Guidelines

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School-level climate risk analysis methodology



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IIEP-2026/RP/5 Rev.

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Please cite this publication as: Ortiz, D., Pérez-Núñez, G., & Poullain, M. (2026). *School-level climate risk analysis methodology*. Paris: UNESCO International Institute for Educational Planning (UNESCO-IIEP).

Acknowledgments

This project was supported by the UNESCO-IIEP Innovation Fund 2024–2025, an initiative promoted by Director Martín Benavides. The authors thank Dr. Carolina Albán for her support during the project's initial phase; Mariel Bedoya for her technical insights; and Dr. Pablo Heresi for his thorough review and constructive recommendations, which significantly strengthened the methodology. We also thank IIEP colleagues, particularly those working on climate-sensitive planning, for their interest and comments, as well as those involved in the design and editorial preparation of the document for their valuable support. Finally, we thank the Ministry of Education of Madagascar for generously sharing data and authorizing the application of the methodology, which enabled a rigorous and contextually grounded analysis.

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Contents

1. Climate risk in education 5

2. Measuring risk in education 7

Stage 1: Estimate the hazard index 8

How is the hazard index calculated? 8

Tropical cyclone hazard index in Madagascar 9

Stage 2: Estimate the exposure index 9

How is the exposure index calculated? 9

Tropical cyclone exposure index in Madagascar 10

Stage 3: Estimate the vulnerability index 10

How is the vulnerability index calculated? 11

Tropical cyclone vulnerability index in Madagascar 12

Stage 4: Estimate the risk index 13

How is the risk index calculated? 13

Tropical cyclone risk index in Madagascar 13

Stage 5: Interpret exposure, vulnerability, and risk for decision-making 15

Using the tropical cyclone risk index in Madagascar for policy planning 16

3. From risk measurement to better education planning 18

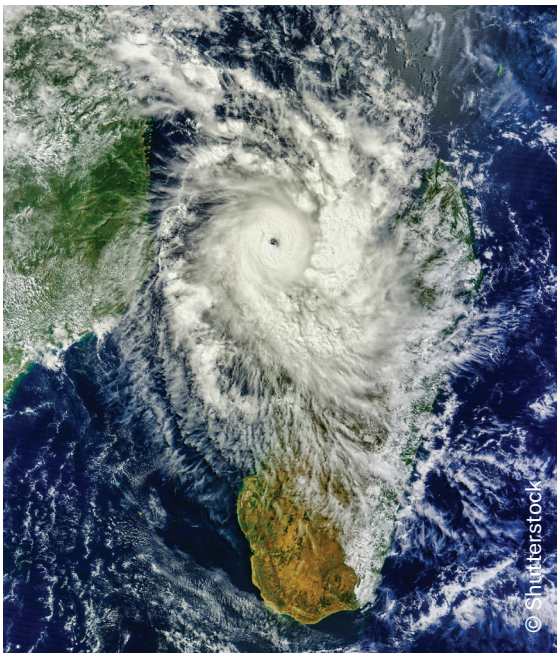
From school-level risk analysis to public policy action in Madagascar 19

References 20

1. Climate Risk in Education

Climate change is increasingly disrupting education systems worldwide. Between January 2022 and June 2024, an estimated 404 million students experienced school closures due to extreme weather events, resulting in an average loss of 28 instructional days per country (World Bank, 2025). In the absence of adaptation measures, governments are often forced into reactive and costly emergency responses with little time to prepare. Building resilience in the education sector is therefore no longer optional; it is a planning imperative (World Bank, 2024, 2025).

Yet the tools available to support risk-informed education planning remain limited. Existing indices mostly operate at the national or regional level (UNICEF, 2021, 2024; Chen et al., 2024; INFORM, 2024). UNESCO-IIEP has also contributed to this growing body of work through the development of hazard exposure indices and mapping tools tailored to education planning (Gagnon et al., 2024). However, school-level applications have so far focused only on hazard exposure in specific country contexts (Fabinc, 2024). No scalable methodology currently incorporates measures of vulnerability or of education systems' preparedness and recovery capacity in the face of climate hazards and, consequently, allows risk to be estimated as the result of the interaction between exposure and vulnerability at the level of individual schools. This work presents such a methodology for the first time: a replicable, multi-hazard framework for estimating climate-related risk for every school in a country.



Illustrative satellite image of Tropical Cyclone Hellen (16S) over Madagascar, the application country and one of the climate hazards analyzed in the methodology.

The methodology is grounded in the risk framework of the Intergovernmental Panel on Climate Change (IPCC, 2021), which defines risk as the interaction of three components: hazard, exposure, and vulnerability. When this framework is applied to the education sector, risk is not determined by any single factor in isolation. Rather, it emerges from the interaction between the physical manifestations of climate change, the degree to which schools and education communities are exposed to hazards, and the school-specific physical, social, and institutional conditions that make them more or less susceptible to damage and disruption. The three components are defined as follows:

- **Hazard:** Climate- or weather-related physical events and processes with the potential to cause harm to people, infrastructure, or ecosystems. These include *rapid-onset* events such as floods, heatwaves, and tropical cyclones, as well as *slow-onset* processes such as droughts and sea-level rise. Assessing the frequency and intensity of these hazards helps identify areas where schools, students, and education personnel are more likely to be affected.

Figure 1: Selected climate hazards assessed by the methodology

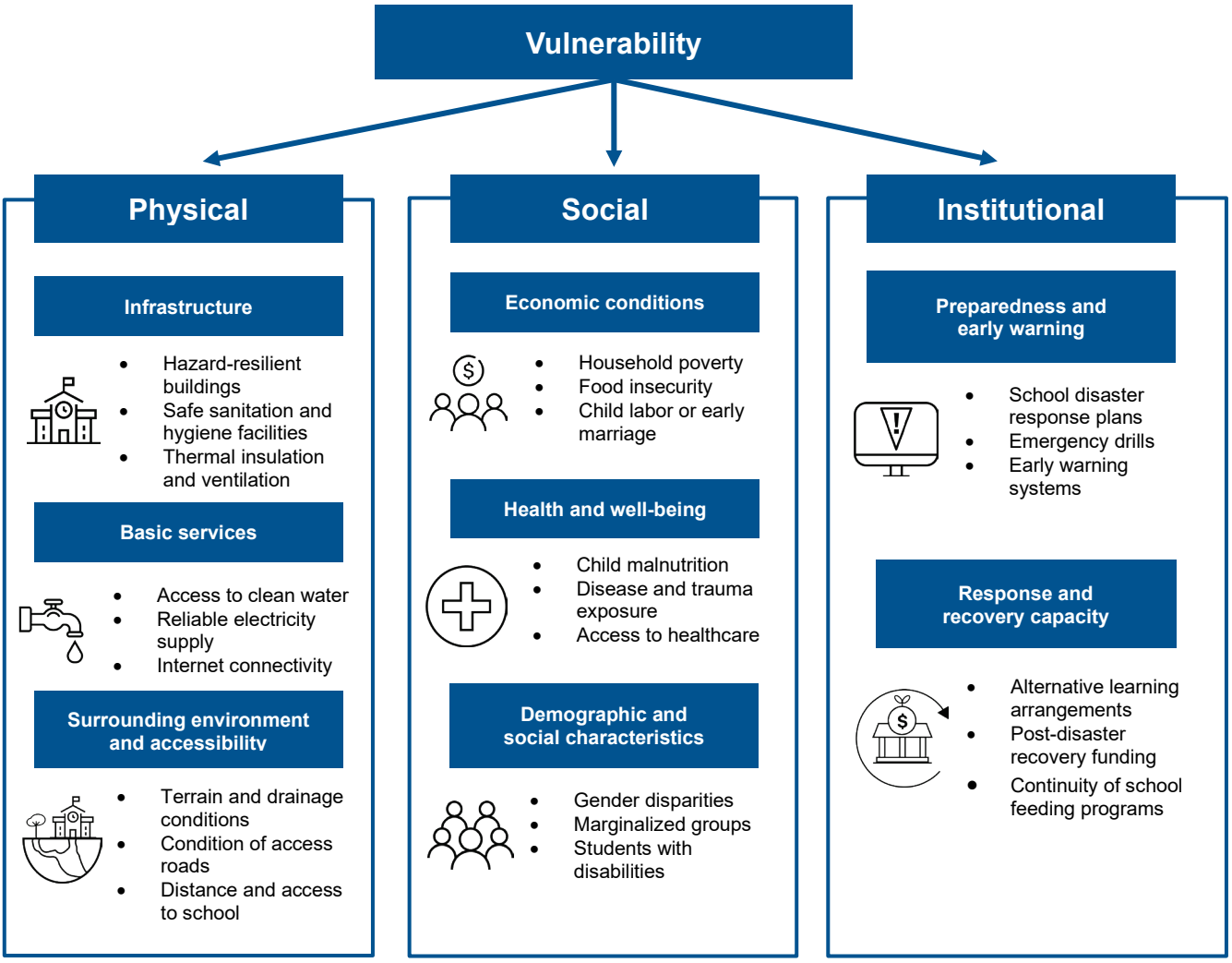
Hazard	What it is	Main data source(s)	Data type	What the hazard index measures
Tropical Cyclone	Rapidly rotating storm that forms over tropical oceans and varies in speed, size, and intensity	IBTrACS storm records	Multi-source observational data	Probability that at least one tropical cyclone occurs in a given location within a three-year period
Flood	Temporary inundation of land that is normally dry	VIIRS / ABI / AHI flood observations	Satellite	Probability that at least one partial or total flooding event occurs in a school year
Drought	Prolonged period of unusually dry conditions that disrupt water availability	SPEI / CRU TS climate data	Climate data	Probability that at least one month of severe drough or worse occurs during a school year
Heatwave	Period of unusually hot weather lasting several days or more relative to local climate conditions	HI / CHIRTS-ERA5 heat data	Reanalysis-based climate data	Probability that at least one heatwave occurs during a school year

Note: These are the climate hazards analyzed in this application of the methodology. Exposure was estimated for all four hazards, while vulnerability and risk were quantified only for tropical cyclones. This conceptual framework can be extended both to other climate hazards and to environmental hazards of a different nature, including geophysical hazards.

- **Exposure**: The presence of people, assets, and systems in locations that could be adversely affected by climate hazards. In the education sector, exposure includes students, teachers, staff, and school infrastructure located in hazard-prone areas. Quantifying exposure helps determine which schools and how many learners may be affected by specific hazards. In this methodology, exposure is measured using the geographic location of schools.

- **Vulnerability**: The degree to which schools and education systems are likely to experience harm when exposed to a hazard, as well as their capacity to anticipate, cope with, and recover from its impacts. In this methodology, vulnerability in the education sector is examined across three complementary dimensions: **physical**, **social** and **institutional** (see Figure 2).

Figure 2: Dimensions of vulnerability and illustrative features



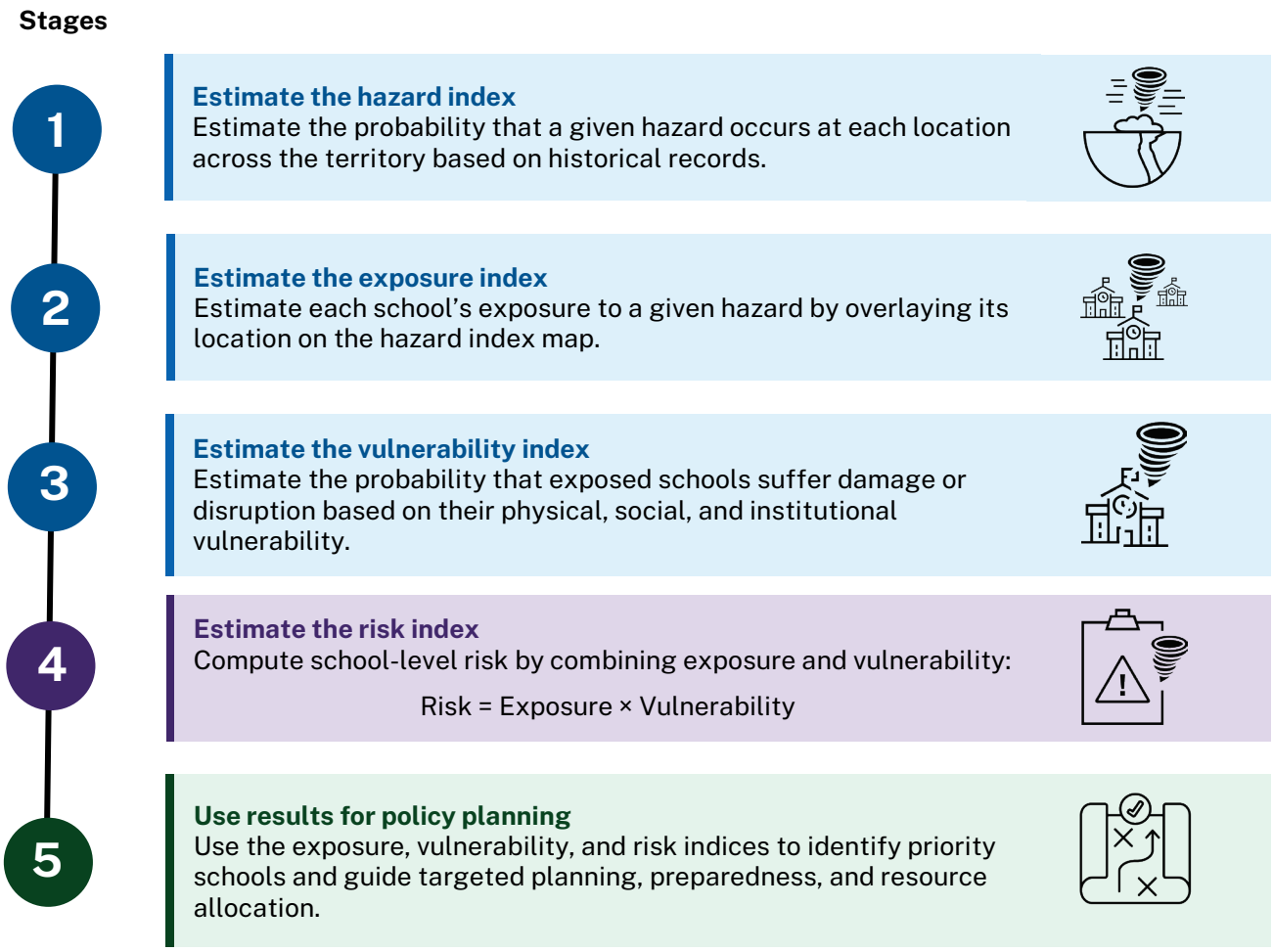
Note: The features presented are illustrative and not exhaustive.

2. Measuring risk in education

Despite the urgency of the challenge, no standardized methodology currently exists for assessing climate risk at the school level. Existing frameworks tend to operate at national or subnational scales, leaving educational authorities without the granular, institution-level evidence needed to prioritize investments and interventions. This work presents a methodology designed to fill that gap: a flexible, multi-hazard approach that can be applied to a wide range of climate hazards, as well as other environmental hazards affecting education systems worldwide.

Although the framework is designed to be applicable to any meteorological or climate-related hazard in any region of the world, this note illustrates its implementation through the case of **tropical cyclones** in **Madagascar**, given their severe and well-documented impacts on school infrastructure, attendance, and learning continuity.

Figure 3: General methodological framework for school-level risk analysis



Note: The methodology is organized into five stages that support risk-informed policy planning.

Stage 1: Estimate the hazard index

Hazards do not occur in exactly the same locations every time, but they often follow recurring geographic patterns. By analyzing where and how often hazards have occurred in the past, it is possible to estimate the areas where they are more likely to occur again in the future. For each hazard, this historical information is translated into a single comparable metric: the hazard index.

How is the hazard index calculated?

Historical records for each hazard are first compiled and processed to identify the locations where they have occurred most frequently over time. This historical frequency is then converted into a probability: the probability that at least one extreme event of a given hazard occurs at a location within a defined time period. This probability constitutes the hazard index, where higher values indicate a greater probability of occurrence. The same logic is applied independently to each hazard. In this work, the hazard index has been developed for four hazards: tropical cyclones, floods, droughts, and heatwaves (see Figure 1).

Tropical cyclone hazard index in Madagascar

The tropical cyclone hazard index is built from historical cyclone records and follows the same logic regardless of country. The starting point is a sufficiently long historical record of tropical storms and cyclones; in this case, all events recorded between 2000 and 2025 in the IBTrACS database, including each storm's trajectory and wind field. For each event, the areas exposed to wind speeds of 34, 50, and 64 knots are mapped, converting each cyclone track into a spatial footprint of the extent of its winds. These footprints are then accumulated across all recorded events to estimate how often each location has been reached by cyclone-force winds.

This historical frequency is then converted into a probability: **the probability that at least one tropical cyclone occurs at a given location within a three-year period**. A three-year reference period is used because tropical cyclones are relatively infrequent hazards, and their average return period is better captured through a multi-year probability window. The result is the tropical cyclone hazard index, which ranges from 0 to 1, with higher values indicating a greater probability of occurrence.

Applied to Madagascar, the index reveals a clear geographic pattern: eastern coastal regions consistently show the highest levels of tropical cyclone hazard, while the interior of the island shows substantially lower levels (Figure 6, Panel A).

Although the hazard index identifies the locations with the highest probability of occurrence of a given hazard, it does not indicate whether schools are located in those areas. The next stage therefore estimates the degree to which the education system is exposed.

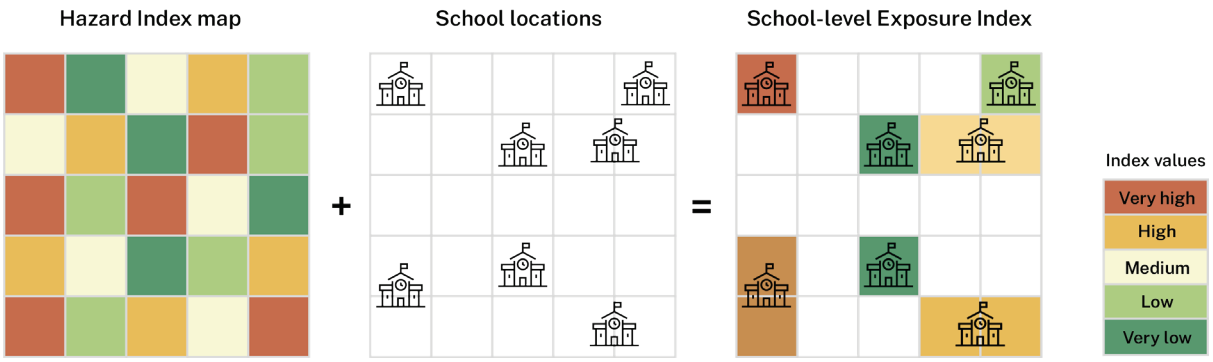
Stage 2: Estimate the exposure index

The second stage estimates each school's level of exposure to a given hazard. While the previous stage estimated where the hazard is likely to occur, this stage determines each school's level of exposure based on its location.

How is the exposure index calculated?

The exposure index is obtained by overlaying the geographic coordinates of schools onto the hazard index map created in the previous stage. Each school is assigned the value of the hazard index at its location. In other words, every school receives one exposure index value for each hazard analyzed.

Figure 4: Estimating the school-level exposure index



Note: The exposure index is estimated by overlaying school locations with the hazard index map and assigning each school the hazard index value of the location where it is situated. As a result, each school receives an exposure value that reflects the probability that the hazard occurs at its location.

The key difference between the Hazard Index and the Exposure Index lies in their unit of analysis. The Hazard Index measures the likelihood of hazard occurrence across the full geographic area under study, while the exposure index expresses that same likelihood specifically at the locations where schools are situated.

Tropical cyclone exposure index in Madagascar

The tropical cyclone exposure index for Madagascar (Figure 6, Panel B) is estimated by overlaying the tropical cyclone hazard index map (Figure 6, Panel A) with the most up-to-date school locations provided by Madagascar's Ministry of Education.

In practice, each school is assigned the hazard value of the location where it is situated. The tropical cyclone exposure index therefore measures the probability that at least one cyclone event occurs at the location of a given school within a three-year period. The results indicate that the schools most exposed to tropical cyclones are concentrated in Madagascar's eastern coastal regions.

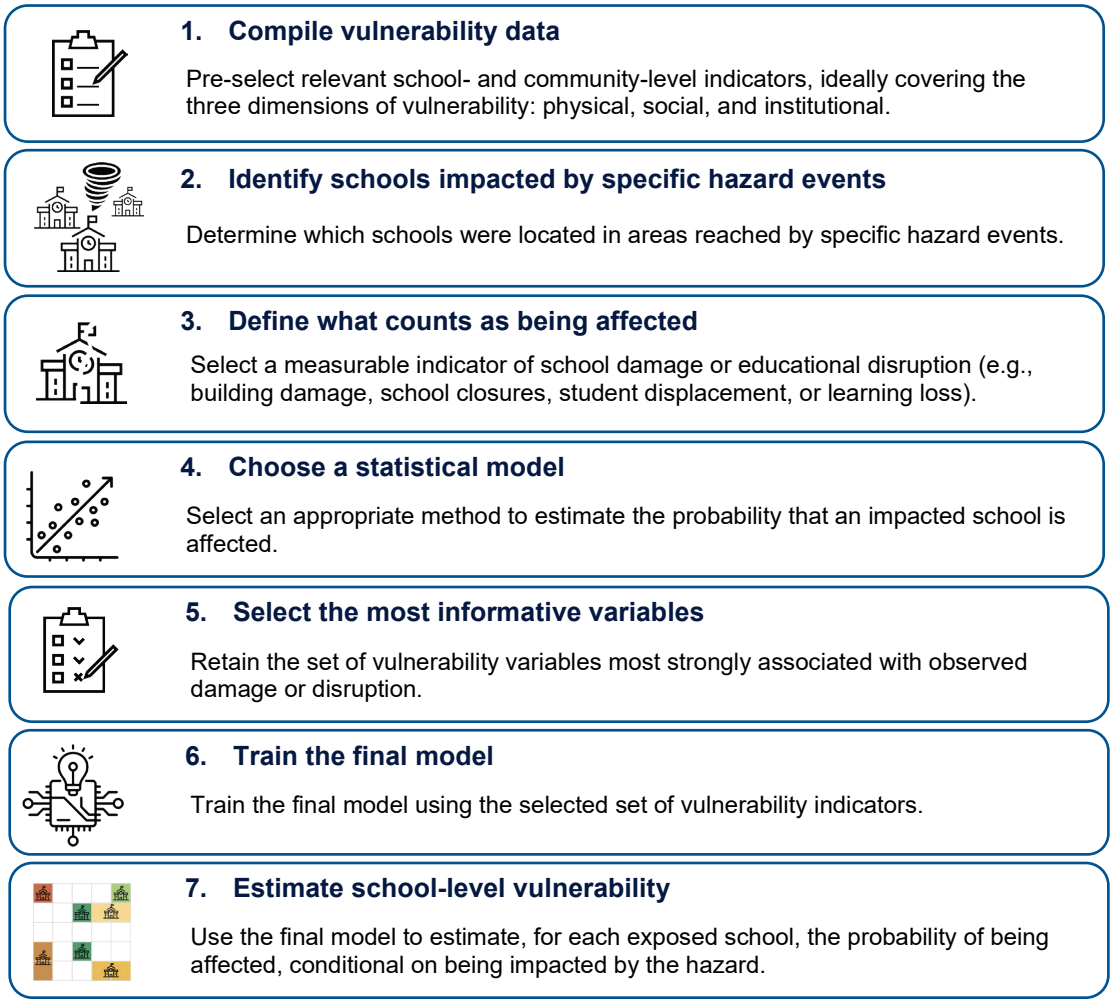
Stage 3: Estimate the vulnerability index

The third stage estimates school vulnerability: how likely schools are to suffer damage or disruption when they are impacted by a hazard. While Stage 1 estimated where a hazard is likely to occur, and Stage 2 identified which schools are exposed to it, this stage examines how susceptible those schools are to damage or disruption. Vulnerability is hazard-specific, meaning that a separate vulnerability index is estimated for each hazard.

How is the vulnerability index calculated?

Vulnerability is estimated through a seven-step statistical methodology, summarized in Figure 5. The objective is to identify which school and community characteristics are most strongly associated with observed hazard-related damage or educational disruption, and then use those characteristics to assign each exposed school a vulnerability index. This index is defined as the probability that a school is affected, given that it has been impacted by a hazard event.

Figure 5: Methodology for quantifying school-level vulnerability



Note: This figure summarizes an adaptable, data-driven approach for estimating, for each exposed school, the probability of being affected, conditional on being impacted by a hazard.

This methodology is intentionally flexible. Reliable school-level data on both vulnerability and observed damage or disruption following hazard events are often among the hardest inputs to obtain, and the type and quality of available information vary considerably across countries. For this reason, the methodology is designed to be adaptable: the specific variables, data sources, and indicators used to measure whether a school is affected in one country-hazard application may not be appropriate in another. What remains constant is the analytical logic; what must be tailored is its implementation to the characteristics of each country and hazard.

Tropical cyclone vulnerability index in Madagascar

For Madagascar, vulnerability indicators were drawn from two main sources: the national Annual School Census, which provides information on school infrastructure and governance, and the latest national Population and Housing Census, which provides community-level poverty indicators (Step 1, Figure 5). The analysis was restricted to schools located in areas reached by wind speeds above 64 knots during recorded cyclone events, and to events occurring during periods covered by the available vulnerability data (Step 2). A school was classified as affected if records showed classroom destruction (partial or total), roof damage, or student displacement following a cyclone event (Step 3).

A logistic regression model was then estimated (Step 4), and the most informative predictors were selected using a combination of feature-selection algorithms (Step 5). Based on this model, the probability that a school is affected given that it had been impacted by a tropical cyclone was estimated for each exposed school (Steps 6 and 7). This probability constitutes the tropical cyclone vulnerability index. The index ranges from 0 to 1, with higher values indicating a greater probability of damage or disruption under comparable cyclonic conditions.

Figure 6, Panel C, presents the resulting tropical cyclone vulnerability index for schools in Madagascar. The model indicates that schools located in poorer communities and those lacking recently renovated classrooms, external management support, and pedagogical training have a higher probability of cyclone-related damage or disruption. These characteristics should be interpreted as statistical markers of vulnerability rather than direct causes of damage. Each variable may capture a broader set of underlying conditions than its label suggests. For example, a recently renovated classroom may also be more likely to have sound walls and roofs, adequate electricity, and access to water, making renovation status a useful proxy for broader infrastructure quality.

In Madagascar, more than half of schools have a tropical cyclone vulnerability index above 0.8, pointing to a high and widespread level of vulnerability across the education system.

Stage 4: Estimate the risk index

Once hazard, exposure, and vulnerability have been quantified, the final analytical stage estimates the risk faced by each school for a given hazard. While the previous stages estimated where the hazard is likely to occur (Stage 1), which schools are exposed to it (Stage 2), and which schools are more vulnerable if impacted (Stage 3), this stage answers the final question: which schools face the highest levels of risk?

How is the risk index calculated?

School-level risk is calculated as the product of the exposure index and the vulnerability index. The hazard dimension does not appear separately in the formula because it is already embedded in the exposure index. Because exposure represents the probability that the hazard occurs at the school's location, while vulnerability represents the probability that the school is affected conditional on being impacted by the hazard, the resulting Risk Index can be interpreted as the probability that a school is impacted by a hazard and affected by it within a given period. This calculation is performed independently for each hazard.

$$\text{Risk} = \text{Exposure} \times \text{Vulnerability}$$

The resulting risk index ranges from 0 to 1. A value of 0 indicates that estimated risk is zero because exposure, vulnerability, or both are zero. Higher values indicate a greater probability that both conditions underlying risk are present: that the hazard reaches the school's location and that, given its characteristics, the school suffers damage or educational disruption.

Tropical cyclone risk index in Madagascar

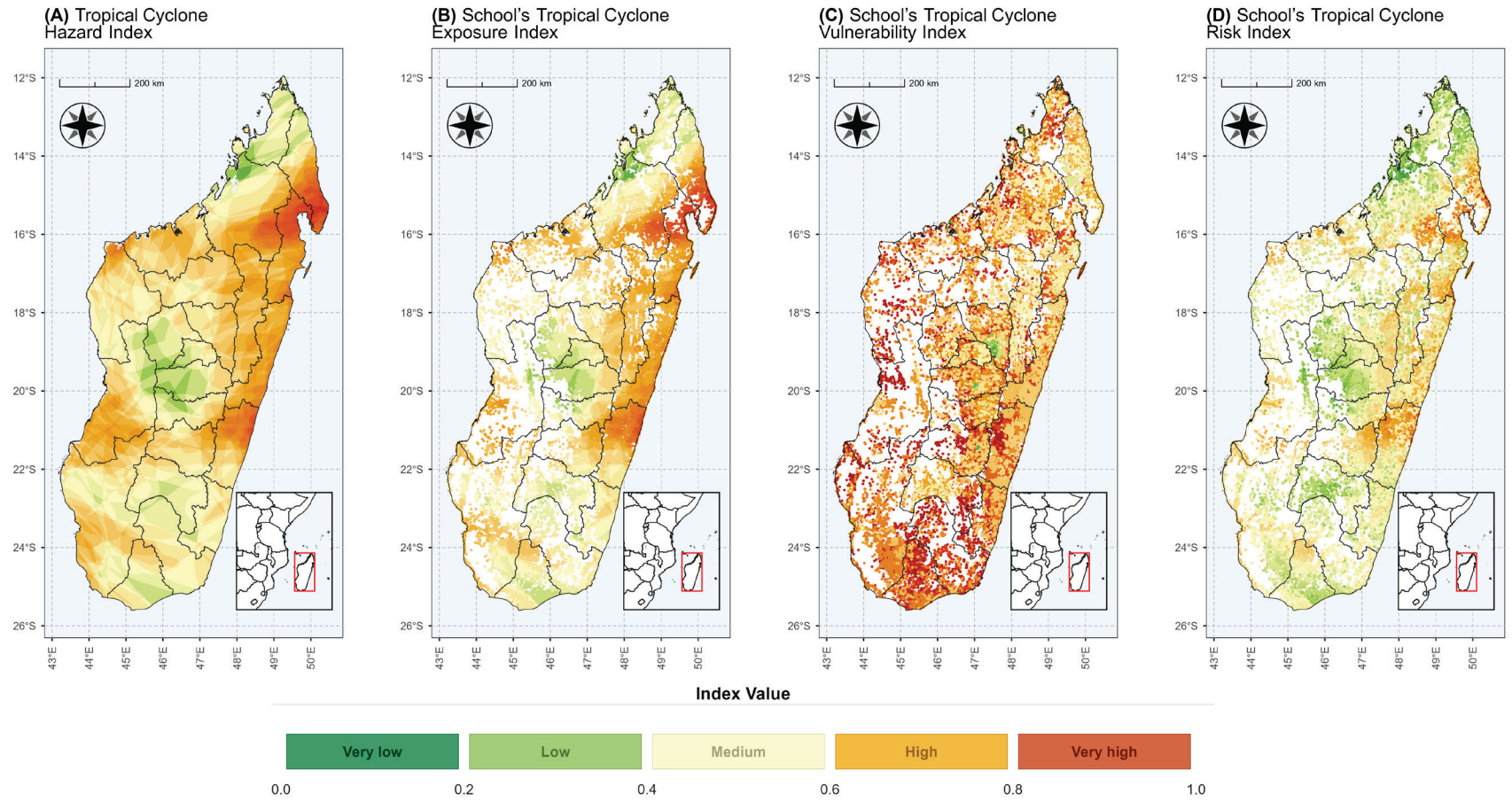
For tropical cyclones (TC), the equation above becomes:

$$\text{TC risk index} = \text{TC exposure index} \times \text{TC vulnerability index}$$

The school-level results for tropical cyclones in Madagascar are presented in Figure 6, Panel D. At the national level, the average tropical cyclone risk index is 0.50, indicating a moderate and widespread estimated probability that schools are impacted by a tropical cyclone and affected by it. However, the index ranges from 0.21 to 0.93, showing that this national average conceals substantial variation. Risk is unevenly distributed both across and within regions.

To assess the methodology's ability to identify the most vulnerable schools, the tropical cyclone vulnerability index was tested using an independent event that had not been used in its estimation: Cyclone Fytia, which impacted Madagascar in early 2026 and affected more than 200,000 people nationwide. The results show that schools with higher index values were consistently more likely to have been affected by the cyclone and that the relative ranking of schools by vulnerability aligns well with observed damage patterns. While the index tends to overestimate the probability of being affected (a conservative bias that may be preferable in a risk-prioritization context), its ability to identify the schools most susceptible to cyclone-related damage or disruption remains robust. This is precisely the type of information needed to target interventions and allocate resources effectively.

Figure 6: Tropical cyclone hazard, exposure, vulnerability, and risk indices in Madagascar



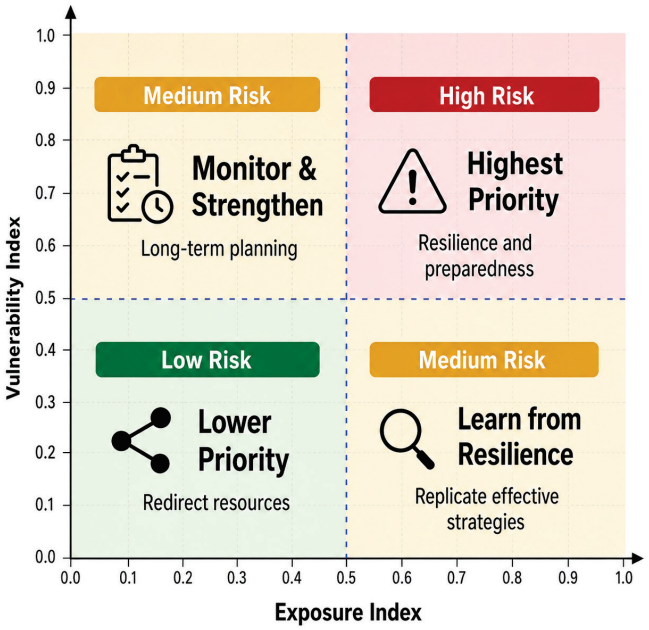
Sources: UN Clear Map, International Best Track Archive for Climate Stewardship (IBTrACS), Madagascar's Third General Population and Housing Census (RGPH-3), and Madagascar's Ministry of Education..
Note: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Map reference: 1000992.2026.02.01.11

Stage 5: Interpret exposure, vulnerability, and risk for decision-making

The final stage focuses on interpreting the school-level exposure, vulnerability, and risk indices and translating them into practical inputs for planning and decision-making. While the previous stages estimated where hazards are likely to occur, which schools are exposed, how vulnerable they are, and their resulting risk, this stage addresses the key policy question: how can these results be used to guide action?

Taken together, the indices provide a practical framework for identifying distinct risk profiles across schools and administrative areas. This makes it possible to move beyond broad averages and distinguish between different planning needs. Figure 7 presents a simple framework for interpreting risk based on the combined levels of exposure and vulnerability, with each quadrant pointing to a different policy response and level of priority.

Figure 7: School risk profiles for decision-making



Note: Schools can be grouped into distinct risk profiles based on their combined levels of exposure and vulnerability. Each profile suggests a different policy response and level of priority for action.

Schools with low exposure and low vulnerability fall into the low-risk, lower-priority category, allowing resources to be directed toward more urgent needs. Schools with low exposure but high vulnerability face medium risk and require monitoring and long-term strengthening, especially as hazard patterns may intensify over time. Schools with high exposure but low vulnerability also face medium risk but offer an opportunity to learn from resilience by identifying and replicating the characteristics or strategies associated with maintaining low vulnerability despite high exposure. At the same time, because they are recurrently exposed to the hazard, they require continued investment to sustain their resilience over time. Finally, schools with both high exposure and high vulnerability face high risk and represent the highest priority for action, requiring targeted investments in resilience and preparedness.

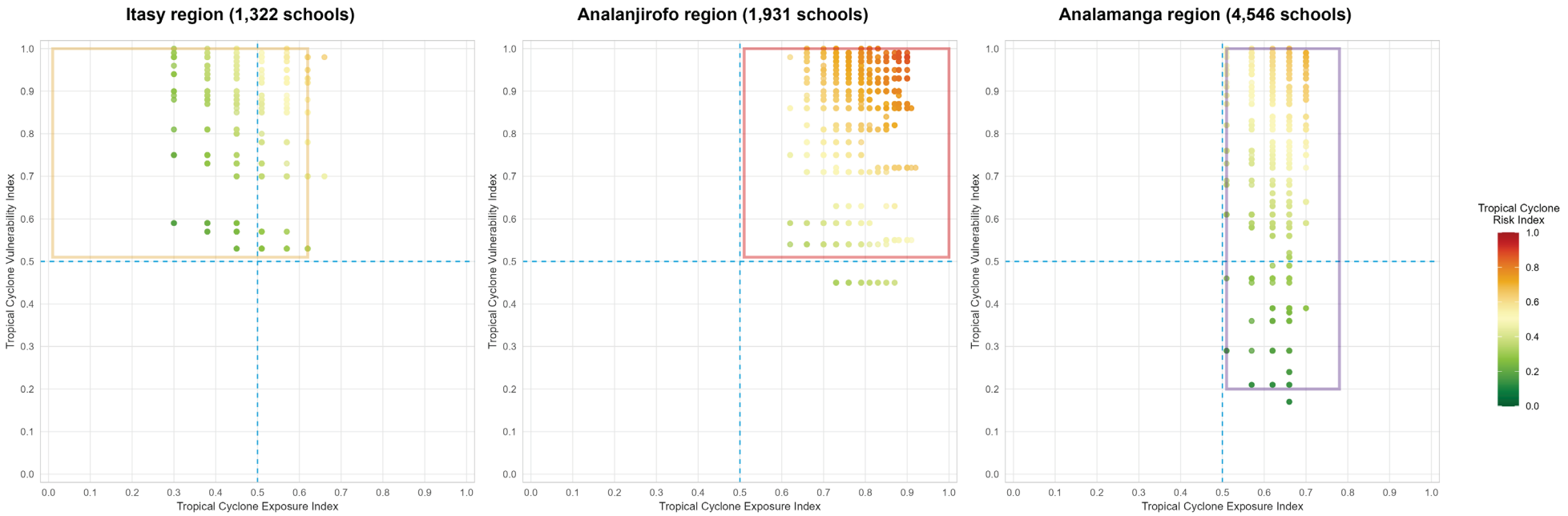
Used together, the three indices—exposure, vulnerability, and risk—allow policymakers to identify which schools face the highest levels of risk and whether those risk profiles are primarily associated with greater exposure, greater vulnerability, or both. This provides evidence for prioritizing where intervention may be most needed. Importantly, these indices are not an end in themselves but decision-support tools that can inform a wide range of planning, investment, and preparedness processes. The examples presented in this work illustrate only part of their potential use.

Using the tropical cyclone risk index in Madagascar for policy planning

Figure 8 illustrates how combining the tropical cyclone exposure and vulnerability indices helps identify contrasting risk profiles across three administrative regions in Madagascar. The analysis shows that schools with similar levels of exposure may differ substantially in their vulnerability, and that schools with both high exposure and high vulnerability emerge as the highest-priority cases for policy action.

This type of analysis is particularly useful for policy and planning. Although the indices do not prescribe specific interventions, they allow decision-makers to compare schools with similar levels of exposure and identify characteristics associated with lower vulnerability. In doing so, they can inform more targeted and evidence-based measures to reduce risk, strengthen preparedness, and allocate resources more effectively.

Figure 8: Using exposure and vulnerability to identify priority schools for tropical cyclone risk reduction in Madagascar



Note: This figure shows how combining the tropical cyclone exposure and vulnerability indices helps identify contrasting risk profiles across regions and prioritize schools where high levels of exposure and vulnerability coincide.

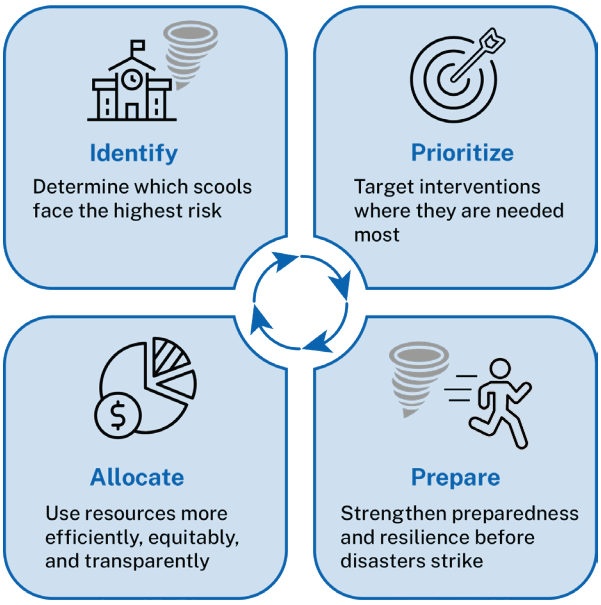
3. From risk measurement to better education planning

The school-level risk analysis methodology represents a step change in how education systems can approach climate resilience. For the first time, it integrates the three dimensions of risk defined by the Intergovernmental Panel on Climate Change (IPCC) — hazard, exposure, and vulnerability — into a single, coherent framework operationalized at the school level. This represents an advance over existing approaches, which typically focus on national or regional averages, partial measures of exposure, or post-disaster damage assessments.

Its value also lies in its practical utility. By generating a comparable risk profile for each school, the methodology makes it possible to move from broad assessments to more precise, evidence-based planning. Ministries of education can identify where risk is concentrated, which schools face the highest levels of exposure, which are most vulnerable, and where the combination of these two dimensions generates the highest levels of risk. This provides a basis for microplanning and for more targeted, efficient, and equitable decision-making.

This information can be used to prioritize infrastructure improvements, guide school rehabilitation programs, strengthen preparedness and contingency planning, and direct limited resources toward the schools and communities that need them most. In this sense, the methodology is not only a diagnostic tool but also a decision-support instrument that can help improve the efficiency of public spending, strengthen the equity of education investment, and support more transparent and defensible resource allocation.

Figure 9: From reactive response to proactive planning



Note: School-level risk information helps shift education planning from reactive response to more targeted, efficient, and proactive decision-making.

The methodology also has broader strategic potential. By integrating geospatial hazard data with education system information, it can facilitate the inclusion of education resilience in national adaptation agendas and climate finance discussions, where the education sector has often been underrepresented. This can expand the sector's access to resources and help ensure that school infrastructure and education continuity are incorporated into national adaptation plans. In addition, the methodology can be updated and refined as new data become available, supporting its scalability and continued use in education planning.

From school-level risk analysis to public policy action in Madagascar

Prior to the development and application of this methodology, risk assessment in Madagascar's education sector relied largely on qualitative and perception-based approaches. Recurrent school disruptions caused by cyclones highlighted the need for a more systematic, data-driven framework to support planning and resource allocation. The methodology presented in this work responds to this need through a quantitative approach with national coverage and school-level disaggregation. By generating comparable risk profiles across schools, it provides Madagascar's Ministry of Education with an evidence base for identifying priorities and guiding more targeted decisions.

The results have also had broader implications for climate policy. In Madagascar, the school-level risk analysis served as an evidence base for incorporating the education sector into the country's National Adaptation Plan. As a result, education resilience needs are becoming part of national climate planning, which can help expand the sector's access to climate finance mechanisms that have historically been concentrated in other sectors.

The application of the methodology also helped identify important data gaps, particularly regarding school-level emergency preparedness and contingency arrangements. These limitations currently constraint the vulnerability index's ability to fully capture the institutional dimension of vulnerability. At the same time, the analysis itself has helped drive improvements in information systems: the Ministry of Education is strengthening its data collection instruments to incorporate dimensions of institutional vulnerability that are not currently captured in national administrative records, including through the development of a district-level vulnerability questionnaire. As data availability improves, so too can the precision and usefulness of the indices for comparing schools, setting priorities, and better targeting planning efforts.

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