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MENAdrought Project Achievements and Prospects in Morocco

Final Report

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والتنمية القروية والمياه والغابات
Ministère de l'Agriculture, de la Pêche Maritime,
du Développement Rural et des Eaux et Forêts

An IWMI training session for the Drought Monitoring Group of the Department of Strategy and Statistics in September 2022.

MENAdrought Project Achievements and Prospects in Morocco

Final Report

Submitted to: USAID Bureau for the Middle East

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International Water Management Institute (IWMI); Department of Strategy and Statistics (DSS) of the Ministry of Agriculture, Maritime Fisheries, Rural Development, Water and Forests of the Kingdom of Morocco. 2022. *MENAdrought project achievements and prospects in Morocco: final report*. Project report prepared by the International Water Management Institute (IWMI) for the Bureau for the Middle East of the United States Agency for International Development (USAID). Washington, DC, USA: USAID; Colombo, Sri Lanka: International Water Management Institute (IWMI). 18p. doi: https://doi.org/10.5337/2023.200

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Overview

MENAdrought is a demand-led applied research and technical support project whose objective is to aid the project countries in building self-reliance in managing the impacts of drought on water and food security in order to limit social and economic losses.[1] It came into being following the High-Level Meeting on National Drought Policy (HMNDP) convened by the World Meteorological Organization (WMO) in 2013, where countries in the Middle East and North Africa (MENA) region sought technical support to improve drought monitoring and management in their water and agricultural systems.

Morocco was involved in the MENAdrought project from its inception. Its participation in specific activities was structured by a formal request from HE the Minister of Agriculture, Maritime Fisheries, Rural Development, and Water and Forests in the form of a Letter of Interest 3696-DSS (2019) and correspondence with the Director General of the International Water Management Institute (IWMI).

The MENAdrought project applies the Three Pillars framework of WMO's Integrated Drought Management Programme (WMO and GWP 2014). The Three Pillars (Figure 1) include monitoring and early-warning systems, impact assessment, and planning to implement drought risk reduction and crisis response management, working together in a holistic manner to realize Sendai Framework objectives.

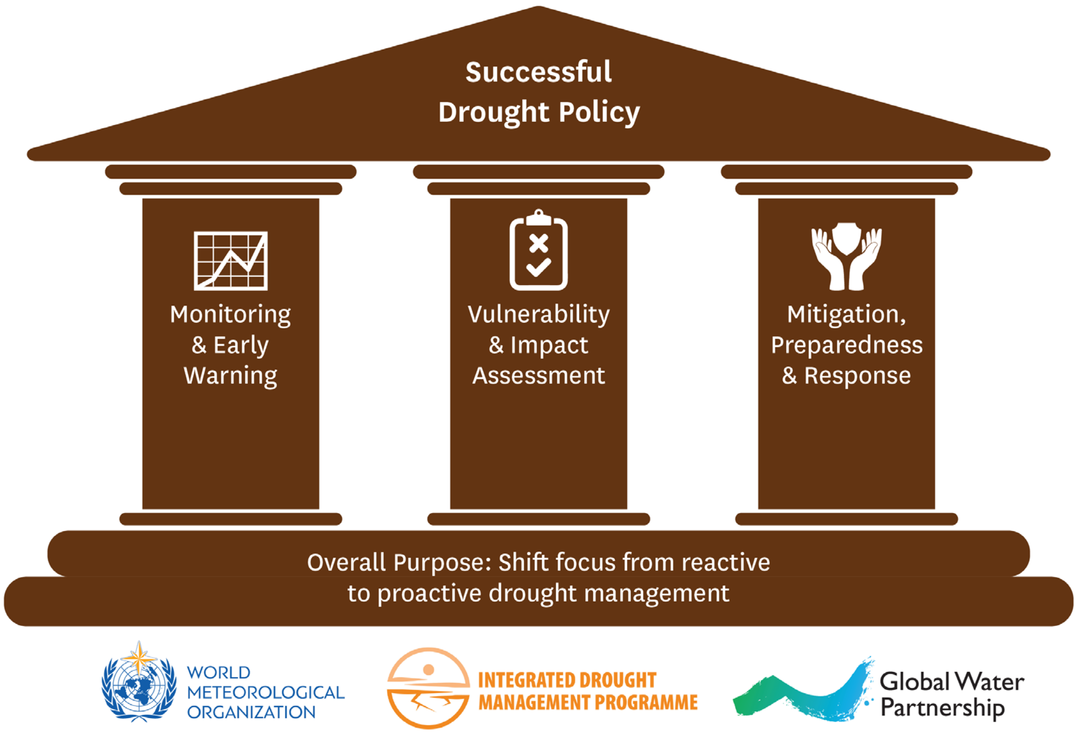

Figure 1. The Three Pillars approach of WMO's Integrated Drought Management Programme. Source: www.droughtmanagement.info

The project team took a 'working with the grain' approach (Levy 2014) to activities with the Department of Strategy and Statistics (DSS), and collaboratively and iteratively developed, tested, refined and applied the enhanced Composite Drought Indicator (eCDI) monitoring product and seasonal forecasting tools for Morocco.

[1] https://menadrought.iwmi.org/

This report focuses on Pillars 1 and 2, and summarizes the Moroccan drought context, the DSS's capability for operational monitoring of drought and forecasting of rainfall on a seasonal basis, and the usage of the tools and web interfaces. In concert, these approaches support thematic drought monitoring and reporting for major crop types with a primary focus on rainfed agricultural systems including cereals and rangelands.

The Drought Context in Morocco

Drought History and Hazard

Tree ring studies dating back to the 12th century indicate recurrent drought periods in Morocco, with the last two decades among the most severe in the last 1,000 years (Touchan et al. 2011). The series of droughts experienced from the 1980s to the present indicate a long-term drying trend (Esper et al. 2007). The imperative for improved drought management is clear, with climate projections indicating a warmer and drier future in Morocco (Niang et al. 2014). The Three Pillars (Figure 1) include monitoring and early-warning systems, impact assessment, and planning to implement drought risk reduction and crisis response management, working together in a holistic manner to realize Sendai Framework objectives.

Analysis using the eCDI shows two major drought periods between 2001 and 2022: the first in 2001, an extension of a dry period that began in 1998, and the second occurring during 2018-2020 (Figure 2).

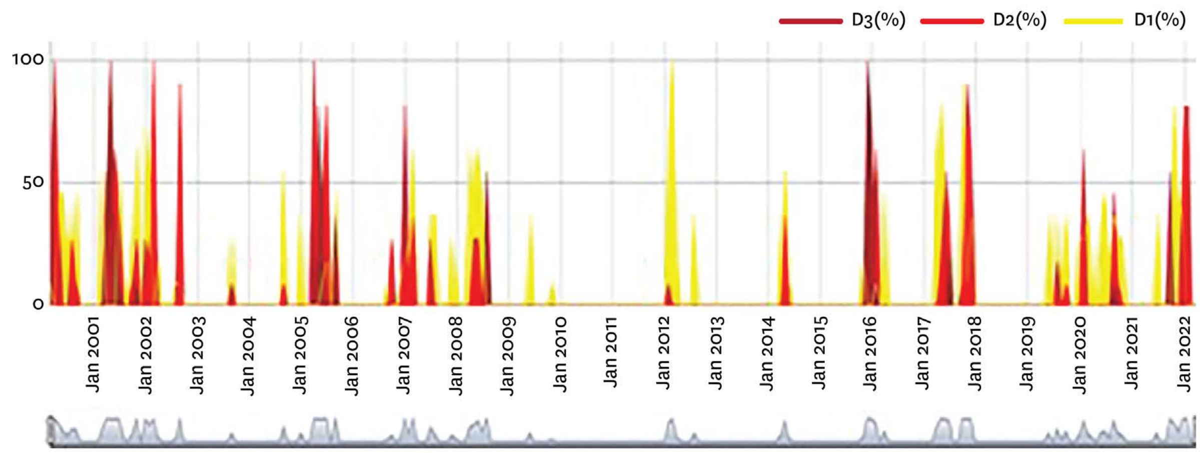

Figure 2. Drought severity in Morocco during the period 2000-2022.

These were primarily years of creeping drought in which there is a continual and gradual increase in intensity and extent, or late-onset droughts that begin after winter. In 2007 and 2008, drought was interspersed over the year. In 2005, 2012 and 2016, there were quick-onset and intense droughts that, though quick to subside, still had significant impacts.

Areas with consistently higher climatological drought hazard predominantly include the densely populated Atlantic coastal plains from Tangiers to Souss-Massa and Figuig province. Areas with consistently lower climatological drought hazard include the Atlas and Anti-Atlas Mountains, as well as Taounate and Fes in the Rif, and Tan-Tan province (Figure 3).

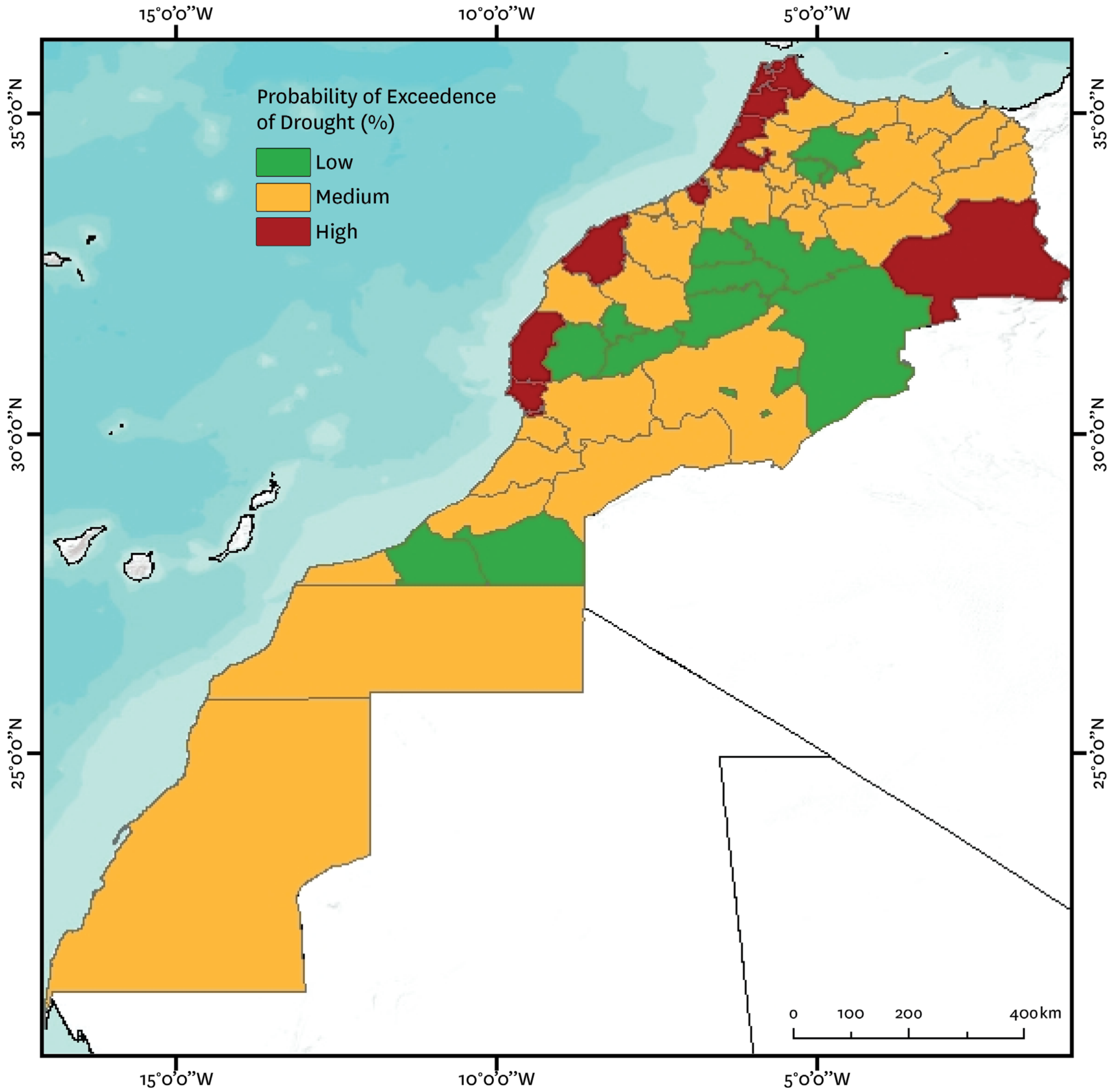

Figure 3. Climatological drought hazard risk in Morocco.

Drought Impacts

We used quantitative, geospatial and participatory research methods across multiple impact assessment approaches as per the typology recently developed by King-Okumu (2019). The quantitative and spatial analyses primarily related to assessments of drought impacts. The participatory research related to assessment of stakeholder needs for, and implementation of, drought monitoring and management in rainfed cereal and rangeland systems (linked to the Moroccan Rangelands Law 113-13 of 2016).

Drought impacts various socionatural systems including agricultural and hydrological systems (FAO 2018). Agriculture is a critical component of the Moroccan economy as it directly contributes about 14-20% of gross domestic product (GDP) and 40% of employment. In dry years, water availability can fall below the UN's absolute water scarcity threshold of 500 m^3/year per capita, and inflows to reservoirs can fall below 30% of an average year.

According to Moroccan stakeholders, the country's fragile ecosystems—including argan forests, oases and rangelands—are prone to desertification and can be significantly affected by drought. Argan forests in particular are highly sensitive to drought impacts due to natural and anthropogenic pressures. The relationship between drought and desertification is complex. While drought causes loss of biodiversity and productivity, which is exacerbated by overgrazing and mechanized nomadism, there is ample evidence that both recover when precipitation returns to more normal levels in the absence of other pressures. Endemic species are drought-tolerant. However, prolonged drought can lead to reduced seed propagation, and other pressures such as land clearance and overgrazing can greatly exacerbate erosion and/or encroachment of sand. Drought also exacerbates desertification and related environmental degradation including through the transformation of transhumance to uncontrolled nomadism.

Persistent dry conditions can upset rural development (Lybbert et al. 2009) and disrupt national-level commodity markets (Wilhite and Glantz 1985; Van Loon et al. 2016). Drought reduces national and agriculture sector GDP, and the government expends significant resources on intervention programmes. The highest impact by far was felt in 1981 (nearly USD 1 billion), and in 2000, the cereals deficit reached a value of about USD 530 million, or nearly 4% of government expenditure for that fiscal year (FAO 2018).

In addition, drought causes challenges related to access to water due to availability problems and water quality degradation.

Drought Management

Over the past 40 years, the Government of Morocco has progressively advanced drought risk management. It has introduced legal and governance frameworks, established monitoring networks and capacity, invested in water supply and distribution measures, developed financial risk- and crisis-coping mechanisms and undertook emergency management. Most importantly, it has learned from the lessons of the recent past. The most calamitous effects of the drought of the early 1980s (for example, livestock herd collapse) were avoided in the intense early 1990s drought. Further, following the early 1990s drought, government responses targeted the next "tier" of drought impacts and management issues (for example, financial risk management of rainfed cereals) and so on.

Morocco's drought management mechanisms have included post-impact interventions, pre-impact programs for mitigation, and development of policies and preparedness plans. In sequence, these range from coping to adaptation mechanisms.

The government of Morocco undertakes a range of short-term coping interventions in the livestock and rainfed and irrigated agriculture subsectors, as well as interventions in municipal water supplies and financial and labor markets. Opportunities remain, however, to improve adaptation through human and social capital development, particularly through education, technical knowledge, and improving linkages throughout agricultural value chains.

A multi-risk insurance product offered by the firm Mutuelle Agricole Marocaine d'Assurance (MAMDA), primarily for rainfed cereals, is a core pillar of Morocco's drought coping and adaptation strategy. It has proven effective by providing quick payouts to farmers during the two drought years experienced since 2015 (speed of payouts is critical to recovery in the season following a drought). More widely, Morocco's efforts to improve adaptation to drought in the water and agriculture sectors have focused on a range of themes including:

- expanding surface water storage infrastructure and interbasin transfers;
- expanding groundwater abstraction;
- expanding, intensifying and increasing irrigation efficiency;
- developing insurance products and subsidizing their purchase for rainfed cereals;
- reducing dam siltation;
- developing non-conventional water resources;
- demand management; and
- shifting incentives from cereals cultivation expansion in marginal environments to growing drought-tolerant tree crops, particularly olives.

Development of the Enhanced Composite Drought Indicator (eCDI)

Requirements and Approach for eCDI Development

The DSS specified a range of requirements for drought monitoring and management, and the eCDI specifically, through the needs assessment process reported by Fragaszy et al. (2020) and Jedd et al. (2020), as well as subsequent engagements during the MENAdrought project. These needs included:

- Output temporal requirements: rapid and frequent production of the eCDI—at least monthly production and low "latency", so that, for example, December conditions are reported in early January.
- Output spatial requirements: high enough spatial resolution to capture major production basins and shifts in agro-ecological zones
- Ease of production and use: must be producible by DSS taking into account computing and modelling requirements, internet bandwidth, technical staff capacity and capability, and institutional setups.
- Initial focus on agriculture and particularly rainfed systems: primarily rainfed cereals and rangelands, which are the basis of smallholder agricultural systems in the country.
- Adequate accuracy and precision for drought management policy decision-making: need confidence in the information produced to support decisions that have major political economic ramifications.

Accordingly, co-development of the eCDI in Morocco occurred in four primary stages, during which the DSS was closely involved with or led core workstreams:

- Stage 1 (2016-2018): Establishment of the initial modeling framework and production of the 'default' CDI;
- Stage 2 (2018-2019): Input calibration and initial model output validation;
- Stage 3 (2019-2021): eCDI model refinement and process improvement; and
- Stage 4 (2021-2022): eCDI model operationalization and validation for monitoring drought in rainfed agricultural systems including cereals areas and rangelands, development of a web interface to generate basin- and administrative-level statistics of the Drought Severity and Coverage Index (DSCI), development of prototypes of rainfall seasonal forecasting and crop-type mapping, and training and capacity-building.

eCDI Composition and Production

The eCDI-based Moroccan Drought Monitor, co-developed, owned and independently operated by DSS, generates drought maps for policy decision support (Bergaoui et al. 2022). It is a spatialized and weighted index produced using a combination of remote-sensing and environmental modeling inputs. It is based on anomalies relative to average conditions since the year 2000 for a specific month and a 5 x 5 km grid location:

- Three-month Standardized Precipitation Index (SPI, 40% weighting)
- Normalized Difference Vegetation Index (NDVI, 20%)
- Root zone Soil Moisture Anomaly (SMA, 20%)
- Day-night land surface temperature (LST) amplitude anomaly (20%)

Following integration, eCDI values for each pixel are categorized into one of the following classes through percentile ranking:

- Exceptional drought (D3, dark red, return period of 50 years) <2%
- Severe drought (D2, light red, return period every 10 years) 2%<eCDI<10%
- Moderate drought (D1, yellow, return period every 5 years) 10%<eCDI<20%

We have a similar ranking for wet conditions (80-90%, 90-98% and >98%). The white color signifies normal conditions (20%<eCDI<80%). An example is shown in Figure 4.

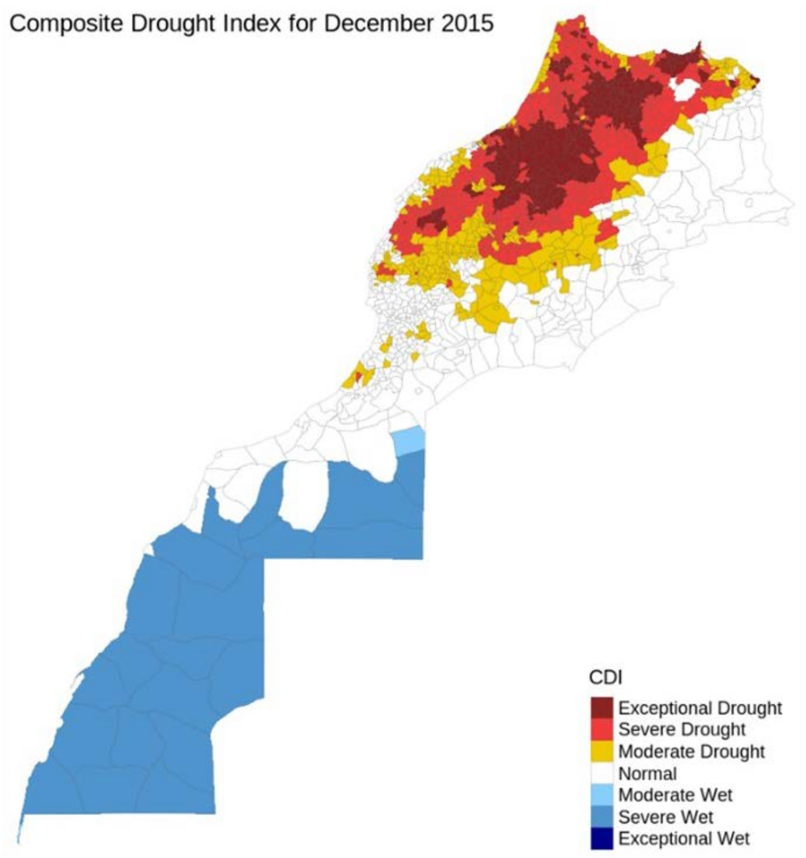

Figure 4. Example of the enhanced Composite Drought Indicator (eCDI) map of Morocco for the month of December 2015.

eCDI Validation, Refinement and Production, and Use in Drought Management

The iterative eCDI development process incorporated quantitative and qualitative validation components to assess the accuracy of the modeled inputs and the eCDI as a whole, and to support subsequent refinements. These initial assessments included:

- Relationship with cereals production and yields;
- Comparison with available observation data;
- Assessment of performance as a function of land cover and use; and
- Qualitative assessment of eCDI performance with key stakeholders.

The satellite-derived precipitation information used in the eCDI compared favorably with ground station precipitation monitoring data. The eCDI showed a better relationship with cereals production and yield data than each of its individual components considered alone.

During the MENAdrought project, we improved the eCDI's performance primarily by changing the data inputs, adding model components, undertaking additional data pre-processing, and modifying the eCDI calculation to reduce errors due to cloud cover and to provide additional (temporal and spatial) datapoints for eCDI calculations using a sliding window technique.

We also simplified the modeling system such that almost all processes are undertaken through a reproducible model workflow. This enables production of monthly drought maps within 10 days of the new month and will help ensure that agencies are able to continue production of the eCDI independently beyond the term of the funded MENAdrought project.

Finally, we developed a web interface to ease visualization, dissemination and additional analysis of eCDI information.

Validation of eCDI for Use in Monitoring Pastoral Areas

After testing the eCDI for monitoring drought in cereal-based systems, we tested its applicability for other purposes. Initial evaluation of its use for monitoring rangelands indicated that it is highly correlated with barley production, which we consider a relevant proxy for productivity of annual rangeland species (see the next section).

Further, Regional Departments of Agriculture in Morocco supported the development of validator networks comprising local agriculture officials who assessed local drought conditions and commented on the perceived accuracy of eCDI outputs. From November 2020 to March 2021, these officials assessed the accuracy of the drought severity and extent shown in the monthly eCDI maps in relation to the pastoral areas they monitor. They also provided information on the most affected localities as well as the status of annual and perennial biomass (including evidence of degradation or regeneration), livestock loading, heat stress, snow cover and unusual transhumant movement. This validation covered the primary rangelands areas—over 1,900,000 ha in the arid, semi-arid and subhumid bioclimatic zones—and provided an important means of connecting data generation to field conditions and those who oversee them.

Overall, these validators judged the eCDI to be 73% accurate (average reported accuracy for drought geography and drought intensity) within a range of 57-83% depending on the specific pastoral area and month (Figure 5). The lowest accuracies were reported for forest areas in the Beni Mellal-Khénifra and Fès-Meknès regions and areas affected by snow cover. The values reported for December and March were 97% correlated with all the months of the season, which shows a strong alignment with the cumulative eCDI trigger.

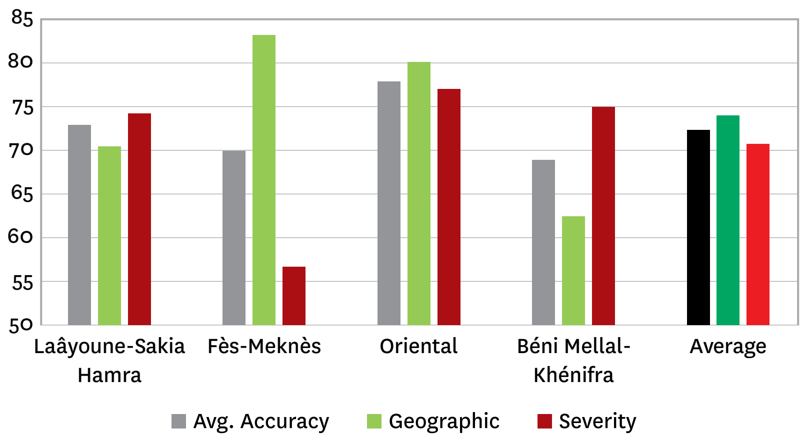

Figure 5. Estimated accuracy of the eCDI in assessing drought geography and intensity in the principal 28 pastoral zones of Morocco (approximately 1.95 Mha) during the period November 2020 to March 2021.

These results, together with an assessment of the eCDI's relationship with barley production shown in the following section, suggest that the eCDI is broadly useful for monitoring conditions in rangelands in the most important arid and semi-arid areas. They also suggest a few simple changes to its calculation (for example, masking forests and snowy areas) that could make incremental improvements in the accuracy of eCDI outputs for pastoral areas.

Development of Drought Triggers for Policy Decision Support

To develop "trigger" thresholds for drought management response actions, we assessed the eCDI results statistically and in relation to annual rainfed staple crop production and yield.

The cumulative eCDI is based on temporal aggregation of eCDI scores within a year to produce a single value per province/governorate, which can then be spatially aggregated. Deviation to maximum barley grain production was estimated as the ratio of production in a given season to maximum grain production over the period 2001-2020. This calculation was performed for quality-controlled data in 30 provinces (9 regions) out of 39. Deviations to maximum production were also calculated per bioclimate: subhumid, semi-arid superior, semi-arid intermediate, semi-arid inferior and arid zones. The cumulative eCDI trigger reflects relationships between eCDI values in specific months and annual production and yield of staple crops.

The Moroccan cumulative eCDI incorporates a statistically derived (stepwise regression) weighting system for the eCDI values of December and March of a given year. We applied a stepwise regression between monthly December-March eCDI values and the yearly deviation to maximum barley production (predictor) to deduce a single CDI value per year as a cumulative eCDI that was estimated to be

$0.1205 + (0.2309 \times eCDI_{December}) + (0.4237 \times eCDI_{March})$.

The cumulative eCDI represents a metric of drought severity that is spatially scalable for all agroecological zones in Morocco (Figure 6). Regressions were significant in all bioclimates except the subhumid zone, where forests are predominant, indicating the need for use of a land-use mask.

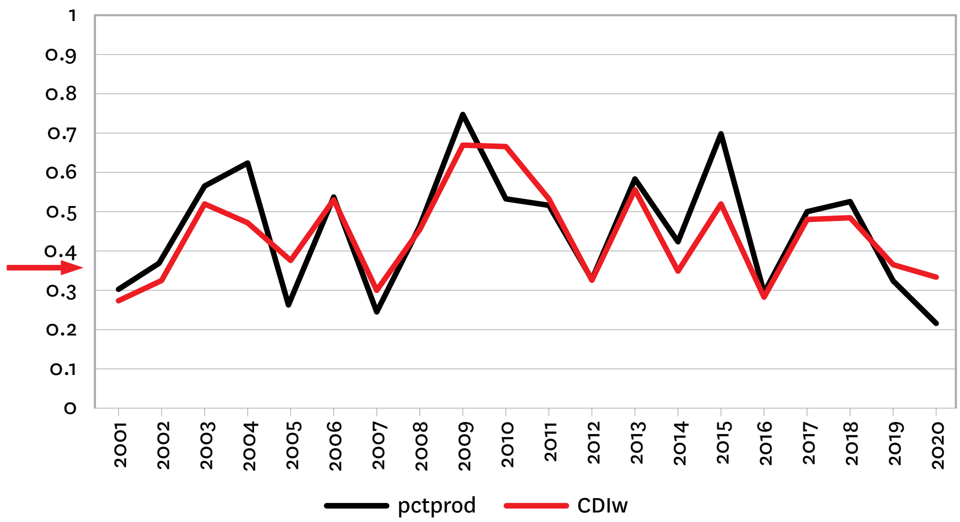

Figure 6. Time series presentation of cumulative eCDI (red curve) and deviation to maximum barley grain production (black) for all agroecological zones in Morocco. The arrow corresponds to the trigger value to avoid a crisis due to production reduction >60%.

Seasonal Precipitation Forecasting

The MENAdrought team developed convolutional neural network (CNN) models, an artificial intelligence approach, to improve global precipitation forecasts in relation to major climatological regions in Morocco (Figure 7). We trained the CNN models using observation data from the 2000-2014 period and applied regionalization techniques for the test period 2015-2019.

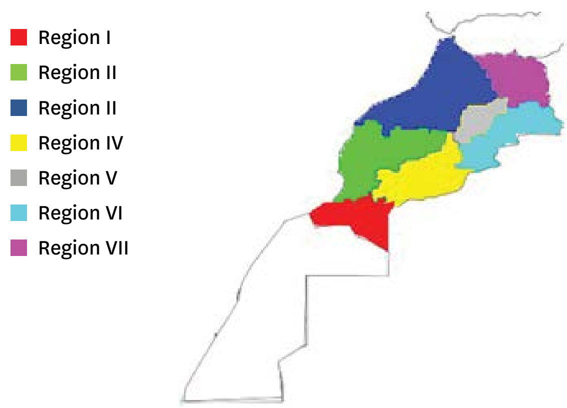

Figure 7. Morocco's climate regions as determined using 1982-2020 CHIRPS precipitation data.

In our first test of the CNN models, despite using only one type of predictor (four precipitation forecasts from a global modeling center), our CNN model accurately forecast precipitation with lead times of 2-3 months. The CNN models' outputs showed major improvement from the global forecast in terms of the spatial location of precipitation as well as the volumes and anomalies.

Subsequently, we improved the accuracy of the CNN models by adding sea surface temperature predictors. The final model accurately forecast the location and timing of drought onset (using SPI) and recovery in Morocco in 2015-2016 and 2021-2022. Overall, the CNN-produced forecast with a two-month lead time had a very high correlation with observed (CHIRPS) rainfall in the subhumid regions of Morocco with an r value of 0.93, and acceptable correlation in the semi-arid regions with an r value of 0.75 (Figure 8).

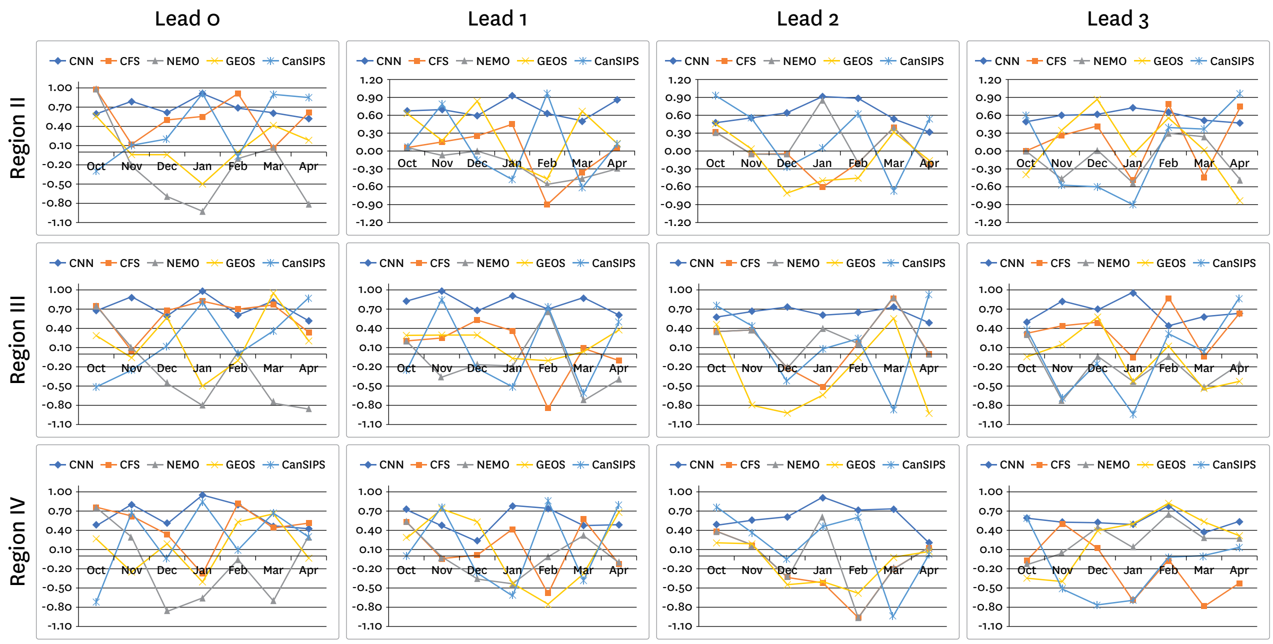

Figure 8. Correlation coefficient between modeled data using dynamical models and the CNN for regions II, III and IV of Morocco.

Pilot Development of Operational Crop-Mapping Software

We developed a prototype operational software for crop-type mapping that is intended to be easily usable by staff of the Moroccan Ministry of Agriculture in several applications to:

- increase the accuracy of annual crop-failure statistics;
- support decision-making on drought management response measures in major rainfed and irrigated cropping systems;
- direct ground-truthing teams surveying drought impacts on cereals damages together with the insurance firm MAMDA and the agricultural bank Crédit Agricole du Maroc (CAM); and

- to enable future development of the drought-monitoring and early-warning system including thematic drought-risk mapping and yield forecasting for staple crops.

The advanced machine learning software developed for Morocco and tested in the 'intermediate' bioclimatic zone around Rabat uses open-source Sentinel satellite imagery to identify over 80 crop classes (Figure 9). To date, the greatest success has been scored with annual field crops. Future work should aim to improve results for orchards.

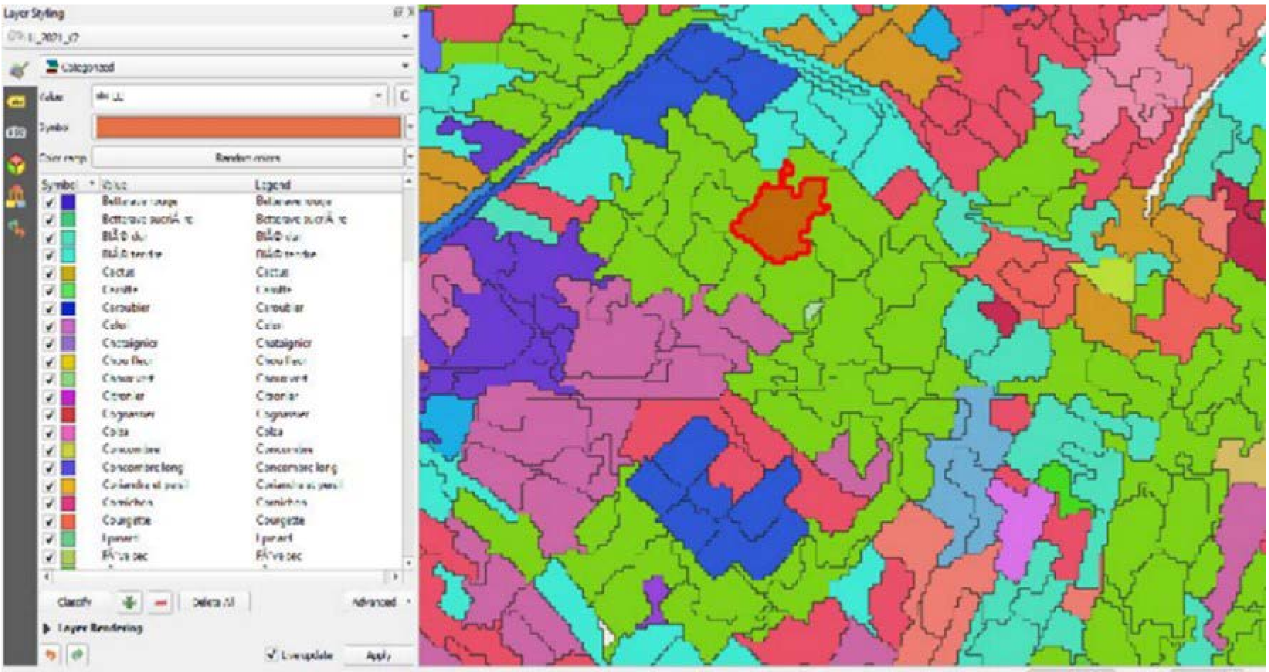

Figure 9. Example of crop-type mapping software output.

Going forward, this approach could be used in other countries if established training data approaches are adhered to.

Development and Institutionalization of Drought Monitoring Capability

A core focus of our system design and associated engagements has been for the project outputs to function and support agency decision-making after the MENAdrought project is completed. This is achieved through the choices of data inputs, and by building capability, technology transfer, and institutionalization of the developed tools and skillsets. For example, input data were chosen based on various criteria such as data being cost-free, length of available data record, radiometric sensing channels that can detect key drought indicators, spatial and temporal resolutions, and the commitment of the data providers to maintain their provisioning systems. The eCDI developments were themselves underpinned by explicit and iterative assessment of partners' needs and collaborative processes. This social and technical effort supported the project's development of drought early-warning systems and their operationalization, including through drought management planning.

These efforts included targeting validation studies with local partners, technical tool co-development and associated research efforts toward specific policy implementation goals in the project countries. Collaborative development efforts have focused on supporting implementation of new legal regimes (namely Water Law 36-15 and Rangelands Law 113-13, both from 2016), including through supporting increased central and local government interaction, collaboration and information-sharing.

We supported various capacity-building approaches through training, technology transfer, and iterative modeling refinements. These covered all the technical aspects required to produce the eCDI operationally and use it effectively:

1. Model installation, parameterization, and calibration;
2. Input data preparation, pre-processing, and model execution;
3. Output interpretation and validation; and
4. Information-sharing.

We focused particularly on simplifying and expediting model execution processes, primarily by streamlining input data preparation, pre-processing and coding frameworks to operate the model. In many cases, this required novel methods and coding frameworks to address the issues identified through ongoing operation of the eCDI over time. It also included training officials with technical and policy roles in the usage of this information for drought impact and vulnerability assessment, as well as in drought management planning and related applications.

The needs assessments initially identified barriers to information-sharing earlier at the start of the project as a key problem for existing drought monitoring and management. We sought to address this through careful prioritization of drought monitoring information required through drought management planning as well as supporting the integration of eCDI outputs into other tools, which Moroccan agencies now do regularly.[2] More broadly, though, the eCDI validation efforts, and especially the creation of a network of regional validators, support the objective of institutionalizing drought monitoring and early warning within the Three Pillars framework.

Conclusions and Prospects

In the first phase of the MENAdrought project, the IWMI-led team worked primarily with the DSS in Morocco to implement drought risk management approaches. Key achievements in Phase 1 included the following:

- Developed a comprehensive understanding of drought impacts;
- Met stakeholders' needs for robust scientific evidence (near-real-time monitoring, rainfall seasonal forecasting and spatial data outputs) about drought to help drought management decision-making; and
- Established reliable operational systems for drought monitoring that are trusted by national decision-makers and reflect drought impacts on different components of the water cycle.

Some of the wider benefits of the project included the following:

- Supported governmental feedback and broader participation in policy processes through the establishment of mechanisms for local feedback to the central government via drought monitoring validation networks and

[2] See Indice Composite de la Sècheresse.

some publication of drought monitoring outputs. This sets the basis for possible permanent local feedback networks and/or public information sharing.

- Used open-source and publicly available models to facilitate wider uptake.

Producing data through early-warning systems was the first step. The DSS highly valued the knowledge they gained and the information generated, so during recent training and results dissemination sessions, the DSS Drought Monitoring Group requested a continuation of the project to build on the solid MENAdrought foundation. Subsequently, the project team developed a proposal for a second phase.

We consider this work to be especially pertinent and important for Morocco now given the international context of rapidly increasing food and agriculture-related commodity price rises and the associated risks to food security. Moroccan stakeholders have identified a range of needs for improved drought monitoring and management in relation to the legislative frameworks provided by the Water Law 36-15 and the Rangelands Law 113-13.

We suggest several potential future research-for-development opportunities that build on MENAdrought's technical achievements. These primarily extend MENAdrought's efforts to date in the technical and drought planning components of the project. Near-future eCDI improvements would focus on modeling improvements as well as building support networks and user/stakeholder engagement mechanisms (Network of Drought Impact Reporters). The research opportunities focus on sector-specific drought mapping and forecasting tools. The latter tools especially relate to crop production and rainfall runoff (streamflow) modeling linked to crop-type mapping, seasonal forecasting and the development of associated information-sharing platforms. They would enable the expansion of drought early-warning systems to cover related food and water security elements, and potentially also associated economic and financial risk components.

We now propose that IWMI, in partnership with leading international centers working on water and food security, collaborate with international and regional partner organizations to:

a) Develop sector-specific drought mapping and forecasting tools;

b) Develop operational water and food security monitoring and forecasting systems; and

c) Implement interactive decision-support systems and dashboards for financial actors.

The systems could be used in a coordinated way across multiple ministries to meet the objectives of the Nationally Determined Contribution reports to the United Nations Framework Convention on Climate Change. This requires a long-term commitment to supporting key government agencies and emerging drought management institutions that oversee drought preparedness, mitigation and response actions.

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This document was made possible through the support of the Office of Technical Support, Bureau for the Middle East, U.S. Agency for International Development, under the terms of Award No. 7200-ME-18-10-00001. The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the U.S. Agency for International Development or the United States Government.

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