CRISIS RISK FINANCE ANALYTICS REPORT

Compilation of achievements and results to date, from the World Bank Crisis & Disaster Risk Finance Analytics program, on the integration of Earth Observation, Big Data, Machine Learning and Artificial Intelligence for Disaster Risk Finance

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Global Risk Financing Facility
Supporting Early Action to Climate Shocks, Disasters, and Crises

Disaster Risk Financing & Insurance Program
SUPPORTED BY WORLD BANK GROUP

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I. INTRODUCTION

ABOUT THIS DOCUMENT

This report presents a selection of projects from the Crisis Risk Finance Analytics program (CRFA), as part of the World Bank Crisis and Disaster Risk Finance work to apply innovative technology for risk finance applications. It presents the successes and challenges faced by the program to date, highlighting the potential of satellite imagery, Big Data, and advanced analytics techniques for disaster risk finance, as well as the implications of various governance and partnership models with the private and public sectors to bring some of these applications to scale. The cases selected for analysis in this report possess the following qualities:

1 Demand-driven:

Each of the applications illustrated here came at the request of World Bank client countries in their efforts to better understand, manage, and respond to complex crisis and disaster risks.

2 Impactful:

The progress and outcomes of the projects have shown the potential to better support financial decision-making and Disaster Risk Finance (DRF) applications through more comprehensive and more timely risk information, for a better targeted and more effective financial response to populations and economies at risk.

3 Sustainable:

Each project is designed within the client's technical capacity to ensure sustainability of the solutions over time. This is provided through strategic technical assistance, allowing World Bank clients to eventually own and manage the analytics delivered within their decision-making framework.

Based on these criteria, the projects selected to illustrate impactful contributions to date are the following:

1 Next Generation Drought Index Platform:

A comprehensive toolkit combining multiple sources of latest satellite data into a single drought index, resulting in more accurate and timely drought insurance applications.

2 Satellite data and AI-based Exposure Mapping and risk Modeling:

Commune-level mapping of financial exposures and natural disasters in Tunisia.

3 Operational use of satellite data and Integrated Disaster Risk Finance and Management Program:

Near-real-time flood monitoring and financial response in Morocco.

4 Compound Risk Assessment:

Modeling extreme climate events and their combination with additional shocks, with a focus on financial sector impact evaluation.

CONTEXT

The escalation of natural and man-made disasters, exacerbated by climate change, has caused unprecedented social and economic losses for governments, businesses, and households around the world. Every year, natural disasters generate an average of US$152 billion in economic losses, directly impacting 200 million people.[1] In the absence of appropriate Disaster Risk Financing (DRF) and Management (DRM) solutions, fragile and vulnerable countries face significant financial losses through their contingent liability and emergency response efforts, as well as long-term recovery and reconstruction costs. In Haiti alone, the 2010 earthquake directly impacted approximately 15% of the population, with the damages estimated to exceed the national GDP in 2009.[2] In that same year, natural and man-made disasters generated US$440 billion dollars in losses.

DRF policies and instruments offer governments a potent tool to mitigate the large range of risks associated with natural and man-made disasters by improving financial preparedness and resilient recoveries through ex-ante financial planning.[3] DRF-powered analytics enable governments and policymakers to make risk-informed decisions to quantify, plan, and predict risks with more certainty, as well as to design adequate financial response mechanisms accordingly.[4]

New technologies play a significant role in enhancing DRF analytics. Big Data (BD) and Earth Observation (EO) technologies offer information with unprecedented resolution and comprehensive coverage. Machine Learning (ML) and Artificial Intelligence (AI) algorithms can help process these vast amounts of data and provide near-real-time risk information and more accurate assessments. This information can ultimately improve the timeliness and efficiency of better targeted financial response to affected communities, businesses, and industries.

1 "EM-DAT | The International Disasters Database," accessed October 27, 2021, https://www.emdat.be/. Found in "2020: The Non-COVID Year in Disasters - Global Trends and Perspectives - World," ReliefWeb, accessed October 27, 2021, https://reliefweb.int/report/world/2020-non-covid-year-disasters-global-trends-and-perspectives.

2 The damages were estimated at US $ 7.804 billion in 2010. Government of the Republic of Haiti, "Haiti Earthquake PDNA: Assessment of Damage, Losses, General and Sectoral Needs. Annex to the Action Plan for National Recovery and Development of Haiti," 2010, https://www.gfdrr.org/sites/default/files/GFDRR_Haiti_PDNA_2010_EN.pdf.

3 Understanding Risk, "Understanding Risk | Revolutionizing Disaster Risk Finance: Are You Up for The Challenge?," 2021, https://understandrisk.org/disaster-risk-finance-challenge-fund-round-3/.

4 Disaster Risk Financing and Insurance Program, "Disaster Risk Finance Analytics: Supporting Countries to Manage the Cost of Disaster and Climate Shocks," 2017, https://www.gfdrr.org/sites/default/files/publication/Brochure%20Analytics.pdf.

THE WORK OF THE WORLD BANK CRISIS & DISASTER RISK FINANCE TEAM

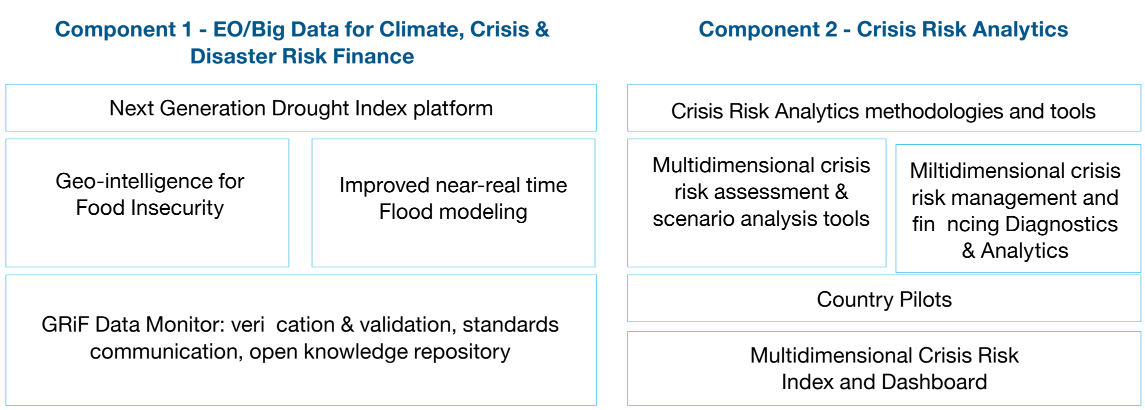
The high cost of natural disasters for nations and individuals is not necessarily a foregone conclusion. With appropriate policies and instruments in place, effective financial risk management can reduce the burden on governments and minimize the impact on livelihoods, development gains, and investments.

The World Bank Crisis and Disaster Risk Finance (CDRF) team supports governments through advisory services and risk financing solutions to strengthen their resilience to climate, crisis, and natural disaster shocks. The Crisis Risk Finance Analytics program (CRFA), founded in 2019, supports new and existing World Bank engagements related to innovative technology for improved risk finance applications. In particular, the program has integrated innovative data sources, including EO and BD technologies, as well as analytical methods (e.g., parametric product design, image-processing, AI) to improve risk financing and management.

To that end, the World Bank CDRF team has established a partnership with the European Space Agency (ESA) to leverage such technological advances for improved pre-arranged financing. Established in 2019, the partnership focuses on leveraging remote sensing, online/social media/ big data, and predictive analytics to support global level identification of risks, national/sectoral diagnostics, and project-specific activities to enable better informed and earlier financial response to crises. A core objective is the development of timely, reliable risk metrics and triggers, as well as innovative approaches to assess overlapping risks in complex situations. As such, the joint partnership with ESA provides the missing link between technology and operations, by providing project-specific risk finance analytics. It focuses on supporting the CRFA program, whose ultimate objective lies in the scaling-up of risk financing operations in a sustainable, robust, and transparent manner.

The CRFA program is funded by the Global Risk Financing Facility (GRiF) and structured around two components as depicted in Figure 1.[5]

Figure 1. CRFA program structure



5 More information at: The World Bank. « Global Risk Financing Facility », The World Bank, accessed October 27, 2021. https://www.worldbank.org/en/topic/disasterriskmanagement/brief/global-risk-financing-facility.

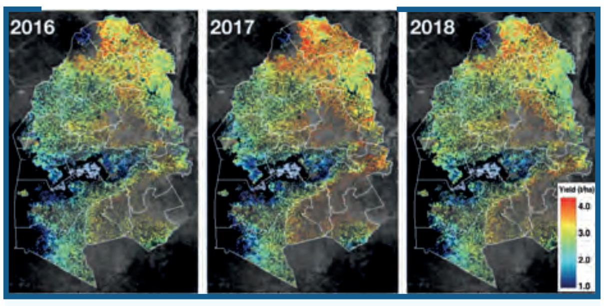
II. SUCCESS STORIES

> The approach developed in the CRFA project “Near-Real-Time loss information on Natural Catastrophe Risks in Morocco”, based on AI and Satellite Imagery, reduces the time required to produce a flood-extent map by 80% (post-event), while achieving robust performance over a wide range of locations and environmental conditions.
> This is essential for the Solidarity Fund for Catastrophe Events in Morocco, as access to near-real-time estimates of physical and financial impact on the ground are needed, especially in urban and peri-urban areas, where compensating uninsured victims is a highly complex, lengthy, and costly process.

Abderrahim Chaffai, Director of Morocco’s Public Solidarity Fund (FSEC)

| World Bank's Crisis and Disaster Risk Finance team & the European Space Agency

1. Next Generation Drought Index platform



Satellite-based estimates of maize yields (2016-2018) for 15 counties in Western Kenya.

Source: Department of Earth System Sciences and Center on Food Security and the Environment, Standford University.

Practice area

Next-generation agricultural insurance indexes, targeting more reliable and timely sovereign parametric risk transfer applications, as well as supporting the improvement of micro-insurance products.

Strategic goal

Climate change and increased food insecurity make drought monitoring more important than ever to ensure access to food for all. Improved monitoring, modeling, and response to severe drought events on the ground are urgently needed and can be facilitated through the application of satellite data into relevant risk information for financial risk management. In particular, parametric risk insurance mechanisms can be implemented more quickly if the environmental triggers of droughts are identified and monitored appropriately.

Objectives

The Next Generation Drought Index (NGDI) platform aims to increase the reliability of drought risk information by creating more robust drought indices and models. This is achieved by enabling context-specific drought monitoring and response solutions that clients can develop, test, and benchmark; based on a wide range of information available from satellite constellations, combined with additional hazard and risk information, to offer a comprehensive view on risk data.

To facilitate access to the latest drought indicators derived from satellite data (e.g., soil moisture) and offer an accessible way to combine them into a single index.

To design high-performance drought indexes tailored to specific needs; while following a transparent design, calibration, and validation process.

To allow decision-makers to unpack critical index design processes and tailor drought indexes to meet their specific micro and macro scale needs.

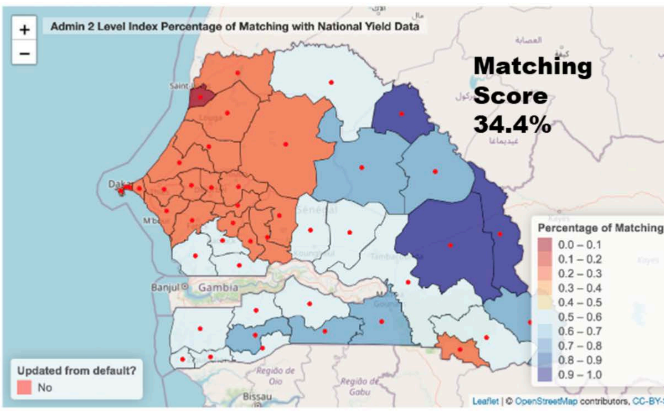
How does it work?

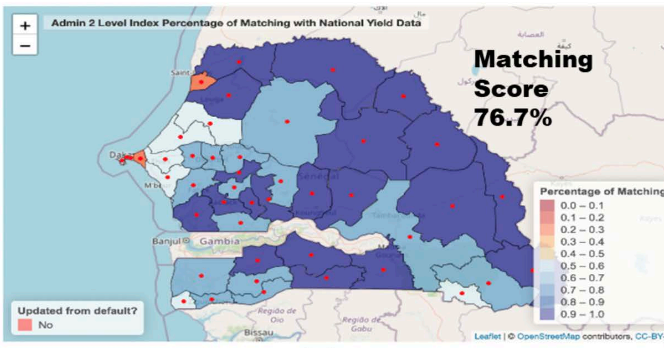
The NGDI platform allows users to generate their own drought risk indicators from a selection of pre-processed data. The platform does not assume a "best" data set or index to monitor drought. Instead, country-clients can select the relevant data from a wide range of variables. Then, through a simple online interface, users receive immediate feedback on the performance of the selected drought variables to select the best index.

Unlike traditional design methods, the NGDI features both top-down and bottom-up approaches to enable co-design with national partners to provide co-generated and locally owned solutions. The index design process begins with basic questions about the geographic unit of coverage, the choice of insurance/risk financing windows, and relevant variables to characterize historical drought impacts. Different datasets can be visualized and integrated; ranging from pre-processed satellite data on soil moisture, phenology (e.g., plant growth cycle), and agricultural practices (e.g., early season planting) to climate and vegetation health. Once designed, the indices are then compared and calibrated. Their performance is evaluated against historical or benchmark data. Users can adjust their assumptions and almost instantly visualize the performance of the final product. As a result, the model complexity is substantially reduced, and transparency is gained (when compared to traditional risk models). Monitoring is done through the obtention of the program feedback from the ground and users after its implementation. Finally, a detailed operational plan, such as distribution of payout, is designed and subsequently used to produce an effective service plan.

Earth Observation and Artificial Intelligence tools

The platform uses data from global satellite networks (e.g., Copernicus Sentinels) which provide continuous coverage of drought characteristics; such as weather, vegetation, and soils. Vulnerability data is also incorporated to link hazard and risk. Then, a risk assessment integrates various components of social, financial, and economic vulnerability into single-risk outputs. These outputs correspond to comprehensive drought risk datasets, which can be easily transformed into simple and visual risk metrics, with the help of the platform. Users can then compare the performance of different indices and select the most accurate. This process allows for more accurate estimates of drought, more effective anticipatory measures, and ultimately, more reliable and impactful risk transfer products to be developed.





Upper image: one rainfall data set measured over one early-season time window.
Lower image: an NGDI design set-up consisting of two measurement windows in the season (early and late) with two indicators combined – satellite-based rainfall and soil moisture, and a resulting much higher matching score (agreement of satellite data with reported drought years), going from 34.4% to 76.7.

Source: WBG/NGDI platform

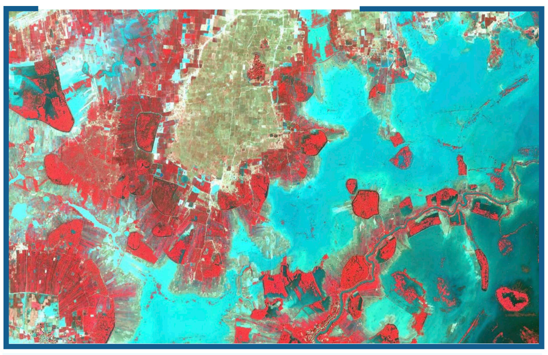
Achievements

- The platform offers a simple toolkit for drought to be accurately captured and models to be easily evaluated and benchmarked with just a few clicks. What was once a complex process is now available to users in minutes, under a single user interface. This also promotes a better understanding of the strengths and weaknesses of the different modeling options and contributes to greater confidence in the financial response mechanism supported by these indices. Users are also empowered to make their own decisions, which are informed by objective and transparent performance criteria.
- NGDI has been applied in Senegal, Mozambique, and Morocco. In Senegal, two different applications are currently being implemented; the first with the food security council (SeCNSA) and the second with the sovereign insurance risk pool African Risk Capacity (ARC). Both projects are leveraging NGDI and satellite-based drought risk information, such as soil moisture, to improve the reliability of drought risk estimates. By the end of 2021, the SeCNSA project will be delivering estimates of food insecure populations during the 2022 lean season, with a 6-month lead-in time, aiming to improve the accuracy and timeliness of food security efforts at national scale.
- The implementation of more reliable risk models improves the speed and accuracy of financial response to severe events. The improvements for drought monitoring and prediction of the NGDI have the potential to reduce basis risk inherent to parametric insurance. As a result, agricultural livelihoods and assets are better protected, financial impact is minimized, and populations are better supported.

6 "Sentinel Online - ESA - Sentinel Online," accessed October 27, 2021, https://sentinels.copernicus.eu/web/sentinel/home.

| World Bank Group (WB) / Ernst & Young (EY), Image Cat, GFDRR, University of Tunis El Manar

2. Satellite data and AI-based Exposure Mapping and Risk Modeling



High resolution mapping of land use and land cover is crucial to assessing changes in ecosystems. This satellite-based map of building footprints and land cover types supports exposure mapping of urban infrastructure and agriculture along the Mekong river in Cambodia.

Source: ESA

Practice area

Mapping financial exposures of earthquake- and flood-prone jurisdictions, disaggregating data from the regional to sub-municipal level, and classifying assets by structure and occupancy types.

Strategic goal

To integrate satellite data into broader risk assessment for DRF strategy development by improving a multi-hazard risk study for territories increasingly exposed to earthquakes and floods. These technologies can map development patterns of the built environment, characterize the physical resilience of infrastructures, identify building occupancy types, assign damage vulnerability functions and ultimately produce financial risk estimates, such as Average Annual Losses (AAL) or maximum probable loss in a well-structured framework and in a highly cost-effective manner.

Objectives

Perform multi-hazard exposure mapping and risk modeling for floods and earthquakes at a national scale using satellite data and AI-based analysis.

- Exposure review and incorporation into a format suitable for loss estimation and data collection.
- To characterize the built environment, including its physical vulnerability and structural resilience.
- To produce reliable, granular financial loss estimates for various geographical, sectoral, and socio-economic dimensions.
- To support visualization of outputs using business. intelligence tools.

How does it work?

The framework has a core catastrophe risk modeling engine that combines data on exposure, hazard, and vulnerability to estimate financial losses. Modeled hazard data for earthquakes and floods were overlaid and combined with exposure and vulnerability data. Outputs at the regional level are then disaggregated to the sub-municipal level with satellite data to produce annual loss estimates from seismic and flood events.

This modeling has been applied at a national scale by the government of Tunisia. Tunisian development patterns were first mapped into rural, residential, high-density residential, urban, and industrial areas using an algorithm that learns to predict development patterns from multi-band images, derived using EO data (optical information, and environmental indicators). The development patterns for training were manually sampled by EO experts. This mapping is then combined with financial exposure data. Earthquake exposure depends on the resistance of buildings to horizontal movement, therefore exposure was based on the distribution of structural systems in Tunisia and their respective vulnerability curves to seismic hazards. Google Street View allowed satellite data experts to analyze the lateral force resistance system (LFRS) of each type of structure and collect the characteristics of the buildings (height, size of openings, shape of roofs, among others.) The proportions of the structural systems were then matched with the Tunisian development models from the mapping of development patterns. Flood exposure was constructed based on the types of occupancy proportions (residential, commercial, industrial) and their replacement costs. Satellite imagery is used to map the data from the governorate-level into grids, which allows for the collection of data at the sub-municipal level; classified by commercial, educational, financial, health, industrial, residential, and tourist areas. Then, vulnerability is estimated for each structural system, based on fragility curves (for earthquakes), and for each type of occupation, based on damage ratios for floods. Subsequently, the return periods (the probability that the hazard will occur in a given time interval) are estimated. Finally, AAL are estimated and disaggregated by governorate and sector.

Earth Observation and Artificial Intelligence tools

This database relies on mapping the existing environment through a combination of satellite data, Google Street View, and AI/ML to disaggregate the exposure database from Tunisia to the sub-commune level; by structure and occupancy. Similarly, the framework has a disaster risk modeling engine that combines exposure, hazard, and vulnerability data to estimate building losses. Modeled hazard data from earthquakes and floods, provided by GEM and Fathom, respectively, were overlaid and combined with the exposure data and vulnerability model integrated by ImageCat, resulting in the calculation of the aftermath of these events. The approach relies on linking development models from EO - roughly consistent with land use classes, with assumptions made concerning structure type and building density.

Rice-Field in Vietnam. Multi-temporal image combining three radar acquisitions from the Copernicus Sentinel-1 mission to show changes in crop and land conditions over time. The bright colours in the image come from changes on the ground that have occurred between acquisitions. The first image, (28 October 2019), picks out changes in pink and red, the second (21 November 2019) shows changes in green, and the third image (27 December 2019), shows changes in blue. As seen in the image, the majority of growth in the rice fields is visible in December. The grey areas represent either built-up areas or patches of land that saw no changes during this time.

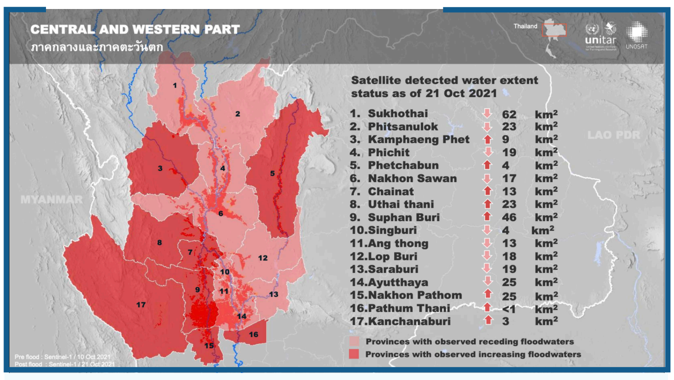
Source: ESA

Achievements

- EO and AI contributed to mapping exposure at both the regional and sub-regional levels. The resulting exposure mapping was successfully integrated with hazard data and vulnerability to model the exposed value of assets and the AAL that Tunisia can expect from flooding and earthquakes.
- The AAL was disaggregated for all governorates and types of building occupancy; including residential, commercial, education, financial, health, industrial, and tourism infrastructure.

DRFIP, the Organization for Economic Cooperation and Development (OECD), Swiss Agency for Development and Cooperation, GFDRR, The Kingdom of Morocco, IBRD IDA, Moroccan Space Center, and UNOSAT

3. Operational use of satellite data and Integrated Disaster Risk Management Program



Floodwaters and receding flood waters detected in Thailand by October 2021, using Sentinel-1 data at 10 m resolution for a preliminary satellitederived flood assessment.

Source: ESA, ESRI, Open Street Map, UNOSAT

Practice area

Near-real-time flood monitoring and financial response for developing economies exposed to exogenous shocks.

Strategic goal

To provide comprehensive risk monitoring and disaster response capacity through operational use of satellite data and weather forecasting, linked with financial response mechanisms on the ground, to strengthen financial resilience to natural disasters in urban and peri-urban areas, where the compensation process for uninsured individuals is the most complex and likely to require the most time.

Objectives

Integrated disaster risk finance and management attempts to combine risk monitoring, mitigation, and response efforts through operational use of consistent and reliable risk information before, during, and after catastrophe events.

To establish a more systematic risk management and financing process in Morocco, covering risk reduction and financial response activities implemented by various ministries and public and private entities; particularly within the framework of the FSEC *(public solidarity fund, or Fonds de Solidarité contre les Événements Catastrophiques)* for compensation of uninsured populations.

To support decision-making with near-real-time risk information made accessible and shared by all stakeholders at the national level through an operational platform that quantifies material damage, physical losses (buildings), and assesses compensation needs.

To improve the accuracy, reliability, and timeliness of financial response mechanisms, through better-informed decision-making, relying on high-resolution imagery data on magnitude and scope of extreme disaster events affecting the country in near-real-time.

How does it work?

Countries need operational risk information to respond to a wide range of perils. Morocco is significantly exposed to climate risks. More than 30% of its population and 33% of its GDP are threatened by two or more natural disaster risks at any given time.[7] The average annual losses due to natural disasters amount to more than USD 800 million. Due to its geographical position, high rainfall variability, and topography, Morocco is especially prone to flooding, with estimated losses of over USD 400 million per year.

Over the past two decades, Morocco has developed a strong, cross-sectoral framework for financial management of disaster risk and adaptation to climate change. Since the early 2000s, a wide range of initiatives have been launched to improve the understanding of catastrophe risks, strengthen their management across ministries, and optimize response efforts through risk reduction, ex-ante financing, and enhanced response efforts coordination. Morocco has also developed an effective disaster risk financing mechanism, with a comprehensive legal framework (Law 110-14), introducing an insurance and financial protection regime against natural disasters at the national scale.

To further operationalize financial assistance mechanisms and post-event response efforts, the CRFA program supported the Ministry of Finance and its Public Solidarity Fund in setting up a near-real-time flood risk mapping platform. Through inputs from the European Space Agency, the Moroccan Met Office (DGM), the UN Rapid Mapping Service of UNOSAT, and the Moroccan Space Center (CRTS); a consolidated flood mapping service (maps of affected areas, severity, and financial losses) was established to support decision-makers, insurance regulators, and insurance markets with state-of-the-art estimates of inundated areas within days after the event onset. This allowed progress tracking of flooding events over time and space, the ability to identify and anticipate which regions will be most affected, and the mobilization of adequate financial support on the ground.

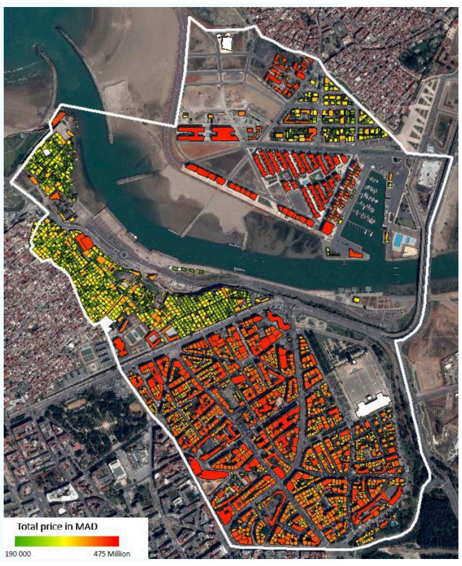
As part of these efforts, the role of high-resolution satellite imagery data proved to be especially useful. It allowed for accurate mapping of the built environment and provided objective evidence of the extent of damage during the event, which could not be captured by existing rainfall-based run-off and routing models, particularly due to the weak design or maintenance of drainage systems in the most affected areas.

This is an important milestone in Morocco's efforts to further operationalize its integrated risk management program, by testing the efficiency of the emergency coordination and financial response mechanisms, through fully integrated, near-real-time decision-making support information. Satellite-based financial assistance mechanisms help further strengthen its socio-economic resilience to climate and disaster events in the future.

Combining climate science with state-of-art risk analytics

The integrated risk management approach in Morocco is based on high-resolution mapping of financial exposure in high-density population centers (such as Rabat-Sale or Casablanca), processed from satellite imagery data. The use of EO also supported the delivery of objective information on the magnitude and extent of the flooding events in near-real-time, further complemented with post-event estimates of financial losses and the validation of damage rates to building, provided by the CRFA program, in close partnership the Moroccan Space Center and UNOSAT.

High-resolution financial exposure mapping of Rabat-Sale, processed from satellite imagery data.
Source: SERTIT/WBG

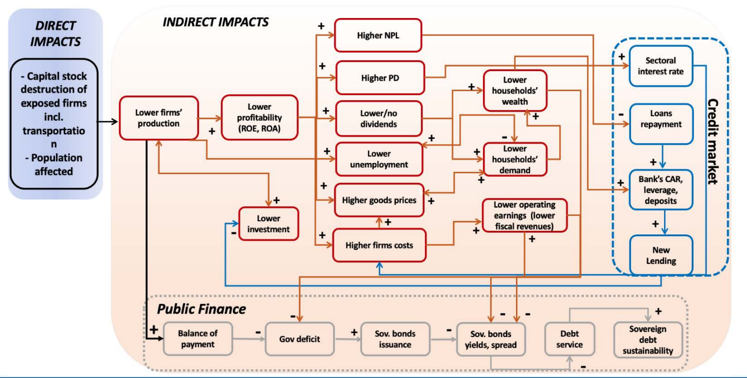


Achievements

- The program is based on extensive capacity-building support and technical assistance - which has laid the groundwork for a comprehensive approach to disaster risk management and resilience. Activities were led in close partnership with domestic institutions and local experts and then integrated into existing information systems. This ensures clients and counterparts further improve the operational platform delivered whilst collecting valuable feedback and lessons learned for the CRFA program, with an aim towards replications in other countries in the region and beyond.
- Moreover, the objective, evidence-based platform allows disaster response funds to flow in a more timely manner to those most in need. These measures, in turn, contribute to reducing the impact of disasters on both the population and the economy. It is estimated that satellite-based, near-real-time information systems could reduce the wait time for financial response by a few days, which would contribute significantly to reducing the ultimate impact of disasters on the ground.
- Over time, the program aims to contribute to a more integrated management of disaster risks as Morocco is already experiencing the impacts of climate change.
- Morocco aims to adopt a more proactive, ambitious, transparent, and results-based strategy to increase the country's resilience to natural disasters. By focusing on enhanced risk information before, during, and after the events; the CRFA program attempts to bridge the gap between satellite technology and big data and fully informed decision-making in near-real-time, for more resilient livelihoods and businesses in Morocco.

7 The World Bank, "The World Bank in Morocco," World Bank, accessed October 27, 2021, https://www.worldbank.org/en/country/morocco.

4. Compound Risk Assessment



Compound Risk Transmission Channels. Determining and characterizing interplay between various economic agents and dimensions of socio-economic and financial impact.

Source: WBG/Ca' Foscari University Venice, Department of Economics.

Practice area

Multidimensional risk assessment focusing on modeling extreme climate events and their combination with additional shocks, such as pandemics, with a focus on financial sector impact evaluation.

Strategic goal

The development of climate physical risk assessments leverages global monitoring of critical climate risk indicators combined with macro-economic modeling of economic sectors and populations most exposed to climate change and future extreme events. Compound risk assessments specifically capture the interplay between risks and transmission channels throughout the economy by utilizing in-depth hazard and macro-economic risk assessments.

Objectives

Increasingly extreme climate events and a global pandemic have highlighted the need for financial preparedness in the face of large-scale catastrophes. However, the effects of natural disasters occur in conjunction with existing systemic or localized weaknesses and shocks, such as economic recession, inflation, pandemics, and other factors that exacerbate financial impacts for certain populations and sectors. Therefore, robust and holistic risk management, which takes into account compounding risks and their effects, is necessary to strengthen financial resilience in the face of climate change.

How does it work?

Climate physical risk assessments at the national level are designed through climate scenarios (e.g., extreme droughts or floods) with direct impact estimates (e.g., capital stock destruction, agricultural production losses). However, the implications of a disaster go beyond the event itself, having long-lasting side effects. Consequently, macroeconomic damages can be much costlier than direct damages. The traditional, actuarial modeling of catastrophe risk does not capture the broader indirect economic and social consequences of large-scale disasters; including impacts on employment, production. investment, public finances, and the country's financial sector. Governments, therefore, need to anticipate the interaction between risks and economic impact through the identification of key transmission channels. Additionally, the combined toll of multiple disasters requires a broader modeling framework that can link a disaster (or the interaction of multiple disasters) to the country's economy. To fully understand the disruptive potential of complex hazards, tools are needed to assess their full economic and social impact. To this end, various macro-economic models complement climate science and traditional catastrophe risk modeling by estimating the impacts of combined shocks such as floods, earthquakes, or droughts associated with a pandemic shock, for instance. This approach not only requires physical risk data and a full understanding of future climate events (drawn from the latest climate science) but also macro-economic and financial sector information. Compiling these datasets is, in itself, a challenge, particularly when ensuring the interaction between physical risk modeling and indirect impact assessment is accurate.

The modeling framework has been applied in pilot countries (Morocco, Vietnam, West African Economic Monetary Union region), with preliminary results showing that the compound impacts can be up to 50% greater than the sum of the individual shocks. Also, the indirect proportion of total economic costs can, in some cases, reach multiples of the direct economic costs generated by the event.

Beyond quantified results, this bottom-up approach (starting from initial characterization of shocks and continuing to ultimate impact on livelihoods, businesses, and the banking sector) helps identify critical sources of financial vulnerability. These include identifying the most affected economic agents, sectors, populations, and geographies, and contributing to sound and more holistic financial risk management to climate change.

Earth Observation and Artificial Intelligence tools

The main services provided by the CRFA program include supporting the ministries of finance and central banks through a multi-disciplinary and holistic approach to better handle compound risks using fully integrated, turn-key solutions, particularly related to climate physical risk management.

To do this, the CRFA program develops a comprehensive methodological framework of extreme climate events risk modeling and guidance for clients, by providing reliable sources of information and outlining every step of the modeling process; from exposure data collection (type, format, granularity) to hazard and vulnerability characterization and risk quantification. A modular risk assessment customized to clients' needs is also designed with a forward-looking analysis for governments and financial actors on impacts of climate physical risks, including: preliminary financial exposure mapping and identification of "hotspots", qualitative risk assessments (both for preliminary views and early engagement and for more advanced clients and applications), a compound risk evaluation, (which combines effects of multiples shocks, such as climate change with pandemics and/or recession), and identifying loss aggravation factors and increased vulnerability of populations and assets. By developing specific financial sector vulnerability assessments to understand, map, and quantify credit risk and the impact for banks on Non Performing Loans and Probability of Default, the team also specifically focuses on financial sector impact assessments. Regarding resilient investments, they offer consistent measures of acute climate risks (i.e., tropical cyclones, floods, droughts) to public and private investors through a simple set of satellite-based indicators, which are openly available.

Fully Integrated, Public Good Technical Assistance

Climate Science	Actuarial Extreme Events Modelling
Financial Exposure Mapping	Financial Impact Assessment
Earth Observation & Essential Climate Variables	Marco-economic modelling

Multi-disciplinary approach to offering fully-integrated turn-key solutions to clients on climate physical risk management

Achievements

- Activities to date have helped improve financial institutions' understanding of climate risks and best practices to enhance the banking sector's management of long-term risks and opportunities. Through country-specific, scenario-based analysis of the potential impacts of climate risks, tailored to the specific structure of the country's economy and banking sector, clients have access to risk information for better decision-making.
- Compound risk assessments broaden the scope of traditional risk assessments by accounting for the interplay between risks, highlighting transmission channels, as well as identifying the most vulnerable sectors in the economies. This type of assessment can improve countries' preparedness to disasters, which in turn allows for a faster and more targeted response to future climate and compounding shocks.
- The integrated risk assessments will help clients in emerging markets and developing economies better understand critical sources of financial vulnerability from future extreme events. This can help strengthen financial preparedness and lead to the implementation of measures to increase the resilience of specific sectors or populations, including the financial sector. The comprehensive framework can also guide investors toward more resilient assets by providing a simple, accessible, and consistent set of climate variables linked with global satellite coverage to provide global information for financial decision-making.

III. CHALLENGES

While these success stories show promising results for increasing financial resilience in disaster-prone areas, challenges, barriers, and gaps still remain in ensuring the uptake of the proposed solutions in affected countries. These include gaps in communication regarding the benefits and usage of advanced technology products, various technological and financial barriers to implementing and scaling up new approaches, and a lack of understanding needed to fully participate in project implementation. The main challenges identified can be summarized as follows:

1 Communicating complex concepts:

The perceived complexity of these projects requires simplified, coherent communication and in-depth technical advice to overcome uncertainties about the usefulness and applicability of these technologies to enhance financial risk management policies and instruments.

2 Low technical capacity for technology uptake:

A lack of human and material resources may constrain client-countries in the use of this data, resulting in low adoption of advanced technologies for financial risk management. Therefore, accessing and processing comprehensive, accurate, and timely data remains difficult, requiring a significant level of expert knowledge to avoid improper processing and misuse of data.

3 Perceived costs of at-scale implementations:

At-scale projects that provide actionable information (derived from satellite data) to policy and decision-makers can be complex and costly. In addition to the investment associated with acquiring technical expertise and the technology itself, up-front costs include the project design and management time necessary when working with multidisciplinary teams, as well as significant data processing capability, and knowledge development investments.

IV. CONCLUSION AND WAYS FORWARD

CONCLUSION

This report has highlighted state-of-the-art applications of innovative data sources and analytical methods for DRF. The projects presented bring objective and practical benefits for policy-making and implementation on the ground, which contribute to increased financial resilience in the face of worsening and compounding climate shocks. These technologies were shown to:

1 Increase data availability:

Risk models are better equipped to understand and monitor risks using comprehensive coverage obtained through BD and EO, thereby providing critical risk information globally, in high-resolution, and in near-real-time.

The project "Near-Real-Time loss information on Natural Catastrophe Risks in Morocco" has reduced the time required to produce a post-event flood map by 80%.

2 Enhanced risk modeling:

The analytical methods used to leverage these data sources improve the understanding of hazard estimates and risks, including systemic risks, allowing for better planning and forecasting.

The NGDI platform provides a match of satellite data with reported drought years of 76.7% compared to 34.4% for traditional monitoring indices.

3 Support risk-informed policies and DRF solutions:

As these technologies provide objective and near-real-time measures, financial response mechanisms can be triggered more quickly, improving targeted financial support for those most in need.

Satellite data and weather forecasts for ex-ante risk monitoring and increased disaster response capacity, enabling the adoption of an effective disaster risk financing mechanism with a comprehensive legal framework (Law 110-14) in Morocco.

Leveraging these technologies for DRF solutions can help improve preparedness, financial protection, and resilient recoveries against a wide range of extreme events. The highlighted projects used innovative data sources and modeling to complement traditional risk information, which facilitated DRF solutions against:

1 Droughts:

Through the increased capacity to monitor, predict, and anticipate rainfall deficit and identify vulnerable individuals, leading to better assessment and response to food security needs.

2 Financial exposure and risk mapping:

By implementing advanced risk modeling to accurately map asset exposure to a wide range of hazards, allowing policymakers and regulators to understand and develop adequate financial risk management mechanisms.

3 Multi-hazard compounding events:

Integrating the advanced mapping and exposure with combined natural and man-made hazards, including pandemics, facilitating assessment of the likelihood and magnitude of extreme events, and their potential to disrupt entire economic sectors and livelihoods, through a more holistic assessment of systemic risk and financial impact evaluations.

For the implementation of these projects, the teams developed technological innovations for DRF that can be scaled and replicated by country need and hazard type. These innovations include the development of:

1 Multisource operational data platforms:

Integrating diverse sources of custom-selected data from global satellite networks (such as weather, vegetation, and soils) with hazard data (such as floods), to create reliable and effective risk-mitigation models, for use by policymakers and DRF practitioners.

2 High-resolution risk mapping of financial exposure:

Disaggregating asset data geographically, from the regional to sub-municipal levels, by utilizing machine learning and earth observation to ensure more detailed, comprehensive, and near-real-time high-resolution imagery data; thereby expanding the scale and scope and providing unique insights into new, emerging, and complex crises at minimal cost.

3 Models for compound risk assessments:

Combining multiple risk information sources and assessments into a single model, incorporating the effects of disaster shocks (including climate and pandemics), with financial and socio-economic indicators (such as unemployment rates, sectoral-level supply deficit, or banks' non-performing loans and solvency ratios).

WAYS FORWARD

As the success stories in this report have demonstrated, there are significant advantages in using innovative technologies to advance DRF in disaster-prone areas. However, despite these proven benefits, the challenges (mentioned above) limit the potential for scaling-up and increasing uptake of these technologies, which is necessary for their potential to be fully realized. Subsequently, the CRFA team continues to work diligently to overcome these barriers. They are doing so by making sustainable financial resilience programs more accessible and by refining their strategic vision on a regular basis, in order to meet the changing needs of World Bank client countries.

The main focus remains on providing support to demand-driven, operational work through innovative and at-scale implementation of advanced technologies. Capitalizing on previous results and addressing the identified challenges, the priority is to maintain and expand the applications, and provide financial risk management insights to post-shock response on a larger scale, by continuing to:

1 Raise awareness on availability and applications of advanced technology to meet the specific needs of clients.

With the constant development of new technologies and data sources, particularly, the increased user-friendliness of satellite EO based methods, opportunities for advancements in DRF abound. Processes that used to be very complex are now being streamlined and set up for non-experts users, an example being the NGDI platform. Nevertheless, the team will continue to deepen the understanding of “fit for purpose” technologies that enhance DRF outcomes through demonstrations of practical applications designed to meet clients’ needs.

2 Build and strengthen the technical capacity by facilitating the transfer of skills and knowledge.

The CRFA program must ensure client ownership, long-term sustainability, and adoption of technologies, notably through the partnership between the WBG and ESA under the Space for IDA initiative[8] and transforming the projects into public goods. This will be done by building on existing capabilities and assets for data production and analysis. The CRFA program seeks to directly involve the main stakeholders in the design and planning of activities, thus leveraging local resources and building institutional capacity to promote long-term uptake.

3 Bridge the gap between the complexity of the technologies and financial resilience needs.

The CRFA program must take on the role of facilitator to ensure data can be processed and streamlined into financial decision-making; with the goal of systematizing the use of high-quality data for DRF policy-making and planning. In this role, the team will continue to address the complexities associated with the application of new technologies by providing technical advice and developing innovative solutions informed by implementation work for client countries globally.

8 Caribou Space, “Satellite Environmental Information and Development Assistance: An Analysis of Longer- Term Prospects,” 2019, https://eo4society.esa.int/wp-content/uploads/2020/01/ESA-Space-for-IDA-v3.pdf.

Overall, the technologies featured in the success stories enhance the client's capacity to respond to three critical needs: anticipating predictable crises, acting more quickly to avoid losses, and enabling localized responses to crises. By taking these needs into account, the CRFA team and its collaborators have been able to develop cutting-edge technological products that increase the ability of states to prepare themselves and quickly respond to the onset of a shock. As work in this field progresses and evidence mounts regarding the usefulness of these technologies to improve financial resilience, efforts are being made to raise awareness of existing applications, provide the technical expertise clients need to facilitate adoption, and the sharing of knowledge to sustain momentum for mainstreaming these technologies into DRF products and policies, while fostering a culture of risk-informed decision making.

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