake, enabling more

CHAPTER 11

Advanced Applications of Artificial Intelligence and Machine Learning in Disaster Prediction, Detection, and Mitigation

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Abstract: Nowadays, technology used has become significant, especially the use of AI and ML to improve the effectiveness of disaster management. They are providing great advancements in the approaches used for the assessment, tracking, and control of disasters with enhanced performance and accuracy. AI and ML rely on massive data obtained from multiple sources such as Earth observation satellites, weather stations, social media, and sensor systems. Big Data is important for the elaboration of realistic models of disaster situations to predict hurricanes, earthquakes, floods, and other events with higher reliability. Thus, these technologies improve early warning systems through the examination of patterns and trends from historical data, which minimizes the damage from disasters by providing timely warnings. Real-time monitoring is another area where the utilisation of AI and ML proves worthy of the effort. They help in the handling and analysis of the streaming data, which is very useful in the initial evaluation of developing disaster scenarios. This capability is extremely valuable in surveillance systems that quickly transition from one condition to another. Optimization of data also assists in proper planning of the resource aspect –the emergency services and supplies are directed to the most strategic areas. Disaster management has again been brought to the next level by the use of AI with IoT devices. Sensors, which are part of the IoT technologies installed in adverse regions, give continuous and real-time data on the condition of the environment, stability of frameworks, and much more. The collected data is then processed by the AI algorithms to detect the onset of threats and initiate responses such as switching to emergency procedures or personnel and equipment. Drones and robots are crucial in search and rescue, removal of debris, as well as in infrastructure repair and maintenance, since they make the process safer as well as faster. Nevertheless, the following challenges can still be forthcoming: Other challenges which must be discussed include the quality of data, prejudice of the algorithms, and the problem of computations on the huge amount of data sets in case of applying AI and ML technologies in the field of disaster management. Also, issues of ethics, such as the privacy and security of individuals or vulnerable communities in the disaster, must be well addressed. The AI and ML applications being implemented in disaster management can only be successful once

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the interdisciplinary collaboration is effective and a significant amount of changes are made to invest in not only new technology but also proper training. These technologies require a concerted effort of scientists, engineers, policymakers, and emergency professionals to design and implement them well. However, with further enhancements and proper applications of AI & ML in the relevant sectors, the disaster management system will become more efficient, more sensitive, and to an extent, capable of dealing with major disasters.

Keywords: Damage assessment, Decision support systems, Early warning systems, Real-time monitoring, Post-disaster recovery, Predictive analytics.

INTRODUCTION

A catastrophe is an unplanned incident that may be more powerful than the impacted individual's capacity to contain it. For many people, earthquakes are an everyday occurrence, and most of time the dangers that lead to disasters cannot be prevented. However, their effect can be mitigated. The objectives of programs for disaster management are to reduce or eliminate potential losses brought on by hazards, offer prompt and appropriate assistance to affected people, and promote a quick and effective recovery. Hospitals have to keep running safely both before and after disasters [1].

Only keyword-based matching, used in geographical information systems (GIS) has been the focus of present-day attempts to integrate geo-information. The difficulty of semantic connectivity is still underappreciated, though. Over the years, ethical quandaries have sparked debate and controversy. In terms of public health, disasters are described as catastrophic occurrences that necessitate the use of numerous emergency resources in order to aid and guarantee the continued existence of the affected people [2].

Context and Background

The purpose of this article is to provide basic information about a range of perspectives and concepts related to AI, and some basic ideas regarding its historical background, as well as certain actual or potential consequences for social, economic, ideological, and ethical domains. Regarding the research on Artificial Intelligence under discussion, there are various standards and perspectives that offer definitions based on its conceptual understanding and axiological evaluation. Since its inception in the mid-1900s at Harvard, the technical development of AI has sparked diverse opinions and expectations [3]. Machine learning is a rapidly developing field of algorithms for computers, which are designed to behave like people by learning from their environment. They are the backbone of the so-called Big Data age. Decisions made in politics, society, and the economy are largely influenced by ethics, which serve as the cornerstone of societies and cultures. Over the years, ethical quandaries have sparked debate and controversy. In terms of public health, disasters are described as catastrophic occurrences that necessitate the use of numerous emergency resources in order to aid and guarantee the ongoing existence of the affected people. When there are many casualties in a circumstance involving mass casualties, there may be unique problems with ethics. This essay's goal is to investigate catastrophe management ethics [4].

Scope and Objectives

As for natural disasters, there is always an opportunity to fail because they can cause significant socio-economic costs and virtually complete destruction. Actual losses and damage have progressively risen in the past few years. Therefore, disaster managers have to employ better stock management techniques to be more proactive and assertive in the protection of society. In order to promote informed disaster management, a variety of research papers process catastrophe-related data using AI approaches. An overview of current AI applications in the management of disasters is provided in this chapter, including the four stages of the process: mitigation, preparedness, reaction, and recovery. It displays several relevant AI-based tools for decision support that are available, as well as sample applications of various AI strategies that are helpful for assisting this activity at different phases of its execution [5]. Disaster management has benefited from ML as it has helped to identify and eliminate redundant data while enabling a faster analysis of relevant data. However, the representation of a complicated system cannot be learned by directly applying conventional machine learning algorithms to the raw data. DL is a subcategory of ML that may identify a complex system's representation to perform detection, classification, or prediction without much human intervention. The elongated causal paths of NN layers in DL facilitate more intricate and hypothetical computations of the actual system [6].

OVERVIEW OF AI AND ML IN DISASTER MANAGEMENT

AI and ML have been explored in various fields, including medicine, history, and technology. AI is used in systems for recommendations, spam filters, and personal assistants, helping historians, heritage managers, and policymakers analyze intellectual and moral knowledge in cultural objects and social practices. This article suggests a paradigm for reviewing technology-based improvements to disaster preparedness that is need-driven and based on processes. A thorough examination of benchmark disruptive technology catastrophe improvements to disaster preparedness was conducted, gathered *via* social media, particularly Twitter. Big data technology was applied to analyze the acquired data, and the

CHAPTER 12

Integrating AI and ML into Early Warning Systems: A Solution to Climate Change Challenges

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Abstract: This chapter explores how Artificial Intelligence (AI) and Machine Learning (ML) can enhance Early Warning Systems (EWS) for climate-related disasters by addressing current limitations and improving disaster preparedness and response. It introduces Artificial Intelligence (AI) and Machine Learning (ML), demonstrating their potential to enhance disaster preparedness and response. The research provides valuable insights into natural disasters, their impacts on countries and communities worldwide, and how climate change is leading to more severe storms. It shows how using AI and ML in EWS can improve data collection, analysis, and communication, enabling better prediction, early warning, response, and resource allocation. Furthermore, the research explores emerging technologies like the Internet of Things (IoT), autonomous drones, and blockchain, and how they can be integrated with AI/ML to enhance EWS in the future. While there are challenges and concerns associated with implementing AI/ML for EWS, especially in developing countries, the research highlights the importance of international cooperation, data sharing, and capacity development. By addressing these challenges and embracing technology, we can realize the full benefits of AI/ML in disaster risk reduction and management, creating a safer and more sustainable future in the face of increasing natural disasters due to climate change.

Keywords: Artificial Intelligence (AI), Climate Change, Disaster Risk Reduction, Early Warning Systems (EWS), Machine Learning (ML).

INTRODUCTION

Climate change, on the other hand, is a major concern simply because of how this phenomenon could potentially impact global weather patterns and temperatures [1]. The principal cause is human activity, which produces atmospheric greenhouse gases that warm the planet and global temperatures [2, 3]. As a result, we are already seeing increased sea levels, more extreme weather events, and

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changes to ecosystems that put biodiversity, food security, water resources and human health at risk [4 - 6]. Estimates suggest that more than 216 million people, mainly in the global southare at risk of having to leave their homes by 2050-particularly because sea levels are rising [7]. These disruptions also threaten to lower agricultural productivity and increase water stress, further risking the survival of humans [8, 9]. The association of climate change and rise in the frequency of extreme weather events like tropical cyclones, typhoons and heatwaves has been widely established, which leads to severe damage risk for infrastructure, property and human life [10, 11].

Climate change is causing an increase in the frequency and severity of natural disasters, which places significant strain on traditional Early Warning Systems (EWS). The complexity and unpredictability of climate-induced events, such as flash floods, heatwaves, and intensified tropical cyclones, challenge the capabilities of current EWS. These systems often rely on historical data and static thresholds, which are becoming less reliable as climate patterns shift. For instance, traditional EWS face challenges such as incomplete data coverage in less developed regions, leading to either underestimation or overestimation of hazards. Additionally, communication and dissemination issues hinder the reach of warnings to isolated or vulnerable populations. Warnings must be culturally and linguistically appropriate to ensure effective community responses. Furthermore, the computational intensity required for advanced EWS, coupled with the inherent uncertainty in climate models, can impede deployment in resource-constrained areas. This often results in errors in predictions that lead to either under-preparedness or over-preparedness for disasters. The non-linear and complex nature of climate systems also limits the predictive accuracy of traditional EWS, often providing insufficient lead times for communities to respond adequately.

By addressing these limitations, Artificial Intelligence (AI) and Machine Learning (ML) can significantly enhance EWS by improving data collection, analysis, and communication. AI/ML technologies enable better prediction accuracy through advanced modelling techniques that process large datasets in real time. These systems can also improve the dissemination of warnings by leveraging personalized alerts and real-time translation tools to reach broader audiences effectively. Integrating AI/ML into EWS is crucial for developing more resilient systems capable of addressing the growing challenges posed by climate change. EWS is paramount to combat these threats as it provides timely warning information that allows communities the opportunity for a proactive response [12, 13]. The technical and methodological developments for climate EWS are addressed in the next section, noting that more complex droughts or storms stretch existing EWS capacity [14].

This chapter's unique strength lies in its thorough examination of the escalating climate crisis and the critical necessity for effective EWS. This chapter is significant because it visualizes the scope of including AI and ML in EWS, provides a few use cases where their presence can make real-time processing, anomaly detection, as well the predictive modelling to help cross over conventional approaches. In addition, the chapter offers an analytical landing in higher intensity fires and cyclones because of climate change which is updated with the latest research information. It also sets out how to take into consideration the issues facing developing countries in strengthening their EWS and focuses on providing low-cost operational solutions appropriate to meet these challenges. The chapter also presents new AI/ML-based approaches to evaluate the impact of disasters and assist in decision-making processes, potentially advantageous for enhancing preparedness and response mechanisms with a focus on vulnerable regions. Namely, the chapter continues to be forward-thinking in an evolving disaster management domain and examines emerging technologies such as Internet of Things (IoT), autonomous drones, and blockchain. Essentially, this chapter presents a new and broad framework to increase the resilience against growing climate threats through linking cutting-edge technologies with EWS platforms and providing future solutions applicable in both developed and developing nations. Building on this understanding of climate change impacts, the next section will delve into the specific effects of climate change on natural disasters.

THE IMPACT OF CLIMATE CHANGE ON NATURAL DISASTERS

As a matter of fact, climate change is fundamentally changing the global climate system, causing natural disasters like wildfires and hurricanes to become more frequent and their intensity to increase consistently over time. Experts predict that as global temperatures rise, we can expect more intense rainfall events, leading to an increased risk of flooding. Warmer temperatures increase the atmosphere's capacity to hold moisture, resulting in heavier rainfall and a greater risk of flash floods in certain regions. The report highlighted that melting ice and snow would cause more water to flow into rivers, raising the risk of flooding downstream areas. The devastating 2021 floods in Central Europe, resulting in over 200 deaths and loss of billions of dollars are clear examples of this rising threat [15 - 17]. Besides floods, higher temperatures worsen droughts by increasing evaporation, depleting soil moisture, and freshwater. Changes in rainfall patterns further intensify dryness in vulnerable areas, as seen in East Africa's severe droughts linked to climate change. These droughts have had devastating effects on millions, jeopardizing livelihoods and food security.

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