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PREDICTING EXTREME WEATHER IN THE CENTRAL HIMALAYAS USING ARTIFICIAL INTELLIGENCE AND AEROSOL DYNAMICS

Alok Sagar Gautam

Himalayan Atmospheric and Space Physics Research Laboratory
Department of Physics, Hemvati Nandan Bahuguna Garhwal University Srinagar Garhwal
Uttarakhand-246174, India.

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Keywords

*Aerosol dynamics,
Extreme weather
events, Central
Himalayas climate,
Machine learning
weather prediction,
AI-based early
warning systems,
Cloudbursts and flash
floods, Climate risk
management
Himalayas*

Abstract

This research aims to evaluate the Central Himalayan aerosol properties and negative impacts on extreme meteorological conditions, like cloudburst and flash floods. In using secondary data, the study analyses the application of machine learning models such as Random Forest, XGBoost and LSTM in findings and forecasting the likelihood of extreme weather by the use of aerosol and meteorological factors. An early warning system, which is vital for disaster preparedness and environmental policy, can be developed using an AI-based predictive model. The results point to the importance of aerosols in weather and reveal the effectiveness of employing AI techniques for better decision-making and climate adaptation. The study describes how AI can be incorporated into conventional meteorological initiatives and offers policy advocacy and capacity-strengthening strategies for meteorological departments in the Central Himalayan region.



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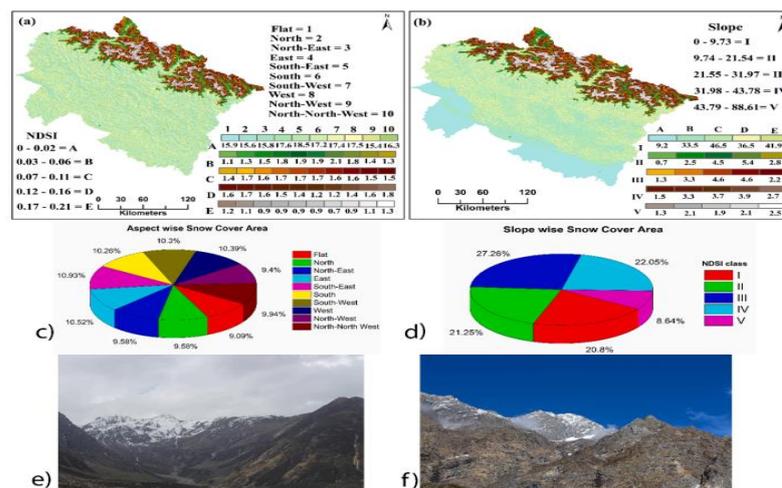
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1. INTRODUCTION

The Central Himalayan region currently experiences intense weather events like cloudburst, flash floods, and unprecedented rain that has potentially hazardous impacts on lives and structures. They are more associated with the aerosol-cloud relationships, which involve aerosol impacts on formation, temperature, and rainfall. Such complexities cannot be solved using conventional forecasting approaches; hence, the need for the incorporation of AI and ML to assist in uncovering hidden patterns to improve forecast accuracy. Majoring on the systematic review method in this study, the tendency of using AI-based models to predict extreme weather in relation to aerosol dynamics for climate risk management as a tool to enhance preparedness for disasters in the region is analysed.

2. BACKGROUND AND RATIONALE

The climate of the central Himalayas may also fluctuate or be unpredictable due to the energy of altitude and/or mountainous area and the energy of the season. It is a warm summer region, which ranges from 12 to 20 degrees and a monsoon region ranging between 10 to 15 degrees, while the other has a very cold winter season, which sometimes drops to -10 and even snowfall sometimes (Banerjee et al. 2021). This particular geography and climate also make the region vulnerable to extreme weather conditions such as cloudbursts, flash floods or sudden rises in precipitation. These are some that relate to aerosol-cloud interactions, which include aerosols, which are particulate matter in the atmosphere that affect cloud formation and varying rainfall intensities (Javed et al. 2024). However, the use of aerosols in such an environment is something that has not been widely researched. This research is deemed necessary as there is little research information on using physical models in this region, as well as developing climate-specific models for this climate region, since the climate greatly influences the effectiveness of such models.



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Figure 1: Snow cover distribution (Source: Banerjee et al. 2021)

3. PREVIOUS LITERATURE

3.1 Analysis of Aerosol Dynamics and Their Role in Extreme Weather Events in the Central Himalayas

In the given context, aerosols play some important roles in climate and extreme weather events in the Central Himalayas. According to Battula et al. (2023), it was established that during the monsoon season, the aerosol loading enhances both convection activity and, therefore, the probability of increased amounts of precipitation over the Western Himalayas. However, Ramachandran et al. (2023) state that aerosols impact the physical properties of clouds in addition to increasing the temperature of the Himalayan atmosphere on a larger scale, which modifies pressure systems and decelerates the monsoon, consequently intensifying extreme weather conditions.

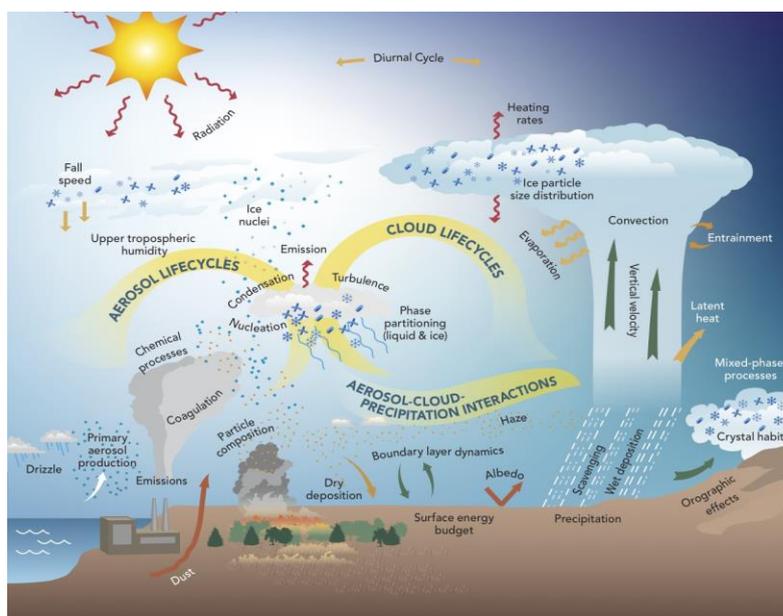


Figure 2: Aerosol Dynamics (Source: Battula et al. 2023)

Long-term observation by Srivastava and Naja (2021) also corroborates the evidence of radiative forcing of carbonaceous aerosols mainly due to biomass burning in the Central Himalayas. Wang et al. (2022), on the other hand, take a more expansive view by stating that aerosols can both inhibit and facilitate precipitation depending on the subtype, aerosol loading, and its relationship to meteorology in a specific geographic area. It reflects the complexity of the aerosols' impact on the



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extreme weather across the terrains and focuses on the specific impacts on the Himalayan environment.

3.2 Machine Learning Applications in Weather Prediction: Models, Performance, and Challenges

Over the recent years, machine learning (ML) approaches have been found to be quite useful for enhancing the ability to make accurate weather forecasts based on large and diverse datasets. According to Bochenek and Ustrnul (2022), Random Forest and XGBoost models are effective in identifying patterns if multiple climate variables are interacting with each other. In contrast, Chen et al. (2023) stated that deep learning models such as LSTM networks yield better results for identifying temporal relations and events with longer lead times, especially when trained on the aerosol and meteorological time series.

However, the integration of ML into climate models is not without limitations. Chantry et al. (2021) categorise these into ‘hard, medium, and soft AI’ and argue that, while ML is extremely effective in soft tasks such as data ingestion and short-range forecasting, it is still deficient in employing ‘hard’ tasks, which include physics-based simulation and model transfer across regions. Unlike Porto et al. (2022), which emphasises and discusses the practical concerns concerning data constraint, noise, and overfitting, especially in high-altitude or urban settings. Nonetheless, all authors are optimistic about the applicability of the potential of ML in improving forecasts in climate-sensitive areas such as the Central Himalayas.

3.3 AI-Based Early Warning Framework for Climate Risk in Mountainous Ecosystems

AI can be considered a powerful tool to enhance early warning systems (EWS) in ecologically sensitive and geomorphologically sensitive areas such as the Central Himalayas. Neset et al. (2024) also state that the incorporation of AI in weather warning systems will enhance the prediction of climate, specifically, and warning mechanisms will enhance preparedness. On the other hand, Adams et al. (2024) describe climate risk models employed by the Swiss AI and emphasise the need for diverse stakeholders and academics to develop robust and effective EWS, which are principles that are necessary for Himalayan applications.

Moreover, Reichstein et al. (2025) also have pointed out how multi-hazard risk assessment is performed using data from satellites, sensors, and social networks through integrated AI. SP et al. (2024), on the other hand, take advantage of deep learning frameworks that learn from past disaster information to make forecasts of natural disasters. They point out that when integrating geospatial analysis with AI systems, it is possible to obtain high-resolution forecasts and individualised risk evaluations.

4. LITERATURE GAP



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Although there has been progress made in the areas of aerosol-weather interaction and embedding of AI in numerical weather prediction, there is still a lack of information regarding the application of these two fields to a particular region and especially in high-altitude areas such as the Central Himalayas. For example in research of Wang et al. (2022) and Ramachandran et al. (2023) there is presence of general research on the aerosol effect on extreme climatic conditions. However, many researchers do not focus on spatially heterogeneous and elevated terrain considerations. Similarly, Bochenek and Ustrnul (2022) and Chen, Cramer, and Chen (2023) discuss AI in a global perspective. But the research has limited application and performance analysis for the Central Himalayan domain using a multi-source dataset. This is the gap that this study seeks to fill by developing a regional model that uses AI and aerosol dynamics, and climate variability within the region.

5. RESEARCH PURPOSE

The objective of this study is to examine the involvement of aerosols in the phenomenon of cloudbursts and flash floods in the Central Himalayan area. The intended application is to enhance the warning frameworks, enhance the preparedness and enhance the understanding of the climate risks in this sensitive and diverse geographical region.

6. RESEARCH AIM

To understand the potential of integrating artificial intelligence and machine learning approaches to forecast severe weather in the Central Himalayas. The objectives of the research is to analyse the causal link between aerosols and the climate intensity of extremes in the Central Himalayan area, to evaluate the effectiveness of machine learning models in identifying patterns and forecasting the likelihood of extreme weather based on aerosol and meteorological variables and to develop an AI-based predictive framework that can support early warning systems and inform disaster preparedness and environmental policy in topographically complex Himalayan ecosystems

7. METHOD

7.1 Research Design

Interpretivism philosophy has been used in this study (Junjie and Yingxin, 2022). This paper uses the inductive approach that work from the specific observation to develop the general theories and hypothesis. It also enables a broad analysis of these phenomena due to the descriptive nature of the design and, therefore, the provision of detailed information on the regional climatic conditions and AI capabilities in climate risk estimation.

7.2 Data Collection Method

This research employs secondary research with an approach of systematic review approach to minimise bias and directionality of research questions (Mazhar et al. 2021). Recent articles in peer-reviewed scientific databases, including Google Scholar, Scopus, and Web of Science, were used to gather relevant data based on their potential applications on aerosol dynamics, extreme weather



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events and artificial intelligence prediction models.

7.3 Databases

The papers obtained from the academic databased such as Google Scholar, Scopus, Web of Science, SpringerLink, JSTOR, IEEE Xplore and PubMed.

Table 1: Boolean search

Keywords	Boolean Search Expression
Aerosol dynamics	"Aerosol dynamics" AND "extreme weather"
Extreme weather events	"Extreme weather" AND "Himalayas" OR "flash floods"
Central Himalayas climate	"Central Himalayas" AND "climate change"
Machine learning weather prediction	"Machine learning" AND "weather prediction"
AI-based early warning systems	"AI-based" AND "early warning systems" AND "climate risk"
Cloudbursts and flash floods	"Cloudbursts" AND "flash floods" AND "Himalayas"
Climate risk management Himalayas	"Climate risk management" AND "Himalayas"

Here, the column on the left denotes the keywords that have been used for the searching of the research papers and the column on the right denotes the search strings that have been used for the searching of the research papers. The search keywords have been conjoined with Boolean operators to form search strings.

7.4 Inclusion and exclusion criteria

Table 2: Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Publication Date	Articles published within the last 5 years	Articles older than 5 years
Study Type	Peer-reviewed articles, systematic reviews, and case studies	Non-peer-reviewed articles, opinion pieces
Language	English	Non-English articles
Relevance	Studies on aerosol dynamics and extreme weather in the Himalayas	Irrelevant studies not focused on aerosols or extreme weather events

The left most column denotes the criteria based on which the identified research papers have been sorted. The inclusion column defines the criteria based on which relevant research papers have been included in the research and exclusion column defines the criteria based on which research papers



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have been excluded from the research.

7.5 Prisma

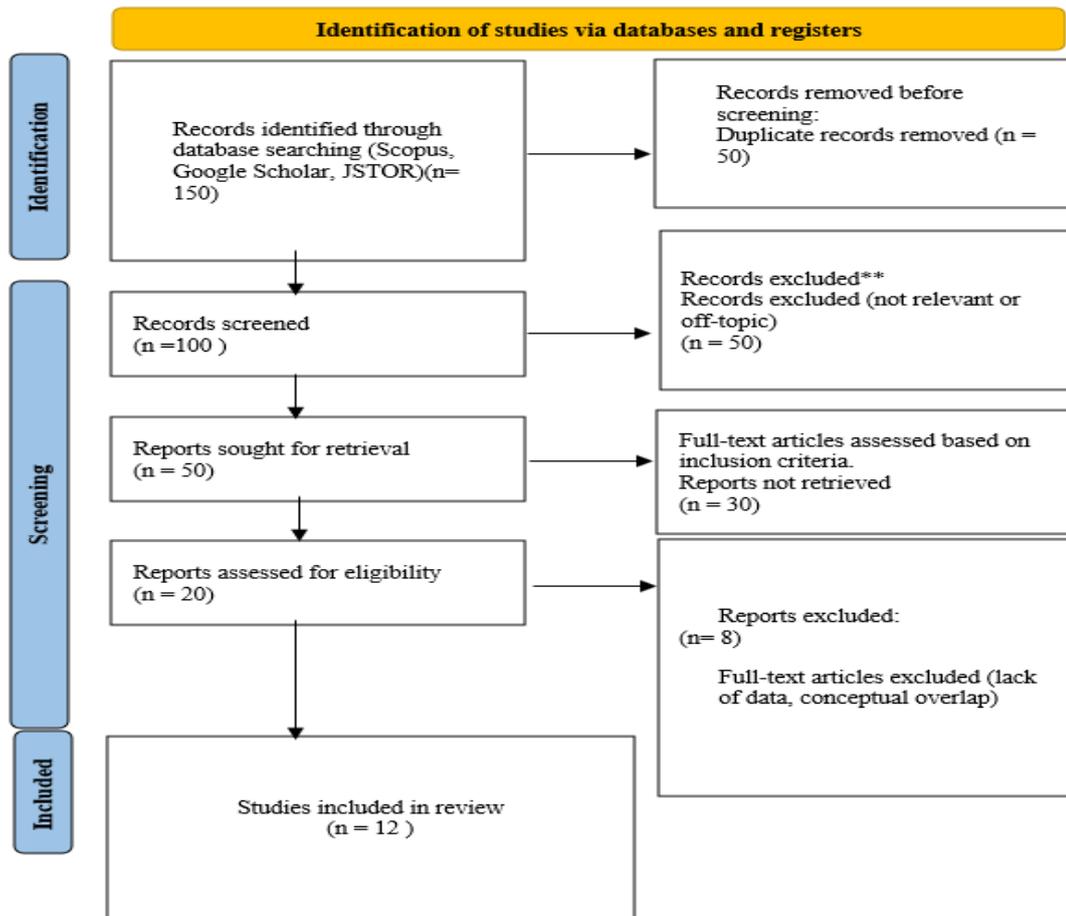


Figure 3: Prisma

The PRISMA contains a flowchart depicting the whole process of research selection before the commencement of the data collection. The boxes on the right defines and depicts the criteria for exclusion of the paper and the number of papers that have been excluded. The boxes with sequential arrows shows the number of papers that have been included in the research. The process is divided into three parts with initial part of identification of the relevant papers, then screening of the ideal research papers and final inclusion of the relevant and ideal papers.

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7.6 Data analysis

The methodology used in this research is thematic analysis with axial coding since it entails a process of coding, analysing and reporting of themes and patterns identified in the literature review (Braun and Clarke, 2024). This method enables a scientific and structured analysis of important topics like the behaviour of aerosols as well as intense fogs and mists.

8. QUALITY APPRAISAL OF SOURCES

To assess the quality of the sources used in this research, the CASP checklist was used to evaluate the studies' applicability and methodological quality. CASP assists in determining the quality, credibility, and methodological rigour of articles of interest. [Referred to appendix 1].

9. RESULTS

As depicted in the PRISMA final, 12 research papers were chosen. They were chosen as they were older than 5 years and were strongly related to the topic under research. they clearly articulated information on aerosol dynamics in the central Himalayan region and discussed the importance of AI and machine learning in monitoring aerosol dynamics in the region. The result has been depicted in the table 3 which is an axial coding table as the table shows keywords and codes identified from the research papers that are common and with those codes themes have been developed which can be further analysed to meet the research objective.

Table 3: Axial coding

Authors	Keywords	Sub-Themes	Themes
Sun and Tang (2021)	Dust aerosols, radiation estimation, satellite data	Influence of aerosol types on radiation and cloud dynamics	Theme 1: Aerosol properties significantly influence extreme weather patterns across the Central Himalayan region
Basit <i>et al.</i> (2024)			
Ferrario <i>et al.</i> (2025)			
Sinha <i>et al.</i> (2025)			
Ren <i>et al.</i> (2024)	Ensemble learning, RF, XGBoost, flood risk	Comparison of AI models in weather-related risk mapping	Theme 2: Machine learning models effectively detect aerosol-weather patterns and predict extreme event
Wu <i>et al.</i> (2024)			
Babu			

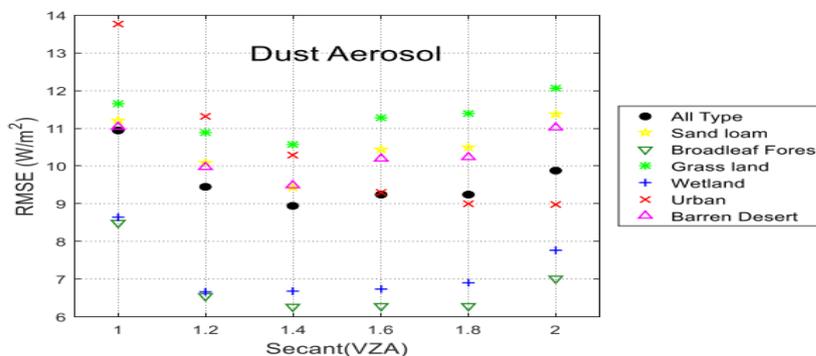


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Nuthalapati and Nuthalapati (2024)			probabilities
Reddy (2024)			
Sain (2022)	Glacial hazards, AI-based IWS, and early warning systems	Integration of AI in Himalayan early warning systems	Theme 3: AI-based frameworks enhance early warnings and guide climate policy in Himalayan disaster-prone areas
Jain et al. (2024)			
Diehr et al. (2025)			
Liu et al. (2024)			

Theme 1: Aerosol properties significantly influence extreme weather patterns across the Central Himalayan region

Properties of aerosols play an important role in modifying extreme weather in the Central Himalayan area. Dust and black carbon impact solar radiation and cloud physics, which govern atmospheric stability and precipitation. In such hilly terrains of the Central Himalayas, these interactions render catastrophic effects, leading to cloudbursts and flash floods since the meteorological patterns differ drastically. Specifically, Sun and Tang (2021) pointed out that the aerosols implied negative net surface shortwave radiation; therefore, cooling of the surface and an increase in instability in the atmosphere. This instability can increase convective activity and lead to heavy precipitation, which enhances the negative impacts of heavy steps such as ice and snow flows and landslides. Their study, which deals with satellite remotely sensed data such as meteorology under dust aerosol conditions, shows that aerosol is crucial for predicting geographical weather events (Sun and Tang, 2021).



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Figure 4: Root-mean-square error (RMSE) (Source: Sun and Tang, 2021)

The use of AI in the monitoring of aerosols has therefore expanded the knowledge of the link between aerosols and the climate. Basit et al. (2024) discussed the use of AI in environmental supervision and threat detection, with a specific focus on the utilisation of machine learning in the interpretation of environmental data. According to their study, artificial intelligence has the potential to analyse the situation and foresee environmental challenges that are shaped by aerosols. Ferrario et al. (2025) analysed the state-of-the-art in machine learning techniques for multi-hazard and multi-risk climate evaluation. They pointed out the usefulness of the data to model various non-linear associations between the hazard and the relevant risk factors: aerosols, as well as the meteorological conditions. It generally agrees with the development of models for prediction to help studies like the one from the Central Himalayas for the early warning systems for possible disasters.

Sinha et al. (2025) described the advancements in weather and climate prediction systems and how they incorporated the use of AI and Machine Learning techniques. They observed that these advances can improve the prognosis of such extremes that are inimical to states with vulnerable effects from aerosol precipitated weather disturbances. Therefore, the use of Artificial Intelligence and Machine Learning to predict environmental events improves the preparedness and management of these occurrences.

Theme 2: Machine learning models effectively detect aerosol-weather patterns and predict extreme event probabilities

ML models have thus provided high accuracy in pattern recognition and in the modelling of the extent of probable calamity that may occur in disaster-prone areas, such as the Central Himalayas. These models are more suitable for modelling complex relationships between the aerosol characteristics and meteorological factors, which are vital in the risk assessment of climate change. In their study, Ren et al. (2024) used ensemble learning algorithms of RF and XGBoost to determine flood susceptibility in Kunming, which is a mountainous urban territory. They found that the RF has an AUC of 0.87 while XGBoost has an AUC of 0.84, which is better than models like Artificial Neural Networks (ANN) and Support Vector Machines (SVM). These findings have only served to demonstrate the effectiveness of ensemble learning methods in predicting flood vulnerable areas, from climatic, geomorphic and anthropogenic factors.



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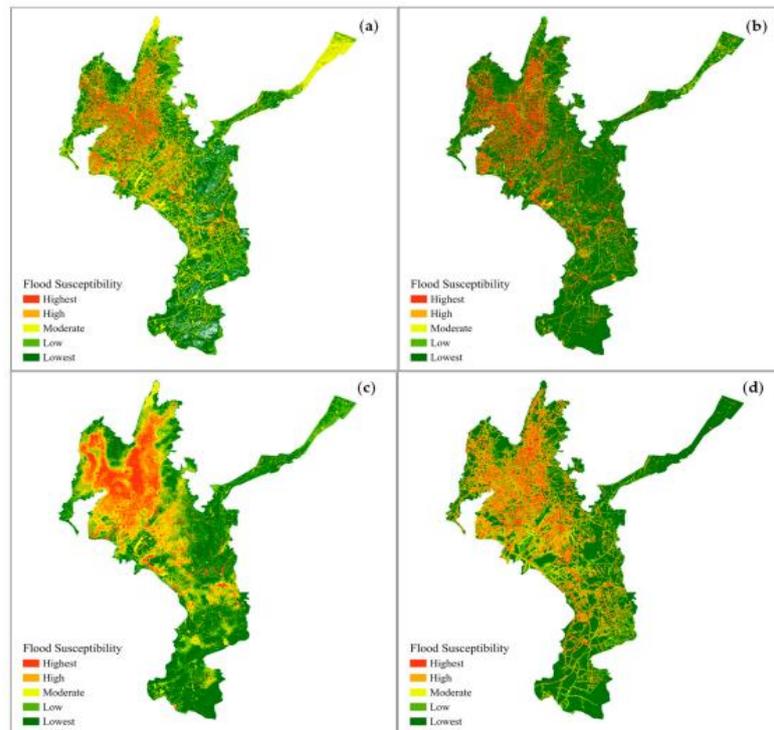


Figure 5: Flood susceptibility maps (Source: Ren et al. 2024)

In the same vein, Wu et al. (2024) have compared Logistic Regression, RF, and XGBoost models for identifying flood sensitivity. Their conclusions showed that heart models as well as XGBoost achieved higher accuracy; this proved that more complex models are way better regarding environmental hazards assessment. With reference to the weather prediction area, Nuthalapati and Nuthalapati (2024) showed the effectiveness of gradient boosting models. Their study indicated that the accuracy of their work was 80.95%, stating that there is a need to improve the forecast precision using ML models.

In addition, Reddy (2024) analysed the use of Explainable Artificial Intelligence (XAI) at the time of climate hazard rating. When combined with XAI, this study applied to the ML models increased the level of predictability when it comes to such phenomena as droughts, floods, and landslides. This is because this approach helps decision-makers to gain insight into the causes of the surge in the occurrence of extreme weather conditions. Taken together, these reviews confirm that ML models, particularly ensemble learning algorithms RF and XGBoost, are capable of accurately identifying aerosol-weather linkages and predicting severe weather in the Central Himalayan region. They are helpful in the early warning systems and are crucial in disaster response, given the fact that this



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region is prone to natural disasters.

Theme 3: AI-based frameworks enhance early warnings and guide climate policy in Himalayan disaster-prone areas

It is primarily imperative to build an AI-based framework to enhance early warning systems and future disaster discrepancies in the geophysically sensitive Himalayan region. The area is deeply influenced by the steep slopes and varying climate, which in turn increases the effects of risks such as GLOFs, Flash floods, and landslides. In this regard, Sain (2022) has indeed rightly emphasised the need for having an AI-based Integrated Warning System (IWS) for the Uttarakhand Himalaya to address glacier- and glacial-lake-related dangers effectively in the future. It also involves seismic and meteorological, and hydrological information retrieved from satellite technology, which is analysed by AI to determine behaviours suggestive of the event. For instance, the dreadful Chamoli disaster in February 2021, where many people died and many infrastructures were destroyed, could have been prevented were there had been a system like this one.

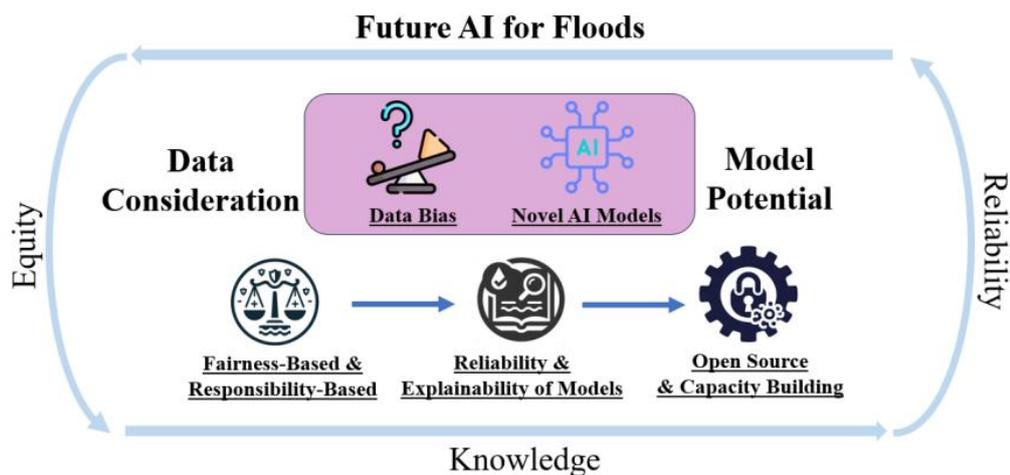


Figure 6: AI for floods (Source: Liu et al. 2024)

In their study, Jain et al. (2024) argue that the application of Artificial Neural Networks (ANN) can improve flood control for the management and early warning of mountain rivers. Their strategy involves the use of ANN models in the modelling of high level hydrological data in order to enhance flood prediction. The study also finds out that the evaluation of the AI techniques would result in the enhancement of the accuracy and timeliness in generating the forecast which is vital for mitigation of losses in disaster prone areas mainly mountainous areas.

In the study by Diehr et al. (2025), the author presents information about integrating AI and machine



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learning in GIS as a measure of disaster anticipation. By integrating the concept of AI and GIS, the framework can evaluate the exact spatial location to find out prospective risks near the susceptible zones. This enhances planning and decision-making in the preparation and management of disasters in the United States. Based on the findings of Liu et al. (2024), various AI approaches have been used in managing flood risk, and these aspects include: AI Flood Risk Prediction and Decision Making. They emphasised the importance of data and how accuracy of the data is important, in addition to how important it is to keep an eye out for the performance of the forecasts by the artificial intelligence.

10. ANALYSIS

Based on the outcome of the study, there are some major variables that are related to aerosols and intensive climate and other parameters and AI models in the Central Himalayan region. It is, as such, important for one to consider the fact that matters such as dust and soot influence the atmospheric conditions and thereby the severity of adverse climate conditions, as is the case in this study. This is in line with other research done by Sun and Tang (2021), which demonstrated how aerosols alter the shortwave radiation and climatology of the areas. By analysing two models, namely Random Forest and Gradient Boosting, it is noted that machine learning introduces very high reliability in detecting extreme climate conditions using aerosol and meteorological information. Thus, as Wu et al. (2024) and Ren et al. (2024) stated, its application helps to determine the potential likelihood of an event occurring regardless of how intricate the pattern may be. Furthermore, the development of AI frameworks can improve the enhancement of the early warning system (AI-Jumeily et al. 2024). These augment measures of disaster response, minimise possible risks, and streamline environmental management, to factor in the numerous steep terrains that characterise the Himalayan areas.

11. DISCUSSION

The study affirms that aerosols such as dust or even soot have an impact on the radiation balance, leading to more episodes of intense rainfall or heat waves. This is especially important for localised weather forecasting in the Central Himalayas, which are sensitive to monsoon variations. The models like Random Forest, XGBoost, and Artificial Neural Network demonstrated high suitability to improve decision-making and the level of preparedness. Ren et al. (2024) and Jain et al. (2024) further illustrate the effectiveness of these models in capturing non-linear relationships between variables and enhancing the error rates for floods and other risks. They help in their enactment in early intervention systems and policies to make sound policy decisions. However, as was already mentioned above, in order to attain the maximum efficiency, AI has to be complemented by conventional methods of meteorological forecasting. As pointed out by Liu et al. (2024), integrating AI with human knowledge and physical modelling can enhance such factors as the system's stability and dependability. Issues remain as the amount of available data in remote areas is insufficient to



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feed into model development; overfitting issues and lack of interpretability reduce trust in, and practical use of, AI solutions (Reddy, 2024).

12. RECOMMENDATIONS

(a) Integration into Early Warning Systems

The use of AI-based systems should be incorporated in the local as well as national-level disaster warning systems to enhance real-time decision-making and fast response in the mountains (Reddy, 2024).

(b) Development of Hybrid Models

Integrating the physical meteorological models with the AI assisted data driven models could help in improving the degree of prediction and accuracy in addition to better tuning with microclimate of the Himalayas.

(c) Capacity Building

Training becomes crucial to enhance the AI awareness of the meteorological staff and to acquire an adequate implementation and interpretation of AI tools (Ren et al. 2024).

(d) Policy Advocacy

The need to heighten measures put in place to improve the monitoring and control of aerosol emissions as a means of reducing their impacts on climate in susceptible ecosystems (Diehr et al. 2025).

13. CONCLUSION

Therefore, this study greatly demonstrates that aerosol increases the impact of extreme weather conditions in the Central Himalayan area. The results have also demonstrated the feasibility of using the Random Forest, XGBoost, and LSTM models in analysing the aerosol-weather patterns and predicting the extreme phenomena. These AI models also demonstrate increased relevance in improving early warning systems that play a vital role in disaster management in multifaceted ecosystems. Moreover, the study underlines the importance of synthesising a secondary qualitative approach in the studies of the environment using Artificial Intelligence, since by doing so, there is correlation and compilation of several data and findings, thus enhancing the knowledge and understanding of climate.

14. LIMITATIONS AND FUTURE SCOPE

The study has its own limitations, such as the fact that most of its findings have been based on secondary data, indicating that the latter may not necessarily present the most current trends in aerosols and weather. The used models might have issues of data scarcity and can easily overfit, resulting in low prediction accuracies. Future research can involve online data feeds and enhancing the resilience of the AI model using more diverse data inputs. Moreover, using the approaches



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derived from AI together with physical meteorological models might be even more beneficial for improved predictions. Future research should also look at other mountainous areas for the application of the AI-based frameworks during severe weather conditions.

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16. AUTHOR(S) CONTRIBUTION

The writers affirm that they have no connections to, or engagement with, any group or body that provides financial or non-financial assistance for the topics or resources covered in this manuscript.

17. CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

18. PLAGIARISM POLICY

All authors declare that any kind of violation of plagiarism, copyright and ethical matters will taken care by all authors. Journal and editors are not liable for aforesaid matters.

19. SOURCES OF FUNDING

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Appendix 1: CASP

Article	Clear Aim?	Appropriate Methodology?	Research Design Justified?	Recruitment Strategy/Scope Clearly Described?	Data Collection Clearly Described?	Ethical Considerations Addressed?	Clear Findings?	Value of Research?
Sun and Tang (2021)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Basit et al. (2024)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ferrario et	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes



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al. (2025)								
Sinha et al. (2025)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Ren et al. (2024)	Yes							
Wu et al. (2024)	Yes							
Nuthalapati and Nuthalapati (2024)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Reddy (2024)	Yes							
Sain (2022)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Jain et al. (2024)	Yes							
Diehr et al. (2025)	Yes							
Liu et al. (2024)	Yes							

