3rd Place Award Winner

Leveraging Artificial Intelligence and Actuarial Techniques to Strengthen Climate Change Resilience and Adaptation Programs

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INTRODUCTION

The year 2024 witnessed unprecedented climate and weather disasters globally, emphasizing the urgent need for resilience and adaptation initiatives. In the United States alone, 27 disasters caused damages exceeding $1 billion each, including hurricanes, tornado outbreaks, wildfires, heatwaves, and flooding events. Hurricane Helene, the costliest, resulted in 219 deaths and caused an estimated $79.6 billion in damages. Beyond the U.S., Cyclone Chido claimed over 1,000 lives, a heatwave in Bangladesh affected more than 33 million people, and a drought in Colombia has had significant economic consequences (NOAA, 2024; CNN, 2024).

These events highlight the growing vulnerability of communities to climate-related risks and underscore the importance of proactive adaptation programs. Decision-makers are increasingly seeking tools that not only mitigate the effects of disasters but also optimize resource allocation.

This essay argues that integrating artificial intelligence (AI) with actuarial techniques provides a rigorous, scalable, and actionable framework to evaluate and enhance climate change resilience and adaptation programs worldwide. Through illustrative global case studies, quantitative methods, and predictive modelling, this paper demonstrates how such an approach can help communities prepare for and respond effectively to climate disasters.

This paper contributes by offering a practical evaluation framework that actuaries and policymakers can adapt across diverse climate-risk contexts.

BACKGROUND AND LITERATURE REVIEW

Governments and organizations have implemented numerous initiatives to enhance climate resilience. In the United States, Louisiana upgraded its building codes after Hurricane Katrina to reduce infrastructure vulnerability, while New York City introduced the *Be a Buddy* program to connect volunteers with vulnerable populations during extreme heat events (NYC Mayor's Office, 2018). Florida has experimented with hurricane-proof communities, such as Hunter's Point, which were designed to withstand major storms (CNN, 2024).

Outside the U.S., developing countries face unique challenges due to limited resources and infrastructure. Bangladesh, prone to heatwaves and flooding, has invested in early warning systems and community preparedness programs. Similarly, Colombia's drought mitigation initiatives aim to protect agricultural livelihoods and the broader economy.

A recurring challenge remains: **evaluating the effectiveness of resilience programs quantitatively**. Many initiatives rely on anecdotal evidence or post-event assessments, which limits their ability to inform decision-making for future interventions.

Recent literature highlights the potential of AI and actuarial methods in addressing this gap. Machine learning models, such as XGBoost, can analyze complex datasets to predict climate risks and optimize program selection. Actuarial techniques, including discounted cash flow (DCF) analysis using real option theory, allow evaluators to quantify potential benefits and costs of interventions under uncertainty, as documented in the broader climate risk and disaster economics literature. Combining these approaches creates a robust framework to design, implement, and assess resilience programs effectively.

METHODOLOGY / FRAMEWORK

To maximize the impact of adaptation initiatives, a structured framework integrating AI and actuarial techniques is proposed. This framework consists of three key stages: **risk identification, program selection, and quantitative evaluation**.

RISK IDENTIFICATION

The first stage involves identifying high-risk areas and populations. Historical climate and disaster data, such as flood, hurricane, or wildfire frequency and intensity, can be analyzed using predictive models like XGBoost. XGBoost is effective for handling complex, non-linear relationships and large datasets, making it suitable for climate risk assessment. Variables such as precipitation patterns, elevation, population density, and infrastructure resilience are incorporated into the model to produce **illustrative probabilistic risk maps**.

Note: For this essay, risk maps and outcomes are hypothetical and based on published literature and expert assessments.

PROGRAM SELECTION

Once risks are identified, programs are prioritized based on expected impact and cost-effectiveness. Machine learning models can rank interventions by predicting their potential to reduce casualties, infrastructure damage, or economic losses. Social adaptation programs, such as community engagement or volunteer coordination, can be evaluated using **participant/non-participant methods**, comparing outcomes between neighborhoods involved and not involved in programs.

QUANTITATIVE EVALUATION

The final stage applies actuarial techniques to evaluate program outcomes. The **pre/post method** assesses changes in key indicators (e.g., fatalities, economic losses) before and after program implementation. For infrastructure-focused initiatives, **DCF analysis using real option theory** estimates the present value of avoided damages, incorporating uncertainty in climate projections and economic variables. This allows decision-makers to understand the expected return on investment (ROI) for each intervention and make informed choices about resource allocation.

Table 1

FRAMEWORK FOR AI AND ACTUARIAL EVALUATION OF ADAPTATION PROGRAMS (ILLUSTRATIVE)

Stage	Technique	Data Source	Expected Output
Risk Identification	XGBoost	Historical climate & population data	High-risk zones
Program Selection	ML prioritization	Socioeconomic & infrastructure data	Ranked interventions
Quantitative Evaluation	Pre/post & DCF	Program & financial data	ROI, risk reduction

This integrated framework allows programs to be **data-driven, scalable, and adaptable** to different geographies and types of disasters.

CASE STUDY: ILLUSTRATIVE FLOOD MITIGATION IN DHAKA, BANGLADESH

Problem Context

Dhaka, the capital of Bangladesh, faces frequent urban flooding affecting millions of residents and critical infrastructure. Traditional flood management strategies have often been reactive, resulting in high human and economic costs. To illustrate the potential application of AI and actuarial methods, a hypothetical pilot program is considered that combines predictive modelling with community-based adaptation measures.

Program Design (Illustrative)

The program includes:

- **Predictive Flood Mapping:** Using XGBoost to analyze rainfall, drainage patterns, population density, and topography.
- **Community Preparedness:** Training volunteers, establishing emergency shelters, and communicating evacuation plans.
- **Infrastructure Interventions:** Building embankments and upgrading drainage systems.

Quantitative Evaluation (Illustrative)

Evaluation employs three techniques:

- **Pre/Post Method:** Comparing flood-related damages and casualties before and after program implementation.
- **Participant/Non-Participant Method:** Measuring differences in preparedness outcomes between neighborhoods involved in the program and those not involved.
- **DCF Analysis Using Real Option Theory:** Estimating economic benefits of infrastructure improvements under uncertain climate projections.

Illustrative Findings

The following findings represent expected outcomes under the assumption that the proposed AI–actuarial framework is implemented using Dhaka-specific climate, demographic, and infrastructure data. The results are illustrative and informed by performance ranges reported in comparable urban flood risk studies in South and Southeast Asia and similar flood-prone urban environments, rather than derived from observed program data in Dhaka.

- **Predictive Accuracy:**
  Under the assumed application of XGBoost to Dhaka flood data, the model is expected to identify flood-prone areas with approximately **85% classification accuracy**, consistent with accuracy ranges reported in urban flood susceptibility literature.
- **Social Impact:**
  Assuming effective implementation of community preparedness initiatives in high-risk Dhaka neighborhoods, potential flood-related casualties are expected to decrease by approximately **20%** in participating areas relative to non-participating areas.
- **Economic Benefits:**
  Applying actuarial discounted cash flow (DCF) analysis with real option considerations, the illustrative program yields an estimated **return on investment of $1.5 for every $1 invested over five years**, reflecting avoided damages and reduced emergency response costs.

Lessons Learned

The case study illustrates that combining AI, actuarial techniques, and community engagement can significantly enhance resilience outcomes. Key takeaways include:

- Predictive modelling enables targeted interventions in resource-limited settings.
- Actuarial evaluation quantifies social and economic impacts to support decision-making.
- Community involvement is critical for program success, especially in dense urban environments.

DISCUSSION AND IMPLICATIONS

Integrating AI and actuarial techniques offers several advantages for climate resilience programs:

- **Proactive Decision-Making:** Predictive models allow governments and organizations to anticipate disasters and allocate resources efficiently.
- **Cost-Effectiveness:** Quantitative evaluation identifies programs with the highest ROI, ensuring limited resources achieve maximum impact.
- **Scalability:** The framework can be applied to multiple disasters (hurricanes, wildfires, droughts) and across different countries.
- **Actuarial Role Expansion:** Actuaries can evaluate social and environmental interventions beyond traditional insurance contexts.

Challenges remain, including **data availability**, especially in developing countries, the need for **interdisciplinary collaboration**, and limitations in predictive accuracy for extreme events.

RECOMMENDATIONS FOR FUTURE RESEARCH

- **Integrating Multi-Source Data:** Combining climate, demographic, and socioeconomic datasets for robust predictive modelling.
- **Long-Term Impact Studies:** Evaluating sustained effects of social adaptation programs on vulnerable populations.

- **Hybrid Intervention Models:** Assessing combined infrastructure and behavioral programs for enhanced cost-effectiveness.
- **Open Data Sharing:** Encouraging governments, NGOs, and the private sector to share datasets to improve model accuracy and applicability.

Such research enables actuaries and policymakers to develop **adaptive, evidence-based programs** that enhance global resilience.

CONCLUSION

Climate-related disasters are increasingly frequent and costly, emphasizing the need for effective resilience and adaptation initiatives. This essay demonstrates that integrating **AI-driven predictive models with actuarial evaluation techniques** provides a **quantitative, scalable, and actionable framework** for assessing and optimizing climate adaptation programs.

The illustrative Dhaka case study highlights practical benefits: reduced casualties, measurable economic gains, and improved disaster preparedness. By leveraging predictive analytics, actuarial modelling, and community engagement, governments and organizations can make informed decisions, prioritize resources efficiently, and build resilience for the future.

Actuaries have a unique opportunity to contribute to climate adaptation by applying expertise in **quantitative evaluation, risk assessment, and resource optimization**, ensuring programs deliver tangible benefits worldwide.

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