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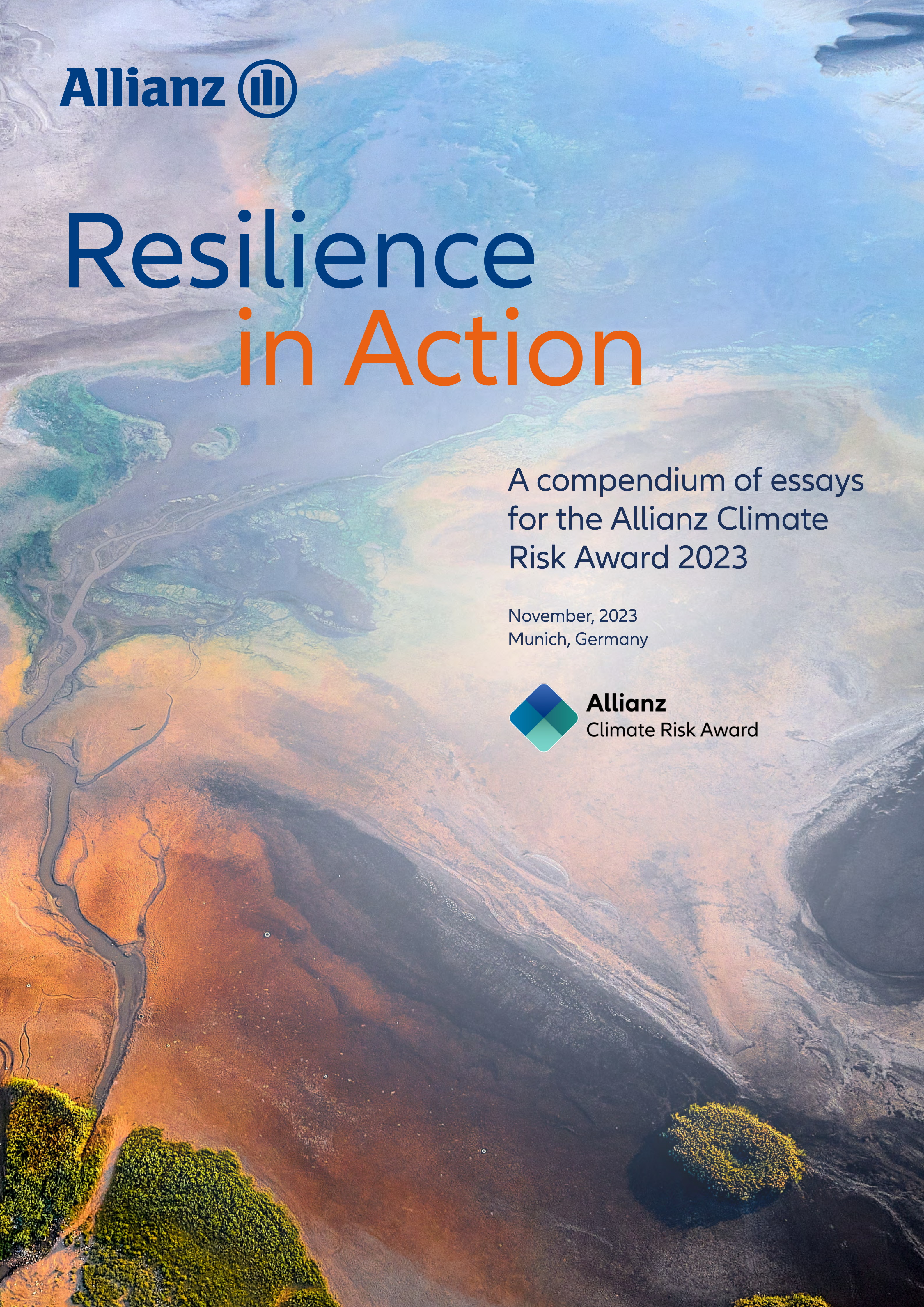

Resilience in Action

A compendium of essays for the Allianz Climate Risk Award 2023

November, 2023
Munich, Germany

Allianz
Climate Risk Award

About the compendium

Launched in 2017, the Allianz Climate Risk Award celebrates scientists at the start of their career whose work sheds light on the nexus between climate change and extreme weather events. The award is open to PhD candidates and Post-Doctoral researchers whose research focuses on: Reducing the risk of extreme weather events that are intensified by climate change and fostering resilience by applying technological solutions.

The compendium is a compilation of selected essays based on the criteria of innovation, research excellence, applicability and impact from applicants of the 2023 Allianz Climate Risk Award. This compendium is issued online only and is published exclusively for didactic purposes.

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Locations of the contributors

Hurricanes claim media headlines for the fury of their destructive power and the devastation they can cause. But what is often overlooked is the consequences, like with Hurricane Ida in New Orleans in 2021, when the storm was followed by a subsequent heatwave that killed more people than the hurricane. With climate change and the urbanization of coastal areas, such compounded events may become more frequent.

Dazhi Xi
Nationality: Chinese
Location: United States of America

The global economic losses due to climate chaos are soaring. Yet, the damage estimates may only scratch the surface as they predominantly focus on physical damage leaving the question of more profound economic disruptions out of the assessments. Such indirect damages are often twice as damaging as direct costs, as the Emilia-Romagna floods of 2023 in Italy show.

Elisa Nobile
Nationality: Italian
Location: Italy

Extreme heat is one of the deadliest climate extremes, posing a significant risk to health and wellbeing. Studies on the mortality impacts of possible extreme summer seasons in the present and the impending climate era show that heat mortality of past extreme seasons could become all too familiar in a world warmed by 2°C.

Samuel Lüthi
Nationality: Swiss
Location: Switzerland

Lamis Amer
Nationality: Egyptian
Location: United States of America

The proper management of human waste is a fundamental aspect of public health. Septic systems are vital for treating 24% of global domestic wastewater. Yet, rising sea levels threaten the functionality of septic systems. Identifying systems imperilled by rising waters is essential before public health problems arise.

Julian Hofmann
Nationality: German
Location: Germany

As global weather patterns become more extreme, flash floods pose an increasing threat, leading to devastating impacts on people, infrastructure, and the environment. Even when early warnings exist, prompt and effective response measures often falter due to gaps in emergency protocols and the limitations of current prediction tools at the disposal of local authorities, as was seen in the extreme July 2021 floods in Belgium and Germany.

Sources: EPA, EOS, IPCC, NOAA, The Economist, United Nations, USDA

Ports are the heartbeat of global trade, with about 80% of trade volume moving through them. Yet, they are often nestled in areas susceptible to natural hazards, such as rivers and coastlines, and such disruptions don't stay localized. They can spill over to other ports and economies, creating a domino effect termed 'systemic impacts.' Yet, academic and insurance catastrophe models often overlook the systemic risks inherent to ports.

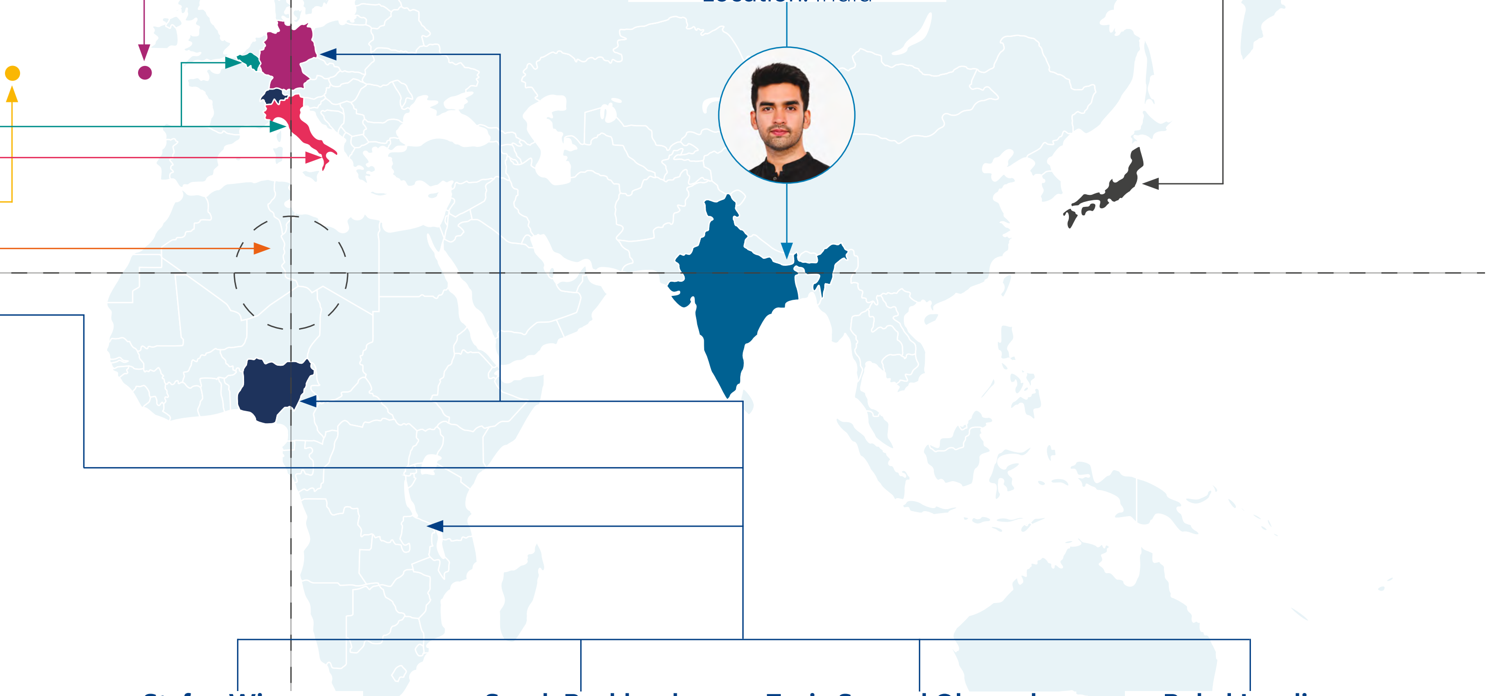
Jasper Verschuur
Nationality: Dutch
Location: United Kingdom

Mangroves are widely recognized as cost-effective alternatives for coastal protection. Countries, including China, India, Mexico and the United States, derive great economic benefits from mangroves, and they protect significant numbers of people. Yet mangrove wetlands are under assault because their value is unappreciated. It is time to flip the script for mangroves and increase their profile.

Tri Atmaja
Nationality: Indonesian
Location: Japan

Monsoons, prevalent across tropical continents, are not isolated storms but vast wind and rain patterns that span wider areas. Good rains boost agricultural output, spurring demand for consumer goods and benefiting businesses serving rural areas. Insufficient rainfall can lead to crop imports, increasing global prices and stoking local inflation. However, research warns that with continued global warming, the Indian monsoon may falter more often in the next two centuries.

Akash Singh Raghuvanshi
Nationality: Indian
Location: India



Stefan Wimmer
Nationality: German
Location: Switzerland

Sarah Buckland
Nationality: Jamaican
Location: Jamaica

Toyin Samuel Olowogbon
Nationality: Nigerian
Location: Nigeria

Rahel Laudien
Nationality: German
Location: Germany

Agriculture is key to global economies and critical for the livelihoods of many in the developing world. Yet it is deeply affected by weather and increasingly by climate change, leading to more frequent extreme weather events that disrupt production. Four researchers examine the impact on farmers in Germany, Jamaica, Nigeria and the sub-Sahara, respectively, and identify strategies to combat climate extremes.

Foreword

Introduction Compendium 2023

HOLGER TEWES-KAMPELMANN
(CEO Allianz SE Reinsurance)

Our Allianz Climate Risk Award has been supporting talented researchers who focus on reducing the risk of extreme weather events since 2017. It is important for us to bring together insurance and academia in the work we do here at Allianz Re, and the Award is one way for us to give back to the scientific community. It was also created to strengthen the dialogue with the scientists of tomorrow: We at Allianz know that collaboration is key in combatting climate change, and we must work together to secure the future for the next generations.

As an insurer, we work with the latest insights from climate science to continuously adjust our underwriting and modelling approach in response to a climate-related rise in loss frequency in the property market in particular. A warmer atmosphere will see more frequent and severe natural disasters and extreme weather events, which will also occur outside traditional high-exposure zones. To understand how these changes will shape the natural catastrophes of the future, we rely on the work of scientists like those we are celebrating with our Award. A future-focused insurance industry also needs to place a greater emphasis on fostering resilience. Building increased climate resilience will be a key element of a sustainable insurance market in future. Here, too, we need insights from science to succeed.

The Allianz Climate Risk Research Grant

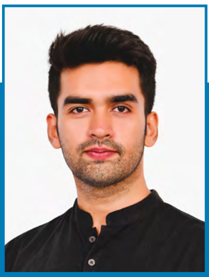
We created the Allianz Climate Risk Award to support science as well as to understand and and learn from current state-of-the-art research across academia. In some cases, the Award has led to collaborations with our in-house team of Cat specialists to translate science into business, and I hope we will see more collaborations like this in the future.

To complement the Allianz Climate Risk Award and to support research that is linked to the insurance business, we have now launched the Climate Risk Research Grant, a program tailored to support innovative research projects on topics aligned with the Allianz climate strategy. Based on a topic framework defined by our internal Nat Cat experts, research institutes and universities are invited to submit research proposals, with the research grant providing the funds to implement the project deemed most suitable and promising.

The topics of the 2023 Climate Risk Research Grant include the quantification of Climate Change attribution, measurement and production of peril correlations, and research in the field of adaption and the assessment of adaptation measures. We are very much looking forward to working together with scientists on these topics.

Climate change and its effect on natural perils is one of the main challenges we and future generations face. Our promise is to continue to strengthen the ties between the scientific community and the insurance industry to find better solutions to make our world more resilient.

Beneath the clouds: Predicting monsoon rains in a warming world



Author

Akash Singh Raghuvanshi

Institution

Indian Institute of Technology, Roorkee, India

Biography

Akash Singh Raghuvanshi, a doctoral student in the Department of Hydrology, examines the link between atmospheric moisture transport and extreme precipitation in the Indian subcontinent. He aims to understand how this transport affects the frequency and intensity of heavy rainfall. Akash's research can enhance predictions, inform mitigation strategies and clarify the effects of climate change on such events. Additionally, his work aligns with the National Monsoon Mission of the Ministry of Earth Sciences, India, which seeks to improve monsoon forecasting, understand its variability, and develop solutions for monsoon resilience and sustainable development.

Title of thesis

Atmospheric moisture's journey: India's extreme precipitation puzzle

Contact

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How atmospheric moisture dynamics is reshaping India's rainfall and its socio-economic impact.

On June 11, 2015, the skies over Mumbai, India's bustling metropolis, opened up. The city's infrastructure reeled from the deluge, with delayed trains and structural failures marking the day. Curiously, the *New Indian Express* saw a silver lining, noting, "Mumbai smiled as heavy showers lashed the city." Such is the paradox of the monsoons. Asia's billions keenly anticipate these annual torrents, though they often bring chaos in their wake.

Monsoons, prevalent across tropical continents, are not isolated storms but vast wind and rain patterns that span wider areas. Unlike the variable weather in Europe and North America, tropical climates experience consistent temperatures with seasonal alternation between arid winters and wet summers due to monsoons.

India, with its booming $2 trillion economy, holds the monsoon in special regard. An astonishing 70% of its annual rainfall comes from the monsoons, impacting the rural livelihood of over half its 1.3 billion population. Good rains boost agricultural output like rice and wheat, spurring demand for consumer goods and benefiting businesses serving rural areas. Insufficient rainfall can lead to crop imports, pushing up global prices and stoking local inflation.

Monsoons also replenish reservoirs and groundwater, essential for irrigation, hydropower and maintaining groundwater levels. However, research warns that with continued global warming, the Indian monsoon may falter more often in the next two centuries.

When the rains do come, they are likely to be more extreme. The 2023 monsoon was accompanied by record-breaking rains that battered northern India, resulting in landslides and floods that washed away houses, roads and farmland.

Charting the rain

With its fortunes so intertwined with the monsoons, India launched the National Monsoon Mission in 2012 to develop powerful monsoon rainfall forecasting techniques.

My work fits into this overall context by examining atmospheric moisture transport's role in extreme precipitation events in India. To understand the origin and variability of extreme precipitation events like monsoons, one must delve into the complex internal dynamics of the hydrological cycle.

This cycle involves stages where moisture circulates from the atmosphere to the earth and vice versa. The pivotal component is moisture transfer from oceans to continents, which serves as a vital link between oceanic evaporation and precipitation over the continents. Abnormal surges in atmospheric moisture can cause extreme rainfall and consequential floods. In India alone, floods have caused staggering losses of up to $3 billion annually in recent decades. Given the escalating frequency of such events, it's vital to understand the relationship between atmospheric moisture transport and extreme precipitation.

The 2021 Report of the United Nations Intergovernmental Panel on Climate Change projects a rise in such events due to global warming, particularly in Asia. The IPCC also has high confidence that intensified moisture transport will make wet seasons even wetter and increase heavy downpours associated with atmospheric rivers. Therefore, analyzing future circulation patterns in the Indian subcontinent under changing climate scenarios is essential.

Rivers in the sky

Atmospheric rivers and low-level jets are meteorological phenomena that transport atmospheric moisture on a planetary scale – nature's very own moisture superhighways. Even minor tweaks in their pathways, frequency and intensity have shown outsized socio-economic impact over a short period. My research dives deep into these undercurrents, seeking to understand:

1. How does atmospheric moisture transport influence extreme precipitation across past, current and projected climates in the Indian subcontinent?
2. How significantly do atmospheric rivers and low-level jets impact overall and extreme precipitation throughout the region over different climate periods?
3. What are the major sources and pathways of atmospheric moisture transport during extreme precipitation events?

The work aims to identify an effective atmospheric moisture transport metric to gauge precipitation variability in India's varied climatic regions. It will highlight regions, termed 'hotspots', where moisture transport frequently correlates with extreme precipitation. This will deepen our grasp of moisture transport mechanisms, including atmospheric rivers and low-level jets, and their ties to widespread precipitation. It will also shed light on the main moisture sources and their routes during extreme rainfall events.

A clear comprehension of the evolving synoptic features will assist in forecasting impending atmospheric moisture-related extreme precipitation, particularly in the Indian subcontinent. Moreover, as the climate warms, I anticipate recognizing new patterns of atmospheric moisture transport, possibly giving rise to distinct regional precipitation events.

This research will notably advance the goals of the National Monsoon Mission by enhancing forecasting accuracy. The subsequent insights could refine agricultural planning, water management, disaster readiness, and societal resilience. By addressing climate change implications and noting alterations in moisture dynamics, the outcomes will aid in devising robust adaptation measures.

Moreover, a broader stakeholder stands to benefit – the insurance sector. By decoding the rain's whims, insurers can sharpen their risk calculus. Early warning systems could emerge, transforming how insurers and their clientele navigate the monsoon's economic ebbs and flows.

The one-two punch of hurricanes: Storms, then deadly heat

Author

Dazhi Xi

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Biography

Dazhi Xi is an Associate Research Scholar with a PhD in Civil and Environmental Engineering from Princeton University and a B.S. in Atmospheric Sciences from Nanjing University, China. With 13 peer-reviewed publications in prestigious journals like *Nature Climate Change, Geophysical Research Letters and the Journal of Climate*, his research spans from fundamental atmospheric science theories to the engineering implications of extreme weather events. Dazhi is deeply invested in unraveling the physical mechanisms of extreme weather events and is dedicated to developing industry-accessible, physics-based models. These models aim to project future alterations in extreme weather, serving pivotal sectors like civil engineering and insurance. His current focus lies in devising systems to predict future tropical cyclone and heatwave compound hazards. As he forges connections with the insurance and reinsurance industries, Dazhi envisions a future where his expertise significantly shapes policies, helping pave the way for a climate-change-resilient society.

Title of thesis

Compound Hazard Related to Tropical Cyclones and Heatwaves

Contact

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Dissecting the deadly relationship between tropical cyclones and heatwaves.

Hurricane Ida, a fierce storm, rolled into New Orleans in early September 2021. It was the second-most damaging and intense hurricane to make landfall in Louisiana on record, behind Hurricane Katrina in 2005. Among the 30 storm-related deaths recorded in the US state, at least 14 were attributed not to the storm's ferocity, but the deadly heatwave that followed.

Extreme weather phenomena in 2021 were unparalleled to that time, with numerous records broken worldwide. Storms, heatwaves, droughts, and wildfires took a severe toll, and many of these catastrophic events were amplified by climate change. Scientists warn of more frequent and intense occurrences as global temperatures rise.

Among the consequences of climate chaos are incidents like Ida, where tropical cyclones and subsequent heatwaves strike the same location. With climate change and the urbanization of coastal areas, such compounded events may become more frequent, increasing the risks and necessitating a comprehensive understanding of their underlying physical mechanisms.

Simulating heatwave events

Tropical cyclones are hazardous weather systems that can severely disrupt infrastructure, including power systems, which are integral to modern living, especially in a warming world. When a heatwave follows a cyclone before power restoration, residents who might have weathered the storm are threatened by extreme temperatures, posing significant health risks and overwhelmed medical facilities.

My research delves into these combined hazards, examining their physical underpinnings and their potential evolution in the face of climate change. The challenge lies in understanding the intricate relationships between cyclones and heatwaves and effectively simulating these events in the context of climate change.

My research used historical data, high-resolution climate models, and statistical techniques to identify patterns in large-scale circulations that favor the joint occurrence of cyclones and heatwaves. The difficulties in projecting such events under a changing climate is due to our lack of understanding of the relationships between cyclones and heatwaves, and the difficulty of simulating a large sample of such hazard events under climate change.

Insights from a high-resolution Geophysical Fluid Dynamic Laboratory (GFDL) climate model revealed potential shifts in cyclone seasonality due to global warming. By evaluating the future changes in the large-scale environments simulated by the full-physics numerical model, my research diagnosed the leading reasons that favors the joint-occurrence of tropical cyclones and heatwaves. It also tackled the reasons for changes in tropical cyclone seasonality to support medium-range forecast/warning and seasonal predictions of such compounding events.

Additionally, my work has also developed a comprehensive system for projecting tropical cyclone hazards, leveraging innovative CMIP6 climate models and synthetic storm simulations. The modeling system can efficiently generate tens of thousands of physically plausible tropical cyclone hazard events under different conditions to support climate studies and hazard or risk assessment.

My research has evaluated future changes in tropical cyclone hazards such as rainfall, surge-rainfall joint risk and back-to-back tropical cyclone hazards. My research also projected future changes in cyclone climatology in the North Atlantic basin using the coupled model and identified the leading sources for projection uncertainties.

Looking ahead, I aim to deepen our knowledge of the interactions between cyclones and heatwaves at the mesoscale, refine projection models for these compounded events, and apply these findings practically. This involves leveraging numerical weather models, enhancing the current hazard projection system and collaborating with engineers and policymakers for real-world solutions. Ultimately, my research both advances scientific understanding and provides tangible societal benefits by helping mitigate the effects of climate chaos.

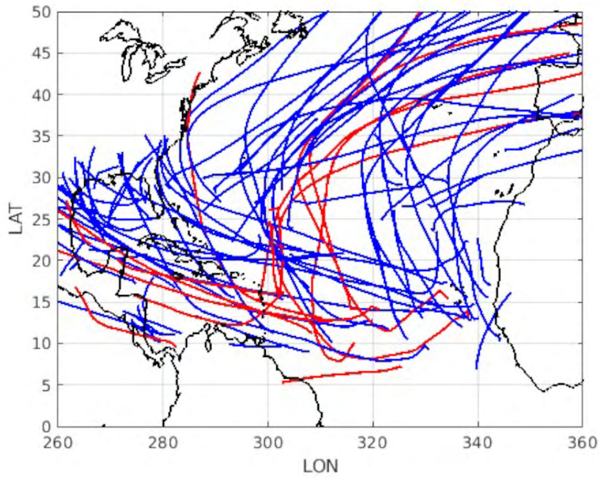

Figure 1: *Sample of the stochastically generated tropical cyclone tracks based on climate model outputs used for hazard assessment.*

Hidden costs of nature's fury:
The economic aftershocks of floods

Author

Elisa Nobile

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Biography

Elisa Nobile is a first-year student in the PhD program in Sustainable Development and Climate Change (SDC), with a focus on Socio-Economic Risk and Impacts. She holds an MSc in Civil Engineering for the Mitigation of Risk from Natural Hazards and hands-on experience in flood risk assessment for cultural heritage in both Portugal and Italy. Elisa's interest lies in quantifying indirect damage to cultural heritage, moving beyond the direct physical impacts. This led her to undertake a comprehensive literature review on indirect economic impacts, which she presented at the European Geosciences Union General Assembly 2023. Recognizing the profound implications of her research for the insurance sector, she aims to provide a holistic understanding of risks, accurately depict the intricate interconnections among exposed assets and enhance insurers' tools through advanced analysis methods. Furthermore, her research highlights systemic hotspots for potential cascading effects.

Title of thesis

Socio-economic risk analysis

Contact

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Traditional risk assessment methods fall short in capturing the cascading economic repercussions of floods, necessitating a systemic approach that integrates economics and engineering to fully understand both direct and indirect impacts.

In a world increasingly threatened by climate chaos, 2023 has already set a somber tone. The global economic losses due to natural disasters have soared to a staggering $194 billion in just the year's first half. Amidst this devastation, the Emilia-Romagna floods in Italy emerged as the third costliest, inflicting damages upwards of $9.7 billion.

Yet, these astounding numbers may only be scratching the surface. Such figures predominantly focus on tangible physical damage, leaving the more profound economic disruptions out of the frame (see Figure 1.). The magnitude and frequency of these extreme events is expected to increase due to climate change, urbanization and population growth, leading to growing economic and non-economic losses[1]. To grasp the issue's magnitude, we must also consider the vast indirect damages – often twice as damaging as direct losses.

Ricocheting disruption

The Emilia-Romagna floods of May 2023 are a stark reminder of nature's unpredictability. In cities like Bologna, Cesena, Forlì, Faenza, Ravenna, and Rimini, seven months' worth of rain deluged the region in a mere two weeks, causing 23 rivers to burst their banks. Some areas even recorded half their annual rainfall in just 36 hours. The catastrophic event claimed the lives of 17 individuals, displaced 50,000 residents, and resulted in damages estimated at over €10 billion (US$11 billion).

Altogether, the catastrophe impacted 130,000 businesses across affected municipalities. To put that into perspective, these businesses contributed a substantial 2.2% to Italy's GDP. The aftershocks from such disruptions ricochet across the nation, far beyond the flood-hit zones. These range from costs incurred for post-flood recovery to production losses in regions unscathed by the flood due to broken supply chains and disruption to crucial infrastructure.

1. *Bruno Merz et al.* "Causes, impacts and patterns of disastrous river floods", Nature Reviews Earth & Environment, 10 August 2021

These wider macroeconomic effects reflect the importance of integrating indirect impacts into the risk assessment framework, considering that indirect damage could be double the magnitude of direct damage.[2,3]

The challenge is to revolutionize how we perceive and assess these risks. Traditional methods, which involve tallying the risk of individual exposed elements, are no longer sufficient. Instead, a holistic, systemic risk approach is needed, delving into the intricate web of connections binding different system elements.

This calls for a marriage of two seemingly disparate fields: economics and engineering. Pioneers in the economics aspect, Henriet and Hallegatte have transformed national economies into interconnected networks. At the same time, engineering luminaries, such as Rinaldi and Menon, have addressed the ramifications of failures in critical infrastructures, the cascading impacts and systemic vulnerability.

Building on these foundations, this research seeks to adopt network theory to intricately model the direct and indirect economic impacts of floods, including those stemming from production and business interruption. The work owes a debt to Arosio's research, as he adopted the network theory measures to represent and model cascading effects due to floods.

Methodology

The methodology adopts a systemic and holistic approach, integrating network theory and multi-layer networks to thoroughly model the indirect economic consequences of flood events.

Chopra and Khanna suggest representing the economic structure as a network[4]. This involves using Input-Output (I-O) tables to craft an economic network that portrays the interdependencies and relations among various sectors in the economy.

To account for the comprehensive nature of the economy, the methodology extends network modeling to include supply chain considerations. This takes into account spatial factors and interrelations among different infrastructures.

Further integrating network theory measures enhances economic system modeling, surmounting the traditional Input-Output models' shortcomings. By employing centrality measures, clustering algorithms, community detection methods, and complex contagion analyses, the methodology captures network dynamics and interactions more effectively.

To ensure a thorough understanding of the impacts, the methodology quantifies indirect repercussions resulting from production disruptions and business interruptions. This is achieved by identifying and examining central and vulnerable nodes in the network. Relevant indicators from existing literature, such as the Risk Exposure Index, are utilized to evaluate the cascading effects and the propagation of economic shocks within the interconnected economic system.

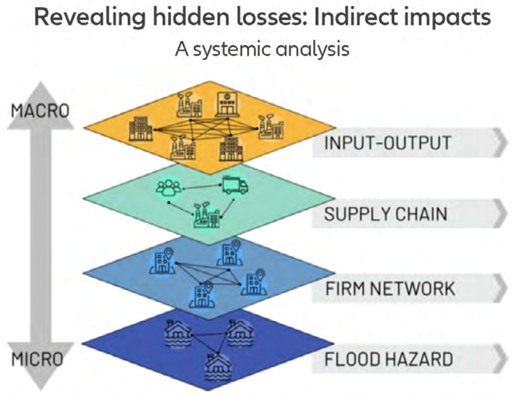
Pivotal cog in Italy's economy

Central to this study is the Emilia-Romagna region itself – a pivotal cog in Italy's economy. The data pools for the research are sourced from the Istituto Regionale Programmazione Economica della Toscana (IRPET) and geo-reference data on Italian plants from the database *Registro statistico delle imprese attive* provided by ISTAT. The insights gleaned from the recent flood will validate the methodologies employed.

The expected outcome of this research is to delineate the relationship between direct and indirect damages, and to offer insights into the time needed for intricate systems to bounce back after extreme events. A metric like 'time-to-recover' could be invaluable in assessing overall economic losses. By tying this to potential profit reductions for interconnected economies, a more nuanced damage assessment is expected.

The repercussions of this study are significant, especially for the insurance sector. From a holistic understanding of risks to an in-depth dissection of intricate interconnections between various assets, the insights gleaned could reshape how insurers evaluate risks and devise strategies. Notably, it could pinpoint systemic hotspots – zones where a delicate balance of centrality and potential cascading effects could precipitate profound economic consequences.

In a rapidly changing world, where the lines between nature's fury and its economic aftermath blur, such a study is not just timely but crucial.



1. ***Figure 1**. This is a graphical representation of the research framework, which highlights the multi-layer approach with different scales.*

2. *E. E. Koks, M. Bočkarjova, H. de Moel, J. C. J. H. Aerts*, "Integrated Direct and Indirect Flood Risk Modeling: Development and Sensitivity Analysis," Risk Analysis, 16 December 2014
3. *Dottori, Francesco et al*, "Increased human and economic losses from river flooding with anthropogenic warming," Nature Climate Change, 20 August 2018
4. *S. Chopra, V. Khanna*, "Interconnectedness and interdependencies of critical infrastructures in the US economy: Implications for resilience," Physica A: Statistical Mechanics and its Applications, 15 October 2015

Climate shocks to ports threaten global trade networks

Author

Jasper Verschuur

Institution

Environmental Change Institute, University of Oxford

Biography

Jasper Verschuur specializes in the intersection of environmental science and engineering. As a postdoc researcher, his focus is on identifying the systemic risks arising from climate-related disruptions to ports across the globe, both now and in the future. Recognizing the crucial role of ports in global economies and their vulnerability to climate extremes, Jasper delves into the cascading effects such disruptions can have on ports, countries and supply chains. His extensive research covers 1350 ports and virtually every country, integrating climate change projections and trade scenarios. He was honored with the 2022 EPSRC Doctoral Prize in the United Kingdom, providing him further support to apply his findings in real-world contexts. Collaborating with the IMF, Jasper is also co-developing PortWatch, a platform visualizing his research data for end-users to dissect and understand systemic risks.

Title of thesis

Global systemic risks from climate shocks at ports

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Ports are crucial to world trade and prosperity yet are particularly vulnerable to climate-induced disruptions. This research uncovers these climate-related systemic risks and emphasizes the need for comprehensive resilience strategies.

Ports are the heartbeat of global trade with about 80% of trade volume moving through them. Yet, they are often nestled in areas susceptible to natural hazards, such as rivers and coastlines. Past climatic catastrophes, from Hurricane Katrina in 2005 to the devastating floods near Durban in 2022, caused costly damages to infrastructures and lengthy closures of the ports.

Such disruptions don't stay localized. They can spill over to other ports and economies, creating a domino effect termed 'systemic impacts.' As an example, post-Hurricane Katrina saw staggering losses of agricultural exports, which caused global shortages and, consequently, elevated food prices. Similarly, recent upheavals at Ukrainian ports sent shock waves across the globe, affecting food supplies and price tags.

Yet, academic and insurance catastrophe models often overlook the systemic risks inherent to ports, focusing solely on quantifying the direct physical damages to infrastructure assets. The maritime transport system is vulnerable to these systemic risks and set up in such a way that about 50% of global trade traffic passes through around 50 major ports[1]. This concentration, coupled with the limited flexibility in the system as the largest size vessels can only go to a small number of ports due to their infrastructure constraints[2], raises the stakes significantly.

My research seeks to bridge the gap in our understanding about the climate-related systemic risks that ports constitute, including the network dependencies between ports and the wider economic impacts. This study provides a comprehensive perspective on how ports, nations and supply chains worldwide hinge on individual ports and how they are exposed to current and future climate risks.

1. *J. Verschuur, E. E. Koks & J. W. Hall*, "Ports' criticality in international trade and global supply-chains," Nature Communications, 27 July 2022
2. *J. Verschuur, E. E. Koks & J. W. Hall*, "Port disruptions due to natural disasters: Insights into port and logistics resilience," Transportation Research Part D: Transport and Environment, Volume 85, August 2020

By identifying these dependencies and potential climate disruptions, we gain crucial insights that could be harnessed to devise resilience strategies against these uncharted systemic risks.

How to quantify systemic risks

To unearth these risks, I employed a blend of global hazard models aligned with specific port asset geolocations. This necessitated creating a new global port infrastructure inventory, derived by classifying port assets from satellite imagery. With the aid of climate models predicting future hazard probabilities, tangible physical asset damages (see Figure 1., including the dominant hazard at each port) and resulting port downtimes for about 1350 ports were determined[3].

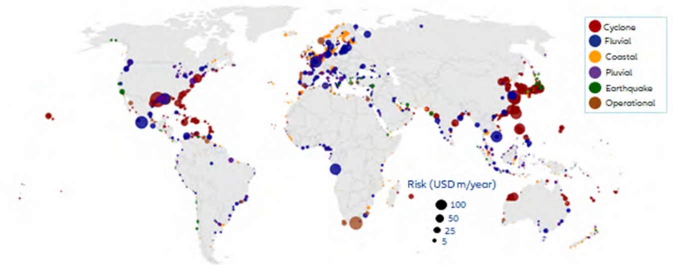

Figure 1. *Overview of the multi-hazard risk to physical assets in ports including the dominant risk driver. The bar plot shows the globally aggregated physical asset risk, including the spread by re-running the model 10,000 times with different input parameters.*

This foundation allowed a deeper dive into understanding dependencies across ports, countries and supply chains on these climate-sensitive ports. Integrating information on maritime transport connections (derived by analyzing two-years of ship movement data of some 100,000 vessels[4]), country trade dependencies on domestic and foreign ports, and supply-chain dependencies with current and projected climate risk data, critical links within these network were uncovered.

The result? A detailed map revealing the most vulnerable nodes within the “port portfolio” of a specific port, country or supply chain.

3. *Jasper Verschuur, Elco E. Koks, Sihan Li & Jim W. Hall*, “Multi-hazard risk to global port infrastructure and resulting trade and logistics losses,” Communications Earth & Environment, 12 January 2023
4. *J. Verschuur, E. E. Koks & J. W. Hall*, “Global economic impacts of COVID-19 lockdown measures stand out in high-frequency shipping data,” Plos One, 14 April 2021
5. *Jasper Verschuur, Elco E. Koks & Jim W. Hall*, “Systemic risks from climate-related disruptions at ports,” Nature Climate Change, 20 July 2023

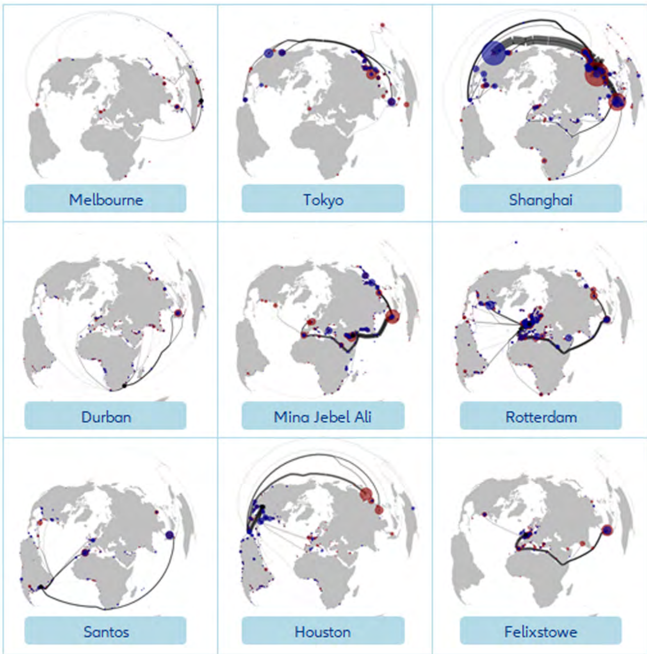

Figure 2. *Port trade networks of individual ports. The dots show the top 200 largest importing (blue) and exporting trade connections originating from/going to the port of interest. The lines show the amount of goods shipping on routes between these ports.*

Identifying critical links

On a global scale, the systemic risks to trade are pegged at US$81 billion annually, with over US$120 billion in economic activity[5]. Most ports, countries and supply chains are more exposed to climate-related risks from around the world, rather than locally. This makes managing these risks challenging and necessitates a collaborative approach that transcends borders.

Small island nations are particularly at risk, given their high reliance on maritime imports and vulnerability to climate extremities. For these economies, it is therefore critical to build resilience in the entire system, both at ports domestically as well as within their supply routes.

This research heralds a novel type of risk modelling framework that can capture climate systemic risks across borders and can be extended to specific commodities (such as food commodities) and non-climatic challenges like geopolitical disruptions.

The research underlines that adapting ports to future climate change is a global public good, as countries around the world may benefit. Second, a holistic view to build resilience is needed across scales, which should include strategies at the infrastructure level, within regional transport networks, and across firms. Finally, this invaluable intel equips stakeholders, from governments to insurers, to more effectively price in and navigate these systemic risks.

Predicting the floods: A shift from general alerts to street-level insights

Author

Julian Hofmann

Institution

RWTH Aachen University, Institute of Hydraulic Engineering and Water Resources Management

Biography

Julian is a postdoc researcher in flood forecasting and early warning systems and currently leads new research group for this scientific subject. He founded this specialized research group in 2023 and has directed over ten research projects. His collaborations include work with industry leaders like KISTERS AG and Hydrotec GmbH.

He showcased his expertise by co-founding FloodWaive, a startup aiming to revolutionize flood forecasting and risk analysis with innovative deep learning technologies. Under his leadership as CEO, FloodWaive, recognized by the EXIST Business Start-up Grant and part of RWTH Aachen's startup Incubator, aspires to be a front-runner in flood risk intelligence. Alongside his entrepreneurial endeavors, Julian is fervent about teaching and advancing research at RWTH Aachen University, specifically in flood risk management, early warning and AI-driven flood modeling.

Besides his professional interest, he is the head of the advisory board of the Flood Competence Center (HKC e.V), a non-profit association from Germany with more than 200 members. Furthermore, he holds the position as representative of the regional Group of Aachen, Association of Engineers for Water Management, Waste Management and Land Improvement (BWK).

Title of thesis

Intelligent and risk-based forecasting system for flash floods: Combining hydrodynamic modelling and deep learning

Contact

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Flash floods, intensified by changing global weather patterns, present significant challenges in timely response due to the limitations of current early warning systems (EWS). A new risk-based EWS combines hydrodynamic modeling with geoinformation systems, offering detailed flood forecasts and tackling real-time modeling computational challenges by the power of AI.

As global weather patterns become more extreme, flash floods pose an increasing threat, leading to devastating impacts on people, infrastructure, and the environment. Even when early warnings exist, prompt and effective response measures often falter due to gaps in emergency protocols and the limitations of prediction tools at the disposal of local authorities.

This was seen in the extreme July 2021 floods in Belgium and Germany. Even with prior warnings of heavy rainfall two days ahead, timely evacuations were not executed. Local authorities did not possess the expertise to understand the forecasts, and the failure to act contributed to the 184 deaths recorded by the extreme weather event.

Traditional early warning systems (EWS) for flash floods have significant limitations. They mainly rely on meteorological (amount of precipitation) or basic hydrological (water level) forecasts, neither offering insights into torrential rainfall's direct aftermath.

Extreme weather's likely consequences and damages can only be derived from spatial flood predictions (water extent, levels, and velocities). Yet, today's hydraulic flood models have computing times ranging from several hours to days. This makes them unsuitable for real-time prediction of flash flood events with the required output variables.

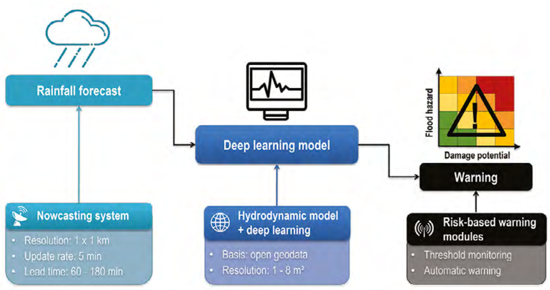

Figure 1: *Design and process flow of the risk-based early warning system for flash floods.*

Bridging the gap between weather forecasts and real-world impacts

Although radar-based rainfall forecasts coupled with topographical, building and infrastructure data play a critical role in flood impact predictions, most current systems primarily predict flood hazards without adequately addressing the vulnerability of urban infrastructures. The real challenge is not just about knowing where floods might occur but understanding their direct impact on structures, transport and the environment.

To fill this void, I developed a comprehensive risk-based EWS for flash floods as an integrated and holistic pluvial flood information system[1]. This system combines hydrodynamic modeling with geoinformation systems to offer detailed, street-level flood forecasts using openly available geodata and weather data. Moreover, this holistic system includes two modules that document past events and create standardized hazard and risk maps. However, the critical aspect of flood emergency management remains the speed at which these hydraulic flood processes can be simulated.

Tackling the computational challenge of real-time flood modeling

The forecast of two-dimensional flooding relies on physically based hydrodynamic modeling, but the complexity of the differential equations demands long computational times, even on the best equipment available today. To address this, I introduced a new multi-model concept, subdividing the HD model domain into several sub-catchment models to compute the local risk[2].

Finally, I programmed a control system to efficiently run these models concurrently and couple them with the rainfall forecasting systems. Although the parallel execution of HD models is a possible solution, the core problem lies within the long calculation time of HD models, which becomes highly relevant when running simulations for urban areas that require high spatial resolution.

Leveraging the power of deep learning

To overcome the computation time bottleneck of HD models, I developed the novel deep-learning model floodGAN[3]. While recent approaches have mainly used conventional fully connected neural networks, which were (a) restricted to spatially uniform precipitation events and (b) limited to a small amount of input data, the floodGAN model combines two adversarial Convolutional Neural Networks that are trained on synthetic data generated from rainfall generators and HD models.

FloodGAN translates the flood forecasting problem into an image-to-image translation task and, therefore, for the first time, enables translations of rainfall data into high-resolution hazard maps within seconds. Performance tests showed a speed-up factor of 10^6 while maintaining high fidelity and accuracy, as well as good generalization capabilities for highly variable rainfall events.

With this astounding speed-up factor of up to one million compared to classical HD flood models, the developed deep learning approach has the potential to revolutionize how we predict, plan for, and mitigate the consequences of floods in real time[4]. Its efficiency not only saves time but also allows for rapid responses to imminent flood risks, potentially saving countless lives and reducing flood losses as we prepare to deal with increasing and intensifying flood events under climate change[5].

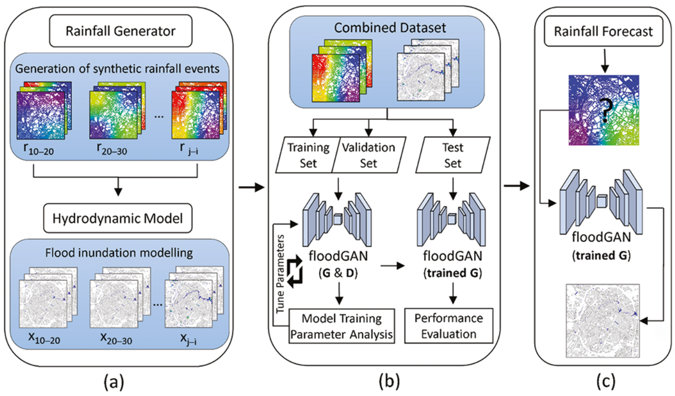

Figure 2: Framework of the deep learning model floodGAN: (a) The rainfall generator generates synthetic rainfall events and the hydrodynamic model simulates corresponding flood inundations. (b) The data pairs are used to train and test the floodGAN model. (c) The trained floodGAN model can be used for online prediction by coupling it with a rainfall forecasting systems.

1. *Hofmann, Julian; Schüttrumpf, Holger (2019)*, "Risk-Based Early Warning System for Pluvial Flash Floods: Approaches and Foundations," Geosciences 9 (3), S. 127.
2. *Hofmann, Julian; Schüttrumpf, Holger (2020)*, "Risk-Based and Hydrodynamic Pluvial Flood Forecasts in Real Time," Water 12 (7), S. 1895. DOI: 10.3390/
3. *Hofmann, Julian; Schüttrumpf, Holger (2021)*: FloodGAN: Using Deep Adversarial Learning to Predict Pluvial Flooding in Real Time. In: Water 13 (16), S. 2255. DOI: 10.3390/w13162255.
4. *Hofmann, Julian (2022)*: Intelligent and risk-based early warning system for pluvial floods: Developing a framework to forecast pluvial flooding in real time combining hydrodynamic modelling and deep learning. RWTH Aachen University.
5. *Burrichter, Benjamin; Hofmann, Julian; Da Koltermann Silva, Juliana; Niemann, Andre; Quirmbach, Markus (2023)*: A Spatiotemporal Deep Learning Approach for Urban Pluvial Flood Forecasting with Multi-Source Data. In: Water 15 (9), S. 1760. DOI: 10.3390/w15091760.

From vulnerability to viability: Rethinking septic systems amid rising seas

Author

Lamis Amer

Institution

University of Miami, Industrial and Systems Engineering Doctoral Program

Biography

Lamis Amer is an Operations Research scientist pursuing her PhD in Industrial and Systems Engineering at the University of Miami. Motivated by her passion for merging science with practical applications, Lamis specializes in enhancing infrastructure and societal resilience against climate risks. Her expertise spans optimization, machine learning-based decision modeling, Techno-Economic Analysis, data mining, and geospatial analysis. Lamis's commitment to interdisciplinary collaboration is evident in her active involvement with teams across the Civil & Environmental Engineering Department and across multiple US-based institutions under partial funding from the National Science Foundation (NSF). With a future focus on community-engaged research agenda, she aims to bridge scientific advancements with societal necessities seamlessly.

Title of thesis

Fostering resilience via diversification: On-site wastewater systems and rising seas

Contact

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Rising sea levels threaten the functionality of septic systems, vital for treating 24% of global domestic wastewater. A resilience index, validated on Miami-Dade County's septic systems, can guide focused adaptation strategies.

The proper management of human waste is a fundamental aspect of public health, as highlighted by the United Nations Sustainable Development Goal 6. With approximately 24% of global domestic wastewater handled by on-site sewage treatment and disposal systems, commonly known as septic systems, their significance as vital conduits for waste treatment is evident[1].

Septic systems process waste from individual properties, with wastewater undergoing initial treatment in a septic tank, subsequently moving to a drain field. This field releases the treated effluent into the earth through perforated pipes, where it undergoes final biological treatment while percolating through unsaturated soils before reaching groundwater.

However, the rising sea levels pose a significant threat to the systems' functionality. The successful treatment process depends on effluent traversing a specific depth of unsaturated soil, acting as a treatment barrier. Encroaching sea levels reduce this buffer, hindering effective waste management.

It is crucial first to estimate the number of systems requiring adaptations to formulate effective adaptation strategies. This evaluation must encompass their vulnerabilities and also their resilience. Measuring septic system resilience is vital as it helps determine their ability to resist failure and their capacity to adapt and recover from such impacts.

For instance, septic systems located in crucial areas, like well-field protection areas (areas surrounding a water well or wellfield, which supplies a public water supply system), hold heightened importance for public water resources and should be prioritized for adaptations. Furthermore, resilience includes the financial scope by determining if homeowners can manage repair expenses or need external support.

1. *UN-Habitat and WHO* "Progress on wastewater treatment—global status and acceleration needs for SDG indicator 6.3.1. Geneva: United Nations Human Settlements Programme and World Health Organization," 2021.

The septic resilience index

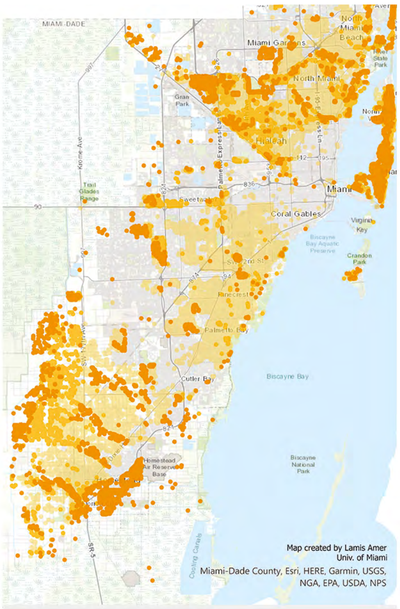

Figure 1. *Septic systems resilience levels in Miami-Dade County, FL*

To address these challenges, this research's first phase deploys spatial data analysis and probabilistic risk assessment to gauge septic system resilience against surface and inland flooding. It also quantifies the potential of impacts propagating to interconnected infrastructure systems[2]. When evaluating resilience, a range of factors, such as the vertical setback underneath the drain field, distance to watersheds, wellfield protection zones and median household income, must be considered.

The resulting resilience index, ranging between 0 (non-resilient) to 1, dictates that a 0.5 threshold is necessary for safe operation. When applied to Miami-Dade County's 110,000 septic systems, integrating resilience narrows the adaptation focus from 50% of highly vulnerable systems (considering only risk and exposure) to 29% of the systems exhibiting low resilience, as shown in Figure 1, thus enabling a more focused adaptation planning.

The developed index is compared to others constructed using statistical methods for composite generation, such as principal component analysis and statistical models for latent variables like path models. When juxtaposed with others formed using statistical methods, this index stands out in capturing underlying indicator relationships. Figure 2 shows how the proposed and existing resilience index methodologies map the 12 underlying resilience-critical indicators into the resultant composite resilience index.

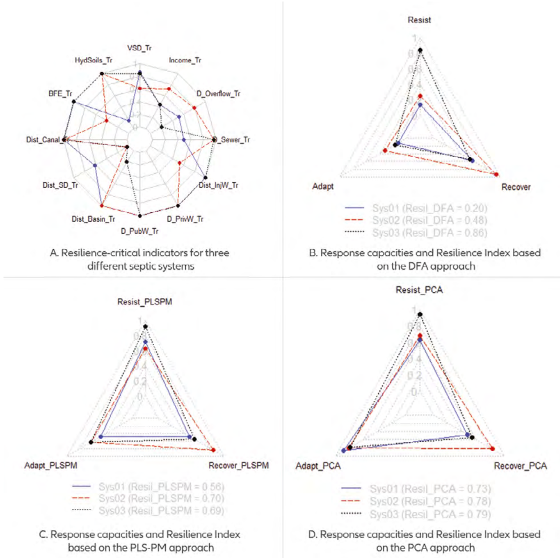

Figure 2. *Comparing the Proposed Resilience Index (a) DFA vs other statistically driven indices using (b) Path Model (PLS-PM) and (c) Principal Component Analysts (PCA), across three different systems*

Adapting low-resilience systems

After identifying septic systems with the lowest resilience, the research delves into adaptation solutions. The project answers: What innovative technologies can enhance system resilience? What are the technical constraints of each strategy? Is a cluster sewer system economically feasible and sustainable? What's the ideal degree of centralization/decentralization in wastewater management that balances costs and post-adaptation resilience?

Existing resilience levels are defined using the proposed method, and post-adaptation resilience is reassessed for different strategies. Founded on a techno-economic analysis, the decision-making model optimizes the diversified adaptation portfolio to ensure a minimum resilience threshold after adaptation. The model is validated using a case study in Key Biscayne City, Florida, housing 98 septic systems.

Optimal adaptation decisions include diversifying micro-sewer networks, connections to the existing sewer network, and on-site adaptations, boosting the average post-adaptation resilience from 0.45 to 0.81. The model also underscores the potential of cluster sewer systems – an environmentally friendly and cost-effective option for small communities.

A machine learning-based decomposition algorithm has also been developed to handle more extensive and intricate scenarios. Using real-world validation, this research is the first in the literature to quantitatively assess the resilience of septic systems and develop a resilience-focused decision-making model that addresses diversification in adaptation planning. It provides a practical framework for enhancing septic system resilience, serving as a template for addressing similar challenges in various settings.

2. Amer, L.; Erkoc, M.; Feagin, R.A.; Kameshwar, S.; Mach, K.J.; Mitsova, D. "Measuring Resilience to Sea-Level Rise for Critical Infrastructure Systems: Leveraging Leading Indicators," Journal of Marine Science & Engineering, Eng. 2023, 11, 1421

Beyond the drought: Innovations in yield forecasting for a resilient Sub-Saharan Africa

Author

Rahel Laudien

Institution

Potsdam Institute for Climate Impact Research (PIK)

Biography

Rahel Laudien is a crop modeler at the Potsdam Institute for Climate Impact Research (PIK) focusing on climate risk management in agriculture in the tropics. In her research, she uses statistical crop models and machine learning approaches for seasonal crop yield forecasting to support early warning systems on food insecurity in Sub-Saharan Africa. The region has the highest share of food-insecure people but is often neglected in scientific studies on yield forecasting due to low data availability. She leads the junior group 'Anticipation' in the working group 'Adaptation in Agricultural Systems'. Before joining PIK, she worked for a consultancy in climate adaptation services based in the Netherlands.

Title of thesis

Yield forecasting for early warnings on food insecurity in Sub-Saharan Africa

Contact

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Sub-Saharan Africa confronts significant food insecurity, exacerbated by climate change and extremes. Innovative crop yield forecasting, leveraging statistical methodologies and machine learning for data-scarce contexts, offers hope by enabling early interventions and promoting regional resilience.

Understanding potential agricultural yield losses beforehand can significantly benefit smallholder farmers. This foresight buys time for decision-makers to prepare and reduce the impacts of climate extremes on agriculture and societies. Yet, the task of predicting expected yields in Sub-Saharan Africa – a region that stands as one of the most food insecure globally – remains daunting.

Conflicts, economic downturns and climate risks converge to drive food insecurity and threaten people's lives and livelihoods. Particularly at risk are smallholder and subsistence-based farmers in Sub-Saharan Africa. Alarmingly, the region has the largest share of food-insecure individuals worldwide, with an estimated 26.6% of its populace facing severe food insecurity.

The vulnerability is exacerbated as farmers are largely dependent on rainfed agriculture. This means they are at the mercy of erratic weather patterns and climate extremes. The severity of this scenario is evident in Eastern Africa's recent drought, the most severe in four decades. The drought has directly affected about 50 million people and another 100 million in the wider area. About 20 million people were at risk of acute food insecurity and famine. Millions have left their homes in search of food, water and work.

One viable countermeasure to such threats is crop yield forecasts. Such predictions can bolster early warnings of food insecurity so that relevant institutions can take preventive actions before disaster occurs. They allow farmers to adapt their farming practices, governments to regulate food imports and exports, humanitarian actors to plan and mobilize resources and insurers to channel timely payouts for crop insurance.

While the Global North has well-established yield forecasting systems, providing them in data-scare regions like Sub-Saharan Africa remains challenging. The problem is that sufficient yield data to train crop models is lacking, which hampers robust forecasts. The gravity of this situation cannot be overstated, especially when early warnings on food insecurity are most needed.

Robust yield forecasts

In my research, I've successfully developed and tested a crop yield forecast in Sub-Saharan Africa that provides accurate and robust forecasts one to two months pre-harvest. The model is based on statistical approaches and leverages statistical methodologies coupled with machine learning and drawing upon climate data.

Specifically, climate data related to climate extremes, such as dry conditions, extremely high temperatures or exceptional wet conditions, are used in the model to represent unfavourable weather conditions that highly impact yields. Recognizing the data constraints prevalent in Sub-Saharan Africa, my model prioritizes robustness, ensuring reliable forecasts even with limited input data. The idea places special emphasis on deploying a completely independent validation, reflecting real-world operational practice.

The model successfully projected yields in Tanzania six weeks before the harvest on the sub-national scale. In another study on Burkina Faso, the forecast was coupled with data on harvest areas. This makes predicting potential food production or shortages possible, offering invaluable insights for policymakers.

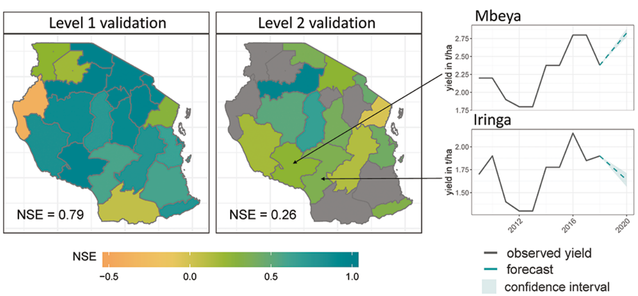

Figure 1: *Performance of a maize yield forecast on the sub-national scale in Tanzania based on the out-of-sample validation (left panel) and a validation based on independent variable selections (middle panel) measured in NSE (Nash-Sutcliffe efficiency coefficient, which ranges from 1 (perfect model) to -∞ (no skill)). The panels on the right show the forecast for Tanzania's main maize-producing regions.*

Can data-scarce areas learn from data-rich areas?

The results show it is possible to forecast yields in Sub-Saharan Africa. However, to increase their usability, we need forecasts for more countries – also for data-poor areas. Therefore, the current research focuses on building a crop model that can learn from data-abundant areas within Sub-Saharan Africa to provide yield forecasts for data-scarce areas.

This makes it possible to create an extended database and use more complex machine learning algorithms, which require more data. With many statistical institutions in Sub-Saharan Africa grappling with funding shortages, a cross-country modeling framework becomes indispensable, ensuring forecasts are achievable across the entire region.

A warning system can improve food security

Anticipating climate risks is better than dealing with their consequences. A sophisticated warning system can save people from losing their harvests, reduce food insecurity and prevent millions from falling into poverty.

For people to be able to take anticipatory actions, they need to have reliable and actionable information on expected weather conditions and the impacts of extreme climate events like droughts. Impact-based forecasts, like a yield forecast, can efficiently reduce agricultural risk and enhance insurance solutions to make the region more resilient to climate change.

The heat is on: The looming danger of heat-related mortality

Author

Samuel Lüthi

Institution

ETH Zürich, Group for Weather & Climate Risks

Biography

Samuel is a researcher who blends epidemiological modeling with contemporary climate science techniques to investigate the severity of heat mortality. His innovative approach hinges on using SMILE (single-model initial-condition large ensembles) climate data. By repeatedly running a climate model, Samuel unveils the nuanced internal variability of the climate system, paving the way to scrutinize extreme climatic years without the crutch of statistical extrapolation. He is currently completing a PhD at ETH Zurich in Switzerland. His research investigates the economic aftermath of wildfires, the intricacies of heat mortality risks in our current era and potential futures, and the conceivable paths and barriers to adapting to heat mortality. From 2017 to 2019, Samuel earned a Master of Science in Environmental Sciences specializing on Atmosphere and Climate Science. He was awarded the ETH Master Scholarship.

TITLE OF THESIS

The risk of heat mortality during extreme summer seasons and how it changes in a future climate

Contact

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Extreme heat is one of the deadliest climate extremes, posing a significant risk to health and wellbeing. To respond, we gauged the mortality impacts of possible extreme summer seasons in the present and the impending climate era. Our results show heat mortality of past extreme seasons could become all-too familiar in a world warmed by 2°C.

Consider the 2003 heatwave that sweltered Western Europe, with temperatures soaring as high as 47.5°C. This catastrophic event claimed roughly 70,000 lives due to heat strokes, dehydration and heart attacks. More recently, the 'heat dome' of 2021, spanning across the Pacific coastlines of the US and Canada, further stretched scientists' comprehension of the magnitude and feasibility of extreme heat events.

As such intense heatwaves will become more frequent, we teamed up with climate extreme specialists and epidemiologists to assess the possible impacts on human mortality. Our approach combined epidemiological models designed to calculate heat mortality with the latest approaches to estimating climate extremes[1].

Heat does not equal heat

Not all heats are perceived equally. Generally, communities are relatively well adapted to their local climate. Accordingly, the same temperatures can have a vastly different impact on human health in Bangkok or Paris.

For example, the optimum daily mean temperature of a location – a measure for the temperature at which statistically the least people die – differs substantially. In São Paulo, Brazil, the optimum daily mean temperature is 23°C, while in Paris, France, it is 21°C, and in Bangkok, Thailand, it stands at a balmy 30°C. Paris sees nearly double its mortality rate when the daily mean temperature hits 30°C compared to its optimal 21°C.

1. *Samuel Lüthi et al., "Rapid increase in the risk of heat-related mortality," Nature Communications, 23 August 2023*

To obtain an encompassing picture, we modelled the temperature-mortality dynamics for 748 locations spanning 47 countries for which daily mortality counts were available. The mortality dataset is collected and maintained by the Multi-Country Multi-City (MCC) Collaborative Research Network, an international network of environmental epidemiologists.

Modelling tail-risks

We combined these temperature-mortality links with climate data from five single-model initial-condition large ensembles (SMILE). The SMILE modeling method runs one single climate model multiple times with perturbed initial conditions but under the same climate scenario. This facilitates the exploration of naturally conceivable extreme years, sidestepping the limitations of statistical extrapolation embedded in conventional risk modeling techniques.

Consequently, we calculated heat-mortality impacts across epochs for four different climate periods representing global warming levels of 0.7 (the value in the year 2000), 1.2 (the value in 2020), 1.5 and 2°C.

Worsening the odds of heat-mortality

The findings emerging from our data are alarming. The heat-mortality levels of past extreme summer seasons must be expected more frequently. For context, the excess mortality in Paris in the summer of 2003 was around 2,700 lives – a once-in-a-century phenomenon in the 2000 climate. In the current climate, it is projected to occur every 18 years. This frequency could be every four years in a world with a 2°C increase in global warming and no adaptation.

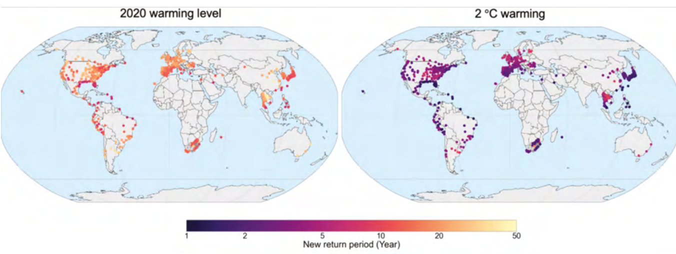

Figure 1: *New return period of a 1-in-100-year season in the climate of 2000 (0.7°C warming). Changes are displayed for the climate of 2020 (warming level of 1.2 °C, left) and at 2.0 °C warming (right). The Figure is adapted from Lüthi et al. (2023).*

Furthermore, potential heat mortalities could increase. In a 1.5°C world, Paris might witness double the mortality impacts, and a 2°C scenario could potentially triple them. Southern Europe emerges as a vulnerability hot spot, as it will endure the most rapidly surging temperatures and still has a growing aging population. With the elderly being one group most at risk from excessive heat, this scenario could be tragic.

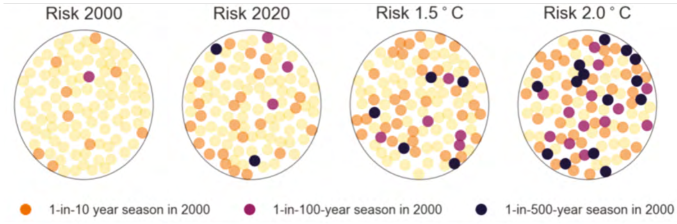

Figure 2: *Schematic display of internal variability of heat-related mortality for Paris (France). Each circle contains 100 points representing the climatic variability of the given warming level. The points denote the return period-based level of mortality in the climate of the year 2000 for a 1-in-10-year season (orange), a 1-in-100-year season (violet), a 1-in-500-year season (black) and more frequent seasons (adapted from Lüthi et al. (2023).*

Our study's findings highlight the urgent need to adapt to these coming climate extremes. We recommend decision makers, such as public health authorities, to consider such extreme scenarios. Adaptive measures such as a heat-health warning? system or urban greening can reduce future impacts. However, the world's current trajectory is set to heat up to a daunting 2.6°C, a value well beyond the 2°C world we modeled.

From crisis to innovation: Jamaica's journey to sustainable drought adaptation

Author

Sarah Buckland

Institution

University of the West Indies (UWI), Mona Campus

Biography

Sarah Buckland has a Doctorate of Philosophy in Geography from the University of the West Indies, Mona Campus. Her specialization in drought risk management research in agriculture highlights her commitment to addressing pressing environmental challenges. In recognition of her scholarly excellence, Sarah received the Editor's award for her reviews in the *Weather, Climate and Society Journal in 2022*. Her dedication extends beyond research; she has made invaluable contributions to the UWI Department of Geography.

One of her achievements is a proposal for a new farmer training curriculum for local Technical and Vocational Education and Training institutions, which gained significant interest from key stakeholders. Sarah's project experience includes collaborations with esteemed institutions worldwide, and her contributions have earned her numerous awards locally and internationally. She currently serves as a Lecturer at the University of the West Indies, shaping the minds of future geographers and researchers.

Title of thesis

Determinants of drought risk and adaptation among farmers in clarendon, Jamaica

Contact

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In the face of escalating drought threats, Jamaica's battle for food security takes center stage. Research from Clarendon Parish, a vital agricultural region, suggests key strategies that can combat devastating droughts and foster sustainable development.

Droughts pose a significant threat to human life and in particular, the food security of small island states like Jamaica. The 2014/15 drought, which affected all the Caribbean islands from Cuba to Tobago, cost Jamaica a billion dollars alone (Brown, 2014).

As the severity of droughts is projected to increase, it becomes crucial to identify key risk factors and effective adaptation strategies for sustainable development. This research focused on Clarendon Parish, one of Jamaica's vital agricultural regions, following the 2015 drought, with four main research objectives:

1. Characterize drought risks in different agroecological zones using the IPCC Climate Risk Index, assessing key risk factors related to selected impacts.
2. Explore the social, economic, and environmental factors influencing farmers' choice of drought adaptation methods.
3. Evaluate the effectiveness of drought adaptation strategies through vulnerability outcome metrics and farmer perceptions.
4. Investigate factors affecting farmers' awareness, access, and use of agro-climate services.

Researching resilience in Clarendon

The study combined drought analyses from 1992 to 2016 using the Standardized Precipitation Index (SPI-3) with surveys of 423 farmers in Clarendon's distinct agroclimatic zones of Thompson Town, Mocho and Milk River. A modified version of the IPCC Climate Risk Framework was used to explore objective one.

Logistic regression models examined the second to fourth objectives, considering approximately 20 social, economic and ecological variables. The study used the Tracking Adaptation Measuring Development Framework to assess the effectiveness of existing adaptation actions in reducing physical impacts.

Innovative approaches were employed to tailor drought risk assessment to local contexts, including incorporating perspectives of unregistered farmers. This was important not to create unintended risks by excluding perspectives in relevant planning outcomes. The study also revised the IPCC risk framework, expanding the examination of 'direct physical impacts' to encompass adverse social and economic consequences.

Reimagining risk assessment

The findings have significant implications for insurance and societal resilience:

- **Rethinking the '0 to 1' index approach to risk evaluation:** The study challenges the simplistic linear approach to risk evaluation and highlights the importance of considering asset-based exposure in risk assessment, especially regarding farm assets' role in risk management and wealth accumulation.
- **Gender and farm diversification:** Traditional proxies used in climate risk indices, such as gender and farm diversification, were found to be unreliable predictors of climate impacts in the Jamaican context. These challenge common assumptions in climate risk studies and suggest a need for a more nuanced approach.
- **The role of perceptions in adaptation:** Farmer powerlessness perceptions and awareness of climate variability were not always prerequisites for adaptive action. Farmers' perceptions of climate variability did not consistently translate into drought-adaptive actions. Farm insurance agents could highlight the co-benefits of adaptive actions so farmers may see the value of adaptation.

The study's practical impact includes the development of climate-smart agriculture manuals, publication in the State of the Caribbean Climate Report, a regional reference for adaptation. Further, the findings also formed the foundation for a new proposed farmer training curriculum for local Technical Vocational Education and Training institutions.

It has also garnered international recognition, including for the Best Graduate Student Paper by the Singapore Journal of Tropical Geography (2022) and being awarded High Commendation by UWI Mona.

Reference

Brown, D. (2014). Lessons from Jamaica's Billion-Dollar Drought. Inter Press Service News Agency. Retrieved 7/2/20.

How farmers adjust crop production and input use to extreme events

Author

Stefan Wimmer

Institution

Eidgenössische Technische Hochschule (ETH), Zürich

Biography

Stefan Wimmer is a postdoctoral researcher at the Agricultural Economics and Policy group at ETH Zurich. He earned his PhD from the Technical University of Munich in 2021. Stefan is deeply interested in the intersection of sustainable agriculture and agricultural risk management, emphasizing weather risks. From his expertise in agricultural production analysis, Stefan is delving into how weather risks influence agricultural production decisions. His research mainly aims to shed light on farmers' production choices in the wake of local weather trends and extreme meteorological events. Not content with just mapping immediate reactions, Stefan's work seeks to unravel the medium-term consequences of shifts in farmers' weather expectations.

Title of thesis

How do farmers adjust crop production and input use in response to extreme events?

Contact

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Climate change poses a major challenge for agriculture because of the increased frequency of extreme weather events. This research shows that extreme weather events affect agricultural production immediately and in subsequent years.

Using data from 1,638 German crop farms from 1996 to 2019, we find that a drought event reduces crop production and fertilizer use in the current year, with lasting adverse effects, particularly on protein crop production, in subsequent years. These insights reveal the resilience of different crops and can help design agricultural weather insurance solutions.

Agriculture is more dependent on the environment than any other sector. Rising average temperatures and changing precipitation patterns have significantly reshaped the growth conditions for crops and livestock. Human-induced climate change has led to severe losses in agricultural productivity globally.

Even in Europe, the increasing frequency of extreme weather events such as floods, droughts, heat waves or frost put agricultural production and food supply at risk. The ability of farms to adapt to these environmental changes is crucial for the resilience and future viability of the sector.

In this study, we analyze how farms respond to a changing climate and extreme weather events using the case study of German crop farms. The main goal is to quantify modifications in the production of individual crops and in the use of mineral fertilizer in response to changing weather expectations.

Our analysis focuses on how farmers decide on cultivating cereals, protein crops, oilseeds, root crops and on fertilizer use. Farmers can modify variable inputs, like fertilizers, as the growing season progresses based on weather conditions. Post-harvest, they can alter in their crop and input choices for the next growing season.
For our empirical analysis, we matched detailed farm-level accountancy data on German farms with granular weather data at the municipality level.

Changing climate affects farmers' planting decisions

Climate change has a significant influence on farmers' planting choices. As climate change unfolds, farmers alter their weather expectations for upcoming growing seasons. Figure 1 shows how changes in weather expectations affect growing decisions in our case study of German crop farmers. For example, a positive change in anticipated rainfall increases the likelihood of planting protein crops, while decreasing the likelihood of planting oilseeds. Conversely, planting decisions for cereals and root crops are barely affected by changes in weather expectations.

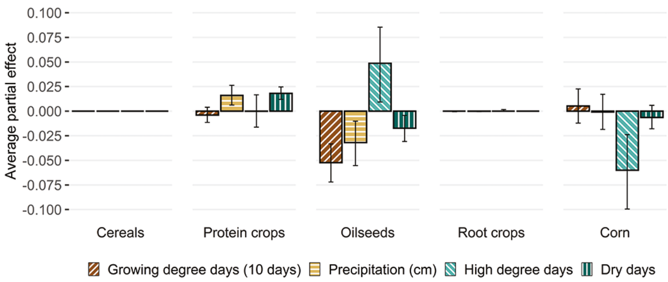

Figure 1. *Effects of weather expectations on crop choice with 95% confidence intervals.*

Extreme weather events have lasting effects

Extreme weather events have long-lasting effects on agricultural production decisions. To measure these effects, we simulate farmers' responses to a drought shock in the current year and in subsequent years.

As highlighted in Figure 2, corn production suffers most significantly from drought, recording a 20% drop. Fertilizer application declines by 26%, maintaining this reduced level for three years post-drought. While cereals production stages a quick recovery, protein crops, corn and oilseeds production remains low in the years following the drought. In contrast, root crops show an upward trend.

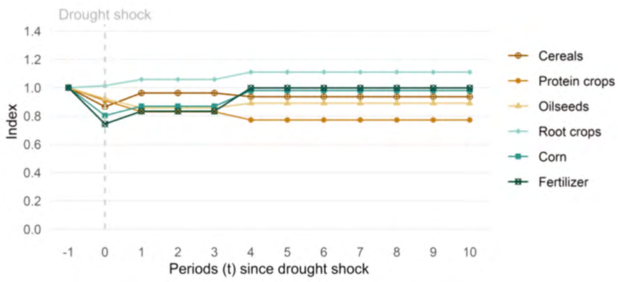

Figure 2. *Changes in crop supply and fertilizer use after a drought occurring in t=0.*

Promoting agricultural resilience for the future

The escalating frequency of extreme weather events caused by climate change poses a significant threat to agricultural production and the overall sustainability of the sector. There's an immediate need to increase farm resilience against environmental shocks to ensure their economic viability. Our findings indicate that farmers are already pivoting in response to the shifting climate and the increased frequency of extreme events by adjusting both their crop selections and input decisions.

Insurance solutions can support farmers to effectively manage the increased weather risk in agriculture by complementing these adaptation measures. The insights from our research can guide the creation of insurance solutions to manage the increased weather risk in agriculture effectively.

For example, our data suggests a pivot away from protein crop cultivation post-drought despite the EU's push to enhance such production. This implies a rising demand for insurance provisions tailored to protein crop yields. Furthermore, reduced fertilizer use after a drought indicates that farmers may expect lower yields after extreme events. Such insights can be essential in configuring insurance premium structures. Finally, by gauging the robustness of distinct crops to extreme weather, we offer important perspectives for policymakers and the broader agricultural sector to increase future agrarian resilience.

Our model can be extended to other extreme weather events, including heatwaves, floods, and frosts. Using climate projection models, the results can be used to forecast crop supply and fertilizer use under different climate change scenarios. Such research will reveal the impact of future climate change on agricultural production, going beyond pure yield effects and considering alterations in farmer behavior. Recognizing and understanding these behavioral nuances is critical in evaluating and reinforcing the resilience of the agricultural sector.

Climate-smart farmers: The SOFADRICLIMATE app hedges climate risk for smallholder farmers

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Biography

Toyin Olowogbon is an Agricultural Economist serving as a Research Fellow at the Institute of Food Security and Commercial Agriculture (IFSCA), Federal University Oye-Ekiti, Nigeria, and with the Centre for Sustainable Agricultural Empowerment (CSAE) Ilorin, Nigeria. Toyin has dedicated over 14 years to agricultural innovations, specializing in developing and testing digital interventions. His passion lies in harnessing development studies for evidence-based policymaking and advocacy. He employs experimental economics, particularly randomized evaluations, in his methodology for designing and analyzing impact evaluations.

At CSAE, his efforts are directed towards optimizing the agricultural value chain, focusing on crucial areas like employment creation, climate change resilience, food security and poverty alleviation. In his upcoming project, Olowogbon aims to shed light on the efficacy of bundled digital climate solutions on agricultural businesses and farming households.

Title of thesis

Climate-smart farmers: Will a bundled digital climate solution hedge climate risk for smallholder farmers?

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Climate change severely impacts smallholder farmers. Bundling climate information with insurance presents a promising strategy for shielding farmers against climate risks.

Climate change's challenges to agricultural productivity and food security are undeniable (***see Figure 1***). Among those hardest hit are smallholder farmers, who often lack the resources or adaptability to cope with fluctuating weather patterns. Combining climate information with weather index insurance has emerged as a promising strategy against climate risk's most adverse impacts. In particular, bundling climate data and weather index insurance could provide a critical climate risk hedge for smallholder farmers.

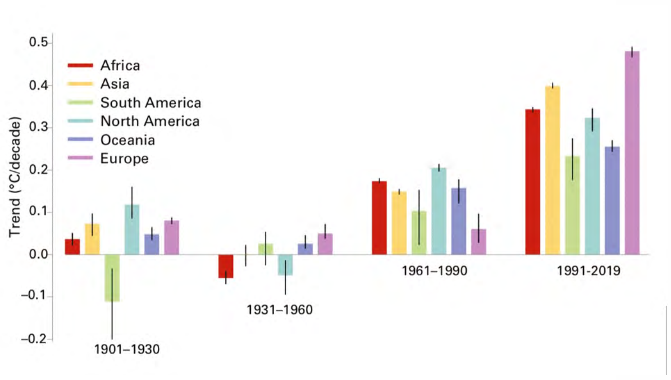

Figure 1: *Shows trends in mean surface temperature over the four sub-periods using HadCRUT4, NOAA Global Temp and GISTEMP data sets[1].*

As part of our study, the agricultural and climate specialists from the non-profit Centre for Sustainable Agricultural Empowerment collaborated with farmers to develop a digital app. **SOFADRICLIMATE** (www.sofadriclimate.com) is a data-rich platform offering farmers the reliable climate change information necessary for smart seasonal farm-level planning and decision-making. Maize farmers in twelve Nigerian states are already using the app.

1. ***Source:*** World Metrological Organization (WMO) (2020). The State of Climate in Africa-Multi-agency report highlights the current and future state of the climate in Africa. 26th October, 2020.

To further its capabilities, our partner insurance company, Royal Exchange General Insurance recently worked with us to integrate a weather-index crop insurance feature, offering users a comprehensive solution toolkit to hedge against related climate risks.

Climate information for efficient decision support

Efficient decision support from climate information gives smallholder farmers insights into upcoming weather patterns, and rainfall predictions. This crucial data, derived and adapted from the Nigerian Metrological Agency (NiMet), provides farmers with specific planting, irrigation and harvesting guidance.

With it, farmers can adjust their annual practices on what and when to plant in line with anticipated weather conditions, thus minimizing unexpected yield losses. For example, if a farmer receives information about an upcoming drought/cessation, they can opt for drought-resistant crop varieties or adjust planting schedules accordingly.

Weather index insurance

Weather index insurance compensates farmers when pre-established adverse weather conditions arise. Unlike traditional crop insurance, which evaluates actual crop loss, weather index insurance uses set weather indicators (such as rainfall levels, temperature thresholds or growing degree days) to trigger compensation. This innovative approach negates cumbersome claim processes and reduces administrative costs, making it ideal for remote smallholder farmers.

The logic of weather index insurance syncs with the climate information provided. Farmers can use this data to understand the weather index parameters better and decide on purchasing the insurance. If the defined adverse conditions occur, the insurance compensates the farmer, cushioning the economic blow of reduced yields or crop failures. This safety net allows farmers to recover more swiftly from losses and continue their agricultural activities without falling into a crippling cycle of debt.

The power of bundling

Integrating climate information and weather index insurance creates a relationship that enhances climate risk management for smallholder farmers. As the insurance design draws from real-time climate data, its compensatory triggers match the farmers' real threats. This alignment enhances the dependability of insurance products, appealing to a broader farmer audience.

Moreover, when climate information informs the design of weather index insurance products, the parameters used for triggering payouts are aligned with the actual risks faced by farmers in a region. This accuracy in defining risk levels increases the reliability and credibility of the insurance offerings, which promotes trust among farmers, attracting more farmers to participate.

In conclusion, integrating climate information and weather index insurance offers a promising solution for shielding smallholder farmers against climate risks. By providing farmers with timely and accurate climate data, informed decisions can be made to adapt to changing weather patterns. Weather index insurance complements this effort by offering financial protection against adverse weather events that could lead to crop losses.

As climate challenges intensify, championing these tools is essential for smallholder farmers' resilience and prosperity. However, it is imperative to address the challenges of access, fairness, and technical capacity to unlock this bundling approach's potential benefits fully.

Coastal communities turning to nature's defense: The role of mangroves in battling flooding

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Biography

Tri is a PhD candidate at the Department of Urban Engineering at the University of Tokyo. An advocate for environmental sustainability specializing in climate change adaptation, disaster risk reduction, nature-based solutions and urban resilience, Tri has over five years of professional experience on both national and international platforms and projects, including in Indonesia and Spain. His focus is on transforming policy-based science to cater to societal benefits. His research insights and recommendations are geared towards mitigating climate change impacts and bolstering sustainability and resilience. From September 2021 to September 2023, Tri served as an Administrative Officer at the Future Earth Urban Knowledge-Action Network (Urban KAN), contributing part-time for two years.

Title of thesis

Advancement of coastal flood evaluation system using GeoAI to promote Eco-DRR

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Mangroves are critical in combating intensified coastal flooding. A new GeoAI approach underscores mangroves' crucial role in ecosystem-based disaster risk reduction strategies and could transform risk assessment and elevate global coastal resilience efforts.

In Timbulsloko, a coastal community in Indonesia's Java Island, villagers battle frequent flooding so extreme that they have to transport soil and stones to elevate their homes and secure the graves of their deceased. The village in the northern Demak region is not alone.

Since 2008, flooding, attributed to coastal erosion, has intensified, affecting daily life throughout many of the 17,000 islands in the Indonesian archipelagos. Locals in Timbulsloko are attempting to re-establish the mangroves, which long shielded the village against flooding and erosion.

Mangroves are widely recognized as cost-effective alternatives for coastal protection. The roots are a dense tangle that acts like netting to trap sediment and arrest soil erosion. The roots also slow the movement of tidal waters and help minimize the wave and wind effects of flooding.

Many countries, including China, India, Mexico and the United States, derive great economic benefits from mangroves. In Bangladesh, India and Vietnam they also offer protection for significant numbers of people[1]. Yet mangrove wetlands are under assault. The area covered by mangroves have declined globally from 139,777 km^2 in 2000 to 131,931 km^2 in 2014, with even greater losses before 2000[2].

Mangroves are declining because their value is unappreciated. People cut them for firewood, convert the area to fish farms or agriculture or for coastal development. This leaves coastal communities more vulnerable to the force of tropical storms at a time when those storms are expected to become more frequent and severe.

Although climate-driven risks are examined extensively, limited attention has been given to the socioeconomic changes that can come with more severe coastal flooding, particularly in low-to-lower-middle-income countries. Integrating ecosystem-based disaster risk reduction solutions is a critical factor in reducing the impact of such events.

1. *Pelayo Menéndez et al.*, "The Global Flood Protection Benefits of Mangroves," Scientific Reports, 10 March 2020.
2. *Hamilton, S. E. & Casey, D.* Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). 729–738, (2016).
3. LLMICs refer to a group of countries where the GNI/capita < $4,095, based on the level of income. For further information, refer to the World Bank.

Advanced mangrove risk analysis

A novel Geospatial Artificial Intelligence (GeoAI), a fusion of geographic information systems with Artificial Intelligence (AI), could advance our understanding of the risks of removing mangroves while underscoring their importance in ecosystem-based disaster risk reduction (Eco-DRR) strategies. By focusing on geographic features, this approach offers a deeper and more resilient understanding of the situation.

This approach extends beyond risk assessment. It introduces a practical methodology by which insights from the GeoAI technique and the role of mangroves can be seamlessly integrated into risk-financing strategies. This aids in steering decision-making processes that fortify coastal resilience. A specially designed interactive dashboard supports these initiatives, accentuating robust risk assessment to highlight coastal flood risk hotspots and encourage the introduction of mangroves through nature-based investments to reduce income loss and property damage.

Highlighting vulnerable regions

This study identified the risks across low-elevation coastal zones (LECZ) with elevations less than 10 meters in low-to-lower-middle-income countries (LLMICs)[3]. The study examined 14 of the 82 LLMICs focusing on those with coastal areas and mangroves and considered various settlement types (Type 1: Large city, Type 10: Hinterland) based on population, proximity to city centers and socioeconomic changes.

From 2000 to 2018, 14 of the 82 LLMIC countries, spanning over 105,535 km^2, experienced coastal floods. Surprisingly, urban regions, which comprise less than 6% of the catchment areas, are home to 51% of assets and 38% of the population, revealing a significant risk of coastal floods.

Rural areas and large cities have the largest populations (48% and 29%, respectively). The population exposed to coastal floods is expected to increase by an average of up to 5% in the large cities from 2018 to 2100. Altogether, up to 300.42 million people live in exposed coastal regions, approximately equal to $1,025,187 million income loss. The estimated property damage amounted to $42,383 million, inundating 10,312 km^2 settlements, in the region prone to ≤ 10 m flooding, with only half of that in the region prone to <5 m flooding.

Emphasizing the role of mangroves in coastal flood risk assessment

The study's innovative approach using GeoAI combined with the random forest (RF) model integrates seven features emphasizing geographic variables in simulations. This model was applied to forecast coastal flooding in El Salvador using various simulations and scenarios (***see Figure 1.***).

For example, the model reveals that in the years 2050 and 2100 that the likelihood of coastal flooding varies depending on different climate and socioeconomic scenarios. One aspect to highlight is that when we combine a high-emissions climate scenario (RCP 8.5) with a future where population and development patterns continue to be intensive (SSP5), the severity of coastal flooding more than doubles compared to other scenarios. This means there's a much higher risk of coastal areas experiencing severe flooding in the future if we follow this path.

The model evaluation confirmed the superiority of the GeoAI approach, with the RF model outperforming others in predicting coastal flood risks. Each feature's contribution varied, but notably, the proximity of mangroves had the highest significance, emphasizing the role mangroves play in coastal flood predictions.

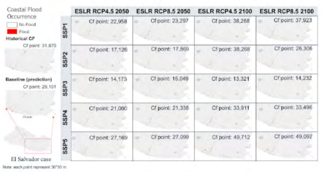

Figure 1. *Coastal flood prediction with different scenarios based on the RF model in El Salvador as a case study.*

An evaluation verified the reliability of the GeoAI approach (Figure 2), with the RF model surpassing other approaches, achieving a recall of 0.67 and a precision of 0.86. The RF model demonstrated the highest performance and robustness in predicting coastal flood risk and impact compared to kNN, ANN models and the Intergovernmental Panel on Climate Change (IPCC) risk approach in adeptly handling imbalance and scaling issues.

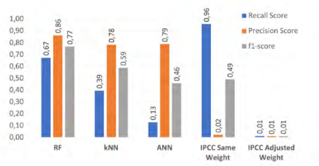

Figure 2. *Model evaluation performance.*

Each feature behaves differently based on its relevance in the simulation. Given anticipated future changes, the proximity of mangroves was determined to be of utmost significance (0.34), suggesting that alterations in mangrove presence substantially influence predictions of coastal flood occurrences (***Figure 3 left***). The continuous presence of mangroves along the coastline has been shown to reduce instances of coastal flooding (***Figure 3 right***).

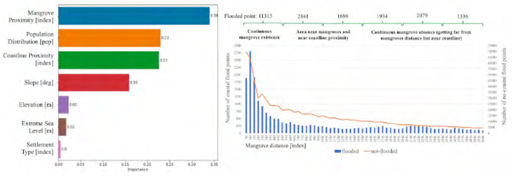

Figure 3. *Feature importance (left) and coastal flood occurrences along mangrove distances (right)*

Interactive dashboard for coastal hazard resilience

A prototype dashboard integrating GeoAI outcomes (***Figure 4.***) has been developed. This platform, which incorporates climate and socioeconomic change considerations, enables users to dynamically explore the potential impacts of flooding on priority areas, affected populations and settlements while highlighting the role mangroves can play as a resilience countermeasure. Furthermore, enhancing the dashboard with innovative technologies like GPT-4.0 and Chatbot will push the boundaries of traditional user interfaces, empowering users to make informed decisions.

This pioneering research has the potential to transcend conventional risk assessment. It could redefine investment practices, bolster societal resilience and propel proactive climate adaptation efforts in the most vulnerable coastal regions, thereby strengthening coastal resilience.

Figure 4. Dashboard prototype

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