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Drought Monitoring in the Middle East and North Africa (MENA) Region: Participatory Engagement to Inform Early Warning Systems

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Abstract: When drought hits water-scarce regions, there are significant repercussions for food and water security, as well as serious issues for the stability of broader social and environmental systems. To mitigate these effects, environmental monitoring and early warning systems aimed at detecting the onset of drought conditions can facilitate timely and effective responses from government and private sector stakeholders. The study uses multi-stage, participatory research methods across more than 135 interviews, focus groups, and workshops to assess extant climatic, agricultural, hydrological, and drought monitoring systems, key cross-sector drought impacts, and drought monitoring needs in four MENA-region countries: Morocco, Tunisia, Lebanon, and Jordan. This extensive study of user needs for drought monitoring across the MENA region is informing and shaping the ongoing development of drought early warning systems, a Composite Drought Indicator (CDI), and wider drought management systems in each country. Over-arching themes of drought monitoring needs include: technical definitions of drought for policy purposes, information-sharing regimes and data-sharing platforms, ground-truthing of remotely-sensed and modeled data, improved data quality in observation networks, and two-way engagement with farmers, organizations, and end-users of drought monitoring products. This research establishes a basis for informing enhanced drought monitoring and management in the countries, and the broad stakeholder engagement can help foster the emergence of effective environmental monitoring coalitions.

Capsule Summary: We found a range of user needs to inform the development of drought monitoring and early warning systems in four countries in the Middle East and North Africa (MENA) region through engagement with governmental, academic, civil society, private sector, and international organizations.

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1. Introduction

The Middle East and North Africa (MENA) region is classified as the world's most water-stressed (World Bank 2017). MENA countries have about 6.3% of the world's population yet only 1.4% of the world's renewable fresh water (Roudi-Fahimi et al. 2002). Evidence from across the region suggests that recent decades have been among the driest in the past millennium (Cook et al. 2016; Touchan et al. 2011), and the severity of droughts from this period is partially attributable to anthropogenic climate change (Bergaoui et al. 2015).

With the dual pressures of climate change and demographic growth, water security is an increasingly pressing concern (World Bank 2017). Already regional leaders identify water crises, of which drought is a precipitating factor, as the most important threat for which they are the least prepared (World Economic Forum 2015). Globally, the World Economic Forum's (2018) Global Risk Report identifies extreme weather events as the most likely and second most impactful risk.

Evidence from the region suggests droughts are among the costliest natural hazards in economic and social terms. In MENA countries, droughts significantly affect national budgets, export earnings, and import bills (e.g., Baubion et al. 2017; Marx and Fouquet 2013). They also contribute to social disparities, negative health impacts, rural outmigration, and broader political disruption (Raleigh et al. 2010, Tangermann and Bennani 2016, Stanke et al. 2013, Weinthal et al. 2015).

Given the region's inherent water scarcity and the scale and severity of drought impacts, drought risk management is a critical undertaking, and one that is underpinned by effective monitoring and early warning systems. The Integrated Drought Management Programme (IDMP, see http://www.droughtmanagement.info), an international collaboration of agencies supporting

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drought risk reduction and planning around the world, describes drought monitoring as the first key component, or pillar, of drought risk management (Wilhite 2014). Past assessments have described MENA drought monitoring systems as nascent, overly-reliant on precipitation-based indices, and in great need of wider stakeholder involvement and participatory development processes (e.g., Erian 2011, UN-ESCWA 2013, World Meteorological Organization 2006).

Because droughts are measured by their local effects, no single definition or indicator alone is sufficient to capture the full range of drought impacts on a given sector (Wilhite 2000). As a result, there has been a movement towards a Composite Drought Indicator (CDI) approach that combines several indicators into a single product through a "convergence of evidence" framework (Svoboda et al. 2002, Hayes et al. 2012).

However, bringing these indicators together requires the support of numerous agencies and organizations. Such public participation in water management has been called "a nuisance and a necessity" because it can slow decision-making (Newig and Fritsch 2009), but also results in improved outcomes (Wall and Hayes 2016) and lasting resilience through collaborative arrangements between the public and private sectors (Johannessen et al. 2014).

Pulwarty and Sivakumar's (2014, p. 14) review of 21 drought early warning systems from across the globe highlights that successful systems rely upon "multi-sectoral and interdisciplinary collaboration among all concerned actors at each stage in the warning process." Ideally, development of drought early warning systems involves the end-users in their creation to ensure that current conditions (as perceived by those affected) are built into monitoring systems. This ultimately results in more accurate information that is more likely to be incorporated in drought risk management policies or programs.

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This paper presents stakeholder-identified needs to improve drought early warning systems and their linkages to drought governance mechanisms in the MENA region. These findings come from a participatory engagement process to develop improved early warning systems including a CDI in four case study countries: Morocco, Tunisia, Lebanon and Jordan. This research was a core component of a USAID-funded project to develop the MENA Regional Drought Management Systems (MENA RDMS).

In addition to informing the development of drought early warning systems, the research helped establish collaborative networks that will be critical to drive long-term drought monitoring improvements and may contribute to the development of environmental monitoring coalitions. The research contributes specifically to the literature on development of environmental monitoring tools and more generally to discussions of water security and management issues in the MENA region.

2. Project structure and participatory approaches

2.1 Project background and structure

The MENA RDMS project builds on past collaborations with Moroccan government agencies and academic researchers to develop drought monitoring tools focused on rainfed cereals and rangelands. These sectors form the basis of smallholder agricultural systems across the MENA region and are therefore critical for food security and socio-economic stability (Hazell et al. 2001). The Maroc CDI produced through that effort (Bijaber et al. 2018), which is a 5x5km gridded dataset that can be produced monthly or more frequently, formed the initial "template" for the MENA RDMS project.

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The CDI produced through the MENA RDMS project primarily incorporates open-source satellite and modeled data and, as a result, is not resource-intensive to produce. Initial inputs and weights for the CDI were:

a. Vegetation stress 20% – NDVI anomaly derived from eMODIS (Senay et al. 2015)
b. Precipitation deficit 40% – SPI 2-month from CHIRPS (Funk et al. 2014)
c. Evapotranspiration anomalies 20% – evaporative stress index (Anderson et al. 2013)
d. Soil moisture anomaly 20% – Land Information Systems modelled data (Kumar et al. 2006)

Because CDI inputs are indicator anomalies relative to short- to medium-term baseline conditions for the specific pixel, CDI outputs inherently reflect local drought as baselines shift due to climate change. However, recent years will be the “leading edge” in this baseline shift, and so one would expect more frequent occurrence of severe drought observations than statistically normal given predictions of climate change impacts in the region (IPCC, 2014).

The MENA RDMS project followed the structure shown in Figure 1. The needs assessments, the findings of which are reported here, sought participant information on current and desired drought monitoring and management practices. These assessments informed the next steps of the process: 1.) for the project team to work with central government agencies involved in developing and producing the CDI operationally (hereafter core agencies) in each country to tailor the CDI to national needs and incorporate it in drought governance structures, and 2.) the launch of further studies on drought impacts and vulnerabilities to help identify priority impacts, regions, sectors and populations as well as potential policy avenues to address the priorities.

Insert Figure 1 here

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2.2 Participatory approaches to developing environmental monitoring tools and coalitions

In order to ensure early warning systems are effective and meet users' needs, it is critical for those who design them to consider drought impacts on society, drivers of drought vulnerability, and the wider social, environmental, and political milieu in which the monitoring takes place (Bachmair et al. 2016). This requires effective engagement between government agencies, civil society organizations (CSOs), the private sector, and research institutions (Pulwarty and Sivakumar 2014). Participatory research methods can provide these required information inputs and, through their engagement aspects, lay the foundation on which longer-term environmental monitoring coalitions can develop.

Participatory research for drought monitoring involves working with stakeholders in an empowerment aspect (capacity building) as well as incorporating participants' observations into knowledge systems. Wide stakeholder involvement is a core feature of successful drought monitoring regimes, and it contributes to more effective drought planning and management (Wilhite et al. 2014). For example, researchers worked with the Hopi Native American community in the Southwestern U.S. to incorporate local drought experiences and climatological indicators (such as a rain gauge observer network) into drought monitoring and management systems; this was an improvement because they found that the previously best-available product, a national map of drought conditions, reflected regional trends but had failed to capture fine scale detail needed for planning (Ferguson et al. 2016).

Drought management is inherently political, and given the stakes for society and sums of money connected to intervention programs, it is a politically charged issue around the world (Mount et al. 2016). To give a MENA example, public expenditure on drought emergency responses in Morocco reached $USD318 million in 1999-2001, an amount equal to 2.3% of total

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government spending in 1999-2000 (Ouassou, 2007). Often only a disaster can provide the political will and therefore policy window to amend drought monitoring and management systems and create new, broad-based coalitions (Low et al. 2015; National Drought Policy Commission 2000).

Indeed, the coalition surrounding water conservation and drought management in American agriculture took decades to build, starting from the major Dust Bowl droughts of the 1930s. This grew over time to encompass regular drought monitoring activities (Wilhite et al. 2005) and is now codified in federal law as the United States National Integrated Drought Information System (United States Congress 2006). Browne (1988, p. 186) articulates the challenges well stating that “[t]he irony of coalitions, at least from the perspective of the participants, is that on more complex policy problems few interests can live without them.”

Likewise, in Australia prior to the 1990s, drought management included crisis relief responses driven largely by the perception that management or policies would have little effect to reduce drought’s impacts (Botterill 2005). However, through improved early warning systems and numerous small committee meetings, national dialogues, and international collaborations (Ibid.), Australia incrementally introduced policies intended to incentivize risk management, shift away from emergency assistance, and depoliticize the deployment of that assistance (National Drought Program Reform Review Working Group, 2018).

Several countries currently follow an iterative process of engagement across stakeholder groups with varied perspectives to improve drought monitoring. Brazil has built a monitoring program for its semi-arid northeast region and plans to expand monitoring eventually to the rest of the country (Hayes et al. 2017). The Brazilian monitoring program grew out of collaborations

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and workshops facilitated by scientists, practitioners, academic experts, and development groups within Brazil and from the U.S., Spain, and Mexico (Ibid).

Likewise, the governments of Morocco, Tunisia, Lebanon and Jordan are working to improve drought monitoring and early warning systems by boosting local expertise and networks with international support. Already, consultative bodies chaired by government agencies and including CSOs, businesses, and other non-governmental institutions contribute to drought declaration and mitigation planning in Morocco (Ouassou et al. 2007) and Tunisia (Louati et al. 2005). Various business sector representatives successfully lobby for interventions during droughts in Jordan and Lebanon, which do not have explicit national drought management policies or plans[1]. That is, in Morocco and Tunisia, non-governmental stakeholders are actively involved in decision-making discussions and implementation of decisions whereas in Jordan and Lebanon, stakeholders can lobby for outcomes but are not actively part of the decision-making process. These are meaningful beginnings to coalition-building and wider participation in policy processes.

In order to obtain the most accurate and useful technical information about a problem that has complex causes and effects, a network of experts must first identify interests, frame issues for debate, and propose responses (Haas, 1992). Though effective drought monitoring requires a cohesive network of observers (Svoboda et al., 2002), there is no single path to build this type of network from the ground up. The nascent literature on participatory drought monitoring contains examples of coalitions, networks, or observer groups and their specific objectives or modes of understanding the drought problem context (e.g. McNeeley et al., 2016), but little emphasis on how these groups were formed and how their needs were determined. Participatory research

[1] According to project interviews with Jordanian and Lebanese officials and civil society stakeholders.

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approaches offer an avenue to assess the needs of in-country producers, and end users, of climate information, and to subsequently modify the production of a drought monitoring tool.

3. Methods

The research fed into a technical development process, and so it required a progression of engagement. The research started with face-to-face individual and group discussions (hereafter called interviews) held from February to August 2016. Following the interviews, we conducted interactive workshops and surveys of workshop participants in each country from October 2016 to January 2017. In interviews and workshops, the research team applied International Association of Public Participation principles for engagement specialists[2].

3.1 Interviews

First we asked about drought impacts, secondly about existing drought monitoring practices and drought monitoring needs, and finally about current drought management activities and drought management needs. The purpose of this progression was to prime participants to consider what drought monitoring components were most relevant based on drought impacts they observe, and then to consider drought management in relationship to drought impacts and existing and desired early warning systems. The level of technical detail, length, and depth of discussion on each theme varied between interviews and depended on the specific participants. For instance, farmer union representatives tended to focus heavily on drought impacts and management whereas meteorologists focused heavily on drought monitoring themes.

[2] https://cdn.ymaws.com/www.iap2.org/resource/resmgr/Communications/A3_P2_Pillars_brochure.pdf

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Interviewees consisted of a wide range of central and local government officials in agricultural, water management, and meteorological roles, farmers and farmer union officials, other CSOs, academics and researchers, private sector interests including agricultural finance representatives, and other relevant stakeholders. In most cases, interviews had only government officials or non-government stakeholders involved to avoid the potential reluctance of interviewees to speak freely.

Central government officials nominated local government agencies to participate, and CSOs facilitated the participation of local representatives and other organizations. For example, in Tunisia, the national farmers' union (UTAP) organized the participation of its regional bodies (URAP) as well as other civil society stakeholders. The Agricultural Engineers' Association did the same in Jordan, and in Lebanon, the Chamber of Commerce, Industry and Agriculture played the same role. In addition, we used pre-existing relationships to identify and include additional interviewees who, in turn, provided suggested contacts for further engagement in a form of snowball sampling. Ultimately, the broad group of stakeholders was intimately familiar with drought topics and had wide-ranging perspectives. Table 1 provides the numbers and categories of interviewees in each country and a breakdown of interviews conducted in the regions versus in the capitals.

Insert Table 1 here.

Interview locations are shown in Figure 2. In each location, there were interviews with local government officials and CSOs at a minimum. Locations were determined primarily by core agencies' preferences and more general time and security constraints. The choice of locations affected stakeholder participants and focused emphasis on locally relevant drought impacts as well as monitoring and management themes.

Accepted for publication in *Bulletin of the American Meteorological Society*. DOI 10.1175/BAMS-D-18-0084.1.

In Tunisia, interviews were conducted primarily in the center of the country and spanned the grain belt in sub-humid to semi-arid climatic zones. In Lebanon, interviews had roughly equal regional representation with the exception of South Lebanon due to difficulty of access. In Jordan, interviews focused on the Jordan Valley and highlands areas, the primary irrigated and productive rainfed lands. Because of Moroccan agencies' previous CDI development work and regional validation efforts (Bijaber et al. 2018), interviews there were limited in scope primarily to central government agencies. Responses from Morocco therefore represent a narrower set of issues and interests compared to the other countries. The results presented in Sections 4.1 to 4.3 primarily stem from the interview findings, and the discussion section relates those findings to wider themes.

Insert Figure 2 here.

3.2 Workshops

Following the interviews, workshops were held in each country to 1.) present interview findings and obtain feedback on them, 2.) elicit participants' concerns and needs for the CDI to inform the technical teams' CDI development process, and 3.) to structure ongoing collaboration for early warning systems development. Workshop participants completed a survey that provided information to confirm and add to the list of drought impacts identified in the needs assessments, rank their relevance, and provide a self-assessment of institutional capacity to monitor them.

Given that the workshops were designed to feed into the CDI technical development process, participants consisted primarily of government officials, though in each country, researchers and CSO representatives were involved as well. Workshops had various participatory components to ensure that individuals could not dominate the proceedings and conversations,

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and surveys provided further avenues for feedback and information to drive the technical development process.

Survey results are primarily reflected in Section 4.1, and the workshop results structured ongoing drought monitoring development and its potential connection to drought management as presented in Sections 4.4 and 4.5

3.3 Data collection and analysis

The interviews and workshops largely followed Squires' (2010) methodological guidelines for cross-language qualitative research to minimize language barrier effects. The lead author conducted interviews in participants' languages – a mix of Arabic, French, and English. As a non-native but competent speaker of Arabic and French, the researcher repeated statements back to participants to ensure mutual understanding and conceptual equivalence of responses (ibid.). Bi-lingual research assistants were present for some engagements, which allowed post-interview discussions to validate summary response notes. At workshops, professionally accredited simultaneous translators were employed to facilitate researchers' engagement with the participants. All documents provided to interviewees and workshop participants were in Arabic or French as appropriate.

Interview summary responses were written in English. These were subsequently analyzed using qualitative coding software (QSR NVivo), including inter-coder reliability checks made by four analysts (Campbell et al. 2013). The primary codes were designed *a priori* (Saldaña, 2016) with secondary codes developed by coder consensus with the emergence of respondents' themes (Zhang and Wildemuth, 2009). An iterative reflection and the addition of secondary categories ensured the most accurate results (Saldana 2016). This process was designed to group and assess

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common themes for drought impacts and drought monitoring and management needs in accordance with the IDMP pillars of drought management (Wilhite 2014).

4. Results

4.1 Drought impacts

Interview and workshop survey results identify a range of drought impacts and contextualize how they overlap and interact with management responses to them. The interview format allowed participants freedom to name impacts that concern them the most, and this varied by sector or occupation. For example, in Mount Lebanon, participants from an agricultural cooperative mentioned drought impacts connected to snow cover and plant phenological and altitudinal changes whereas the chamber of commerce, industry, and agriculture representative from the same area discussed fruit quality degradation and linked marketing challenges.

The broad sample of sectors engaged during the interviews resulted in a wide range of impacts that cascade from the meteorological onset of drought into agricultural, hydrological, ecological, and socio-economic domains. Table 2, based on the interview data, provides examples mentioned in each category. Over time, many of these noted impacts of drought may become the new normal conditions as climate baselines shift. Table 3 provides ranked prioritization of drought impacts from surveys of stakeholder workshop attendees, primarily government officials.

Insert Tables 2 and 3 here.

4.2 Existing drought monitoring

Modern regional meteorological and hydrological monitoring stations date to the late 19th century but became widespread in the post-WWII era. Table 4 below describes the core climatic

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and hydrological monitoring networks and regular vegetative condition monitoring in the project countries as described in interviews and the literature.

Insert Table 4 here.

As described in interviews, agencies in all countries – with various periodicity, degree of detail, and geographic specificity – produce data on precipitation and vegetation cover, and they produce SPI and NDVI maps regularly. SPI is recognized as a core meteorological drought monitoring index worldwide (Hayes et al. 2011) and is used as the primary trigger for national drought management planning in Morocco and Tunisia (Ouassou et al. 2007; Louati et al. 2005). Stakeholders in each country reported monitoring – again with varying degrees of periodicity, degree of detail, and geographic specificity - evapotranspiration, land surface temperature fluxes, wind speed and direction, river and wadi[3] flows, spring discharge, groundwater levels, surface and groundwater salinity, and *sirocco*[4] events. The governments also collect a wide range of data on agricultural, ecological, and socio-economic drought monitoring indicators. Table 5 presents some of the indicators for which information is collected and notes those currently in use in drought monitoring programs.

Insert Table 5 here.

In addition to, and sometimes in partnership with, governmental drought monitoring programs, academic, CSOs, and private sector organizations also conduct both formal and informal drought monitoring. For instance, in Tunisia, farmers union representatives have a formal role in governmental drought monitoring regimes, and in Morocco, the private sector insurance firm MAMDA assesses drought impacts on the ground in conjunction with government officials to determine indemnification.

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[3] Ephemeral streams

[4] Desert wind and/or sandstorm – associated with high wind speed, low humidity, and high temperatures

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Non-governmental stakeholders, particularly farmers, identified a wide range of drought indicators they monitor. As climate change progresses, the relevance of some of these current indicators of drought may change. Many of these drought indicators constitute local, traditional, and historical knowledge of environmental conditions. Stakeholders across the countries mentioned several in common:

- Characteristics of bee activity, condition, range, and honey quality
- Specific bird species' presence and migration timing
- Specific date of arrival and intensity of pest species
- Minimum and maximum altitude of specific plants
- Proportional makeup of rangeland plant species
- Rainfall intensity and seasonal distribution as well as snowpack and melting periods
- Discharge of specific local springs

4.3 Early warning system needs

Here we present descriptions of stakeholders' identified needs for improving early warning systems. They relate primarily to the way in which stakeholders generate and share information, the type of information produced, and how it is used in decision-making processes.

The analysis of interview and survey data produced a hierarchy of specific drought monitoring and early warning needs for each country except Morocco as shown in Table 6.[5] The hierarchy indicates the proportion of interview data that specified needs within a given component. While specific components were to a large-extent country-specific, major similarities in over-arching themes emerged, and these are explained further in the rest of the

[5] We did not use the same method for Morocco because there were fewer interviews, the large majority of participants were central government officials, and agencies there already produce and utilize a CDI; this discrepancy is a research limitation.

Accepted for publication in *Bulletin of the American Meteorological Society*. DOI 10.1175/BAMS-D-18-0084.1.

section: drought definitions, information sharing; ground-truthing of remote sensing derived information; data quality challenges; and inter-sectoral engagement.

Insert Table 6 here.

4.3.1. Drought definitions

In all countries, interviewees – both government officials and others – stated the need to develop technical definitions of drought beyond precipitation deficit and seasonal SPI in order to ease declaration processes, permit tiered intervention processes, and to increase demand from policymakers for rigorous monitoring data. This is one of the primary connections between drought monitoring and management as described further in Section 4.5. Stakeholders particularly focused on the need to incorporate different types of drought impacts in these definitions beyond meteorological and hydrological drought components. This theme was of high importance in Morocco, among the highest-ranked drought management needs in Tunisia, fourth in drought monitoring needs in Lebanon and third in Jordan. This theme was also raised frequently and at length during interview discussions of drought management needs and in the workshops.

4.3.2. Information sharing

Participants universally expressed the need to formalize and automate information-sharing processes, and in all countries, they mentioned the potential of a drought data platform to facilitate this objective. In all project countries, information-sharing within and between government agencies, and between central and local government, is a stumbling block in effective drought monitoring. The reasons for this barrier are varied and include the need to

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purchase data, the need for formal institutional data requests, and the culture of data ownership by producing agencies that leads to their unwillingness to share information.

In all countries, interviewees promoted the idea of creating a data-sharing platform to solve this challenge by legally requiring specific agencies to submit data and then providing all participating agencies with open access to compiled datasets and information. Interviewees believed this would facilitate information collation and therefore be key to address the challenge inherent in attempting to monitor and assess a much wider range of potential drought impacts simultaneously. Addressing data-sharing was the most important theme in Morocco, the second most important in Tunisia and Lebanon, and the third in Jordan.

4.3.3. Ground-truthing remote sensing derived information

Across the project countries, and especially in Tunisia and Lebanon, interviewees expressed skepticism about the capacity of remote sensing and modeled data to provide the relevant indicators at acceptable levels of accuracy, precision and geographic scale. Often, they expressed this skepticism during discussion of highly localized climatic and hydrological patterns and in relation to the geographically small range between agro-ecological zones and transitional areas. As such, stakeholders said that gaining widespread buy-in of drought monitoring using tools like the CDI would require adequate ground-truthing and validation to assess the relationship between reported CDI values and drought effects. Stakeholders want to ensure monitoring tool outputs accurately reflect the drought impacts that they see on the ground including at least the meteorological, agricultural, and hydrological components.

This theme was frequently discussed in Morocco, although some CDI validation has already taken place in the Oum Rabia basin. It was highly relevant in Tunisia, the most important

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issue in Lebanon and the second most important issue in Jordan. This issue was particularly salient in Lebanon because of the expressed need to create political demand for drought monitoring data. Stakeholders there perceive that political decision-makers are not interested in drought monitoring because they do not perceive drought as a significant problem for the country. Stakeholders consider that assuring the validity of drought monitoring and impacts data would help address this perceptions challenge.

4.3.4. Data quality challenges

Interviewees, especially technical government officials, CSO representatives, and researchers, raised concerns about monitoring networks' (those described in Table 4) data quality. The specific challenges differed between countries but revolved around a few specific and consistent themes:

- Data reliability – e.g., related to the placement and calibration (or lack thereof) of climate monitoring stations
- Monitoring data source bias – monitoring networks unevenly distributed in countries
- Data continuity and frequency of production
- Indicator and reporting unit consistency across levels of government
- Lack of electronic data management, as many data are still collected on physical spreadsheets.

4.3.5. Inter-sectoral engagement

Despite significant differences in agro-economic systems between the countries, participants uniformly expressed the need to improve engagement between farmers – and the

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institutions that represent them and interact with them – and government agencies with regard to drought monitoring. This generally reflects farmers' desire to receive more useful and tailored drought-related information, and to provide relevant information and therefore influence the agencies in charge of drought assistance and relief. Likewise, it reflects government officials' realization that farmers and those closest to them hold critical drought monitoring information and understand drought impacts on the local scale, and that ultimately the private sector and civil society drive drought management activities in the broadest sense. This theme was the most important in Tunisia, fifth in Jordan and third in Lebanon.

4.4 Early warning systems development using interview and workshop results

At the time of writing, the International Center for Biosaline Agriculture was producing a 25x25km resolution monthly MENA regional CDI map.. Following the workshops described above, the technical development phase in each country (refer to Figure 1) focused core agencies on collaborative tailoring of the CDI components so that it captures high priority drought impacts (see Table 3) and meets agency capacity and capability needs. It also included CDI validation efforts that are ongoing at the time of writing. Figure 3 shows an example of the regional outputs and the national maps produced in Tunisia.

Insert Figure 3 here

4.4.1 Tailoring the CDI to high priority drought impacts

In each country, the core agencies are further calibrating and validating the initial CDI to focus specifically on the identified high priority impacts and fulfill specific water and drought management roles. In all cases, this work is still ongoing.

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For Morocco, this is being addressed by developing an evaluator network for wider CDI validation, specifying CDI weighting for specific agro-ecological zones, and potentially using it to support development of basin-wide drought plans required by the new water law (No. 36-15) and implementation of a new national law on pastoralism (No. 133-13), both of which include policies for drought management (Yesef 2018).

In Tunisia, validation work showed that NDVI and soil moisture anomalies were more highly correlated with cereals outputs in the semi-humid north of the country than in the semi-arid center, so the core agencies may adjust CDI input weights accordingly. In the near future, core agencies in Tunisia may use the CDI to inform decisions on inter-basin transfers, inter-sectoral water allocation, and water infrastructure operational decision-making (Khemira and Jlassi 2018).

In Jordan, the focus is on highlands rainfed agriculture and irrigation demand and water availability in the Jordan Valley. Therefore, core agencies plan to incorporate hydrological flow and reservoir storage indices to assess differential drought impacts across agro-ecological zones including the desert *badia* areas and groundwater-dependent irrigation areas such as Mafraq and Azraq (Kerablieh 2018). Officials in the recently-formed drought monitoring unit of the Ministry of Water and Irrigation are working with the MENA RDMS team through a multi-stakeholder technical committee in Jordan to incorporate the CDI in ongoing drought governance and planning developments.

In Lebanon, agencies are considering re-weighting the CDI according to land-use and land cover classification systems. Also, they are considering how to incorporate a snow water equivalent indicator given its importance for agricultural and hydrological drought impacts (Fayyad 2018). Similar to the case in Jordan, officials are developing a cross-ministerial team led

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by the Ministry of Energy and Water and the meteorological agency to decide the mechanisms for generating, disseminating and using the CDI outputs in decision-making.

4.4.2 Meeting agency capacity and capability needs

Government officials emphasized that it was critical to use open source data and modeling platforms to ensure that the core agencies could produce, update and continue to shape the CDI beyond the specific donor-funded project activities and to facilitate outputs being incorporated in other national modeling frameworks, especially for groundwater recharge. Also, to ensure ongoing capacity to produce the CDI, they required the coding and modeling to be relatively simple and straightforward. The project team ran interactive technical workshops to accomplish these objectives and train the agencies that now produce the CDI operationally.

Though currently using NASA's Land Information Systems model (Kumar et al. 2006), the project team developed open-source GIS components and a customized python-based model. As agencies adopt these, they can reduce long-term costs of CDI inputs and increase the likelihood it will be used beyond project timeframes. To match local capacity and reduce long-term technical burdens, the project team has developed automated scripts for data acquisition and processing as well as shifted some components from Linux to Microsoft operating systems. Lastly, to reflect local conditions more accurately, core agencies have begun to replace remotely-sensed data with observed data inputs where possible, especially for precipitation.

4.4.3 Ongoing CDI validation

Currently, core agencies are conducting CDI validation assessments that include statistical testing of input components as well as semi-quantitative evaluation of CDI products

Accepted for publication in *Bulletin of the American Meteorological Society*. DOI 10.1175/BAMS-D-18-0084.1.

through expert networks the needs assessments helped form. These expert networks have included central and local government officials, researchers, and in Tunisia, farmer union representatives. Core agencies signaled their intention to widen the representation of these networks as the CDI becomes an operational drought monitoring tool that informs water and drought governance.

An example of this validation process from Tunisia saw the core agencies presenting CDI maps (see Figure 3) in Tunis and in regional meetings to representatives from 23 of 24 regional governments and CSOs. The agencies solicited feedback on the maps' content and accuracy in relation to the past year's drought (Khemira and Jlassi 2018).

In combination, the needs assessments findings, technical development, validation and vulnerability and impact studies are shaping the planned CDI composition and area of focus for each country and helping determine how the CDI and wider early warning systems can most effectively improve drought management.

4.5 Drought monitoring connections to drought management

Interviewees and workshop participants discussed at length the ways in which improved early warning systems could improve drought management. While assessing drought management needs generally is beyond the scope of this paper, it is important to illustrate how stakeholders think about the connections between drought monitoring and ultimate drought management decision-making processes.

Figure 4 synthesizes and visualizes connections interviewees made between the development of the CDI and its integration with wider early warning systems and drought

Accepted for publication in *Bulletin of the American Meteorological Society*. DOI 10.1175/BAMS-D-18-0084.1.

management policies. This diagram was tested with workshop participants and refined slightly according to feedback.

Insert Figure 4 here

In short, the diagram shows the prerequisites for improved monitoring capabilities to influence drought management decision-making processes. It highlights the key mediating role various institutional actors and mechanisms play in the chain of information provision to inform political decisions on drought management. This paper primarily focuses on issues in the first two columns – technical prerequisites and institutional mechanisms – as the latter two columns connect directly with drought management. However, the reported needs, especially developing drought definitions, clearly link to the overall intended outcomes of easing, expediting, and facilitating intervention decision-making via the provision of robust drought monitoring information. At the workshops, participants indicated focus priority areas as: 1) building consensus that CDI values reflect relevant drought impacts; 2) ensuring that data and information was accessible to core stakeholders; 3) establishing pre-determined management roles, coordination mechanisms, and contingency plans; and 4) expediting and facilitating timely decision-making.

5. Discussion

5.1 Participatory research approaches to inform environmental monitoring systems

The needs assessments relied on participatory research methods. It is important to characterize how the participatory component shaped development of the monitoring tools that will support public policy implementation. Using Rowe and Frewer's (2005) typologies, the participatory engagement primarily reflects consultation types 2 (surveys) and 4 (interviews) as

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well as participation type 1 through workshops. Information flow was often uni-directional from the public to agency officials (with the researchers being intermediaries), but in all countries, particularly in the workshops, there was bi-directional information exchange and influence. Overall, the participatory engagement mechanisms included:

- Semi-controlled participant selection (via relationship networks).
- Face-to-face, active elicitation and facilitation of open-ended dialogue.
- Limited and set response modes from surveys.
- Facilitated, unstructured information aggregation through researchers reading back summarized responses for approval or clarification and also workshop feedback.
- Structured aggregation through the data coding process.

The coding of the interview data produced hierarchies of drought monitoring and management needs that were presented at the workshops, and that structure focused officials' attention on the specific issues participants raised. In addition, the hierarchical data provided core problem statements, stemming from Figure 4, that development and implementation of early warning systems, including the CDI, could address. Interview findings thus structured the framing of workshops and surveys, which provided agencies and CSOs the space to deliberate on how to address the identified needs by focusing on the CDI development path and discussing its incorporation in drought management mechanisms in the future.

Using multiple engagement methods was beneficial because different formats stimulated different responses. For instance, in the large workshop setting, participants tended to focus on their formal agency roles and were less willing to admit they struggled to monitor the range of indicators associated with drought. Technical presentations at workshops portrayed strong capacity and ongoing monitoring activities. However, in interviews, participants were not

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hesitant to identify shortcomings in drought monitoring capacities, particularly with regard to data access. This finding reinforces Ker Rault and Jeffrey (2008), whose research on integrated water resources management in the Levant region showed the importance of multiple forms of engagement to reveal dynamics pertaining to participants' varied interests, needs, and communication styles.

Overall, the research incorporates a wide range of stakeholder feedback, concordant with the findings of Rodela et al. (2017) recommending ongoing social investigations to ensure that spatial products meet participant needs. The participatory approaches taken to date in this project are especially positive because early warning systems links to national initiatives with the potential to shape future policy in drought planning and broader water resources management. These are the policy and resource management issues for which MENA government stakeholders typically exhibit the least openness to public participation (Ker Rault and Jeffrey 2008; Heidenhof 2014). However, the involvement of CSOs and other stakeholders to date is encouraging and hopefully continues; regionally it is increasingly common as government stakeholders recognize the value in social learning and mutual problem identification that can occur (Ker Rault and Jeffrey 2008), and also as regional leaders request support in and implement public sector reforms (WeWorld-GVC 2018; OECD 2017).

The participatory research component succeeded primarily because it had strong central agency support and civil society buy-in. The IDMP and specific USAID programme were initiated at the request of regional ministers, and the leaders of CSOs in the project countries accepted initial contacts and quickly facilitated thorough participation from their own organizations and related ones within their networks. Local stakeholders opened the proverbial doors, and without this support, the research would have been severely limited.

Accepted for publication in *Bulletin of the American Meteorological Society*. DOI 10.1175/BAMS-D-18-0084.1.

Researcher involvement was also key: all of the co-authors visited the project countries on multiple occasions and participated in different aspects of the research. Language competency contributed to this as well – conducting the volume of interviews and workshops without local language skills would have been hugely resource and time-intensive. While subtle meanings may have been lost in translation, the back-and-forth that ensured mutual understanding overcame the worst of this problem (Squires 2010), and the social rapport contributed to development of relationship networks. Lastly, circumstances enhanced the salience of the research; it occurred during a severe, multi-year regional drought, which strongly increased stakeholder interest in participation.

The needs assessments processes have contributed to the development of relevant expert networks in the project countries, which may form the basis for longer term environmental monitoring coalitions and/or wider public participation in drought policy development. Engagement beyond central government agencies has been vital to elucidate what end-users need from drought monitoring, how effective monitoring tools could affect their own drought management activities, and, increasingly, to validate information products that central agencies produce. The project's core agencies are now building off expert networks identified through the research and including them in ongoing technical development of the early warning systems. The example of the CDI core agencies in Tunisia conducting multi-sectoral workshops and follow-up regional roadshows to engage local government and CSOs in validation and drought impact and vulnerability assessments is a case in point.

Accepted for publication in *Bulletin of the American Meteorological Society*. DOI 10.1175/BAMS-D-18-0084.1.

5.2 Discussion of drought impacts findings

When asked about the most significant drought impacts, interviewees typically progressed from household level to national issues – from basic household food and water security to issues as wide as rural outmigration, foreign trade imbalances, and regional stability. MENA regional, national, and local case studies that incorporate examination of drought impacts mirror this progression. In each country, the impacts were different, and the adaptive steps taken by different actors to ameliorate conditions varied. For example, in some areas of Lebanon, private sector tanker drivers stepped into supply water when municipal systems were shut down for extended periods.

Regional studies tend to focus on food and water security issues as well as agricultural productivity and sectoral economic effects (e.g., World Bank 2017) whereas national studies tend to focus on specific drought impacts such as Tarawhneh's (2011) evaluation of drought's hydrological and municipal supply impacts in Jordan. Relatively few studies integrate across multiple impact domains. Notable exceptions, even though they did not all explicitly focus on drought, include the works of Verner (2013) and Arif and Doumani (2012).

There has been minimal research in Lebanon on drought impacts beyond meteorological and environmental effects (e.g., Bergaoui et al. 2015; Ministry of the Environment 2003). This is likely due to the paucity of long-term hydrological and agricultural statistics as well as the widespread national perception that because Lebanon is water-rich compared to neighbors, drought effects are minimal (CNRS 2015; interviews).

Perhaps most importantly from a longer term risk management perspective, few studies thoroughly evaluate the social dislocation drought can cause, particularly as it relates to rural outmigration. In a warmer, drier, more populous MENA region, water security will increasingly

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connect with broader social stability concerns. Already, regional water resource issues fall under the domain of "national security" in some contexts (Weinthal et al. 2015).

Interviewees in all countries described rural outmigration as a major social issue connected to drought. The evidence for this is strong but not conclusive: the data show that drought is definitively responsible for short- to medium-term internal displacement to medium or large cities with young men the most likely to move. This has implications for the areas migrants left, those receiving migrants, and for the migrants themselves. Unfortunately, though, longer-term impacts have not been assessed rigorously due to the paucity of targeted studies and adequate demographic information (Raleigh et al. 2010; IOM 2016). However, studies of regional rural outmigration emphasize the role of long-term environmental degradation that drought precipitates: rangeland, soil and groundwater quality degradation, livestock loss, and oasis desiccation (Taha et al. 2014; Belgacem 2011; Karmaoui 2015).

This study's findings make explicit the possible range of drought impacts and highlight the issues on which the governments will focus drought monitoring and management efforts. This study's findings aimed to focus and frame more substantive evaluations of drought impacts in the project countries (see Figure 1) and also to provide context for discussions on early warning systems. Indeed, anticipating and having the ability to act proactively to avoid and mitigate these drought impacts relies on improved environmental monitoring.

5.3 Discussion of drought monitoring needs findings

Past assessments of MENA governments' drought monitoring capacity and capability have concluded that even though most countries have well-functioning and generally adequate hydro-meteorological monitoring networks, the governments are not well-prepared to use them

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in a drought early warning or drought monitoring capacity. To do so, they would require a number of improvements (De Pauw 2005, UN-ESCWA 2013):

- Enhanced data quality and collection network densities
- Reduced cost and increased data-sharing
- Making early warning information products more accurate and user friendly
- Integrating physical and social drought indicators into systematic and comprehensive monitoring and early warning systems
- Providing support to create and maintain systems

Our findings echo these themes and add substantial detail and context to them.

In relation to the specific data quality issues raised, the CDI will contribute to addressing them as it can provide a nationally consistent and gridded dataset produced monthly or more frequently if desired. It will fill data gaps where monitoring networks are sparse and pre-existing modeling capacity is insufficient, and thus it augments existing networks.

Over time, agencies hope to incorporate socio-economic and environmental indicators more directly in formal drought monitoring regimes in order to capture more fully and immediately these variegated and complex systems; the gap in socio-economic indicators' incorporation in early warning systems is a common feature globally (Pulwarty and Sivakumar 2014). Also, the results highlight that although interviewees almost universally described drought impacts on groundwater resources as a critical issue, drought monitoring programs in the region include few specific components related to groundwater monitoring.

One of the most notable findings is that stakeholders – both governmental and non-governmental – mainly focus on how they could integrate and use available monitoring information more effectively. With the exception of specific data issues discussed above, the

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primary needs relate to how government officials and other stakeholders share, use, and communicate information rather than the types and volumes of information generated. These themes are not isolated to environmental monitoring and connect to wider issues of public governance, public administration, and state-society relationships in the region that are generally beyond the scope of this paper. However, a brief example is illustrative.

Individual MENA states are highly variable regarding public-private sector boundaries, administrative setups, and relationships with civil society (Dixon et al. 2018). The public availability of government-held information in the project countries is a case in point for this wide theme. While all the project countries have "access to information" laws, their scope and practical implementation vary significantly. With the exception of Jordan, these laws were not in force during the fieldwork, and no interviewees mentioned them explicitly. Given that drought early warning systems are being developed and implemented by government agencies, this is highly relevant to the likelihood of future public provision of that information.

Morocco's Law No. 13-31 was passed in 2018 and is not yet active as public agencies are given time to prepare for its implementation (Ben Saga and Benabou 2019). However, there is a chance it will be of limited use for drought-related information given the law's provisions for not disclosing information that could harm the public interest and penalties for those who distort the information provided. As noted previously, drought declaration is highly politically charged, and thus information related to drought could be seen as "sensitive".

Tunisia's 2016 Law No. 22 is the most wide-ranging, and the government established an independent agency to oversee compliance and hear appeals to decisions, a first in the Arab world. Initial indications show it is working well (Human Rights Watch 2019). Whether this law, the proactive release of information it encourages, and the already wide use of the agricultural

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observatory's (ONAGRI) data portal ease and widen public access to drought-related information still remains to be seen, though.

Implementation of Lebanon's recent Right to Access Information Law 2017/28 was thoroughly tested by a Lebanese civil society organization (Gherbal Initiative, 2019) and responses overall were poor with only 34 of 133 administrations complying. However, the law is new and CSOs are actively working with government to promote successful implementation.

Finally, despite being an early adopter, Jordan's 2007 Freedom of Access to Information Law No. 47 has not resulted in markedly improved information flows between the government and the public and a recent review concluded that the law "is a formality more than a tangible gain" in openness of information (Arab Reform Initiative, 2016).

5.4 Drought monitoring to management and nascent coalitions

The participatory research process and results contribute to meeting the technical prerequisites for drought monitoring to facilitate improved drought risk management as identified in Figure 4: results define relevant drought impacts, begin to characterize what indicators constitute emerging crises, lay clear the necessary information sharing needs, and inform how the early warning systems and CDI development process can most reach technical consensus and increase likelihood of political buy-in and support. CDI development may also facilitate robust assessments of future drought scenarios as research overcomes limitations of understanding how precipitation and temperature changes will affect soil moisture, runoff, and vegetation health (Cook et al. 2018).

While contentious drought management topics emerged during the research process, the effort focused on the development of concrete drought monitoring tools. This was an explicit

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choice stemming from the project's planned progression following the IDMP framework in which drought management planning follows monitoring and early warning systems development (Wilhite 2014).

This progressions allows participants to build trust through collaboration on important, but not politically sensitive, issues. In this way, they build the groundwork and relationships for more effective participatory engagement – or public participation – around politically charged issues such as drought declaration processes (Ansell and Gash 2008). Distinguishing between the technical and political dimensions of a problem, and focusing on how external technical resources can match internal capacity, results in higher stakeholder involvement in and improved quality of environmental management decision-making (Beierle 2002). Given the outcomes to date, this process will likely inform drought monitoring tool development in other MENA countries and regions where drought management is a politically sensitive theme and relief is primarily a function of the central government.

Drought management changes require broad, and likely contentious, political discussions. Thus, starting the participatory engagement with a focus on drought monitoring may have reduced barriers for that initial collaboration between governmental and non-governmental stakeholders, effectively increasing stakeholders' acceptance of the collective decisions and approaches (Schuman 2006).

6. Conclusion

A wide range of stakeholders from various levels of government – and research, CSOs and private sector organizations – described drought monitoring needs to inform the development of early warning systems and facilitate improved drought management. The

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primary themes consisted of technical needs (ground-truthing remotely-sensed data, CDI validation, and data quality issues), institutional needs (information sharing processes and platforms as well as inter-sectoral engagement), and political needs (drought declaration processes and creating demand from political decision-makers for rigorous drought monitoring data).

The results reinforce findings elsewhere that involving a wide spectrum of participants, albeit with varying levels of involvement at any given time, is beneficial for the development of early warning systems. Narrow perspectives of what constitutes a drought (e.g. lack of rainfall, at one extreme, or water scarcity at the other) limit agencies' ability to develop comprehensive monitoring programs. Through the participatory research approach and its results, these various stakeholders have shaped ongoing early warning systems development and now constitute nascent expert evaluation networks. These networks are critical for ongoing production and future improvement of the CDI, and they have the potential to form the basis of drought monitoring and management coalitions that actively participate in public deliberations drought management systems, policies and interventions.

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Appendix 1: Acronyms[6]

Morocco:

ABH – River Basin Agency
CRTS – Royal Center for Remote Sensing (Ministry of Defense)
DGE – Water Management Directorate (Ministry of Energy, Mines, Water, and the Environment)
DMN – National Meteorological Office
DRPE – Water Research and Planning Directorate (Ministry of Energy, Mines, Water, and the Environment)
Dir. of SS – Strategic Services Directorate (Ministry of Agriculture and Marine Fisheries)
HCEFLCF – High Commission for Water, Forests, and the Fight Against Desertification
INRA – National Agricultural Research Institute
MAPM – Ministry of Agriculture and Marine Fisheries
ONCA – National Office of Agricultural Extension (Ministry of Agriculture and Marine Fisheries)
ONEE – National Office of Electricity and Potable Water

Tunisia[7]*:*

CNCT – National Center for Mapping and Remote Sensing (Min. of Defense)
DGF – Forestry Directorate
DGSV – Veterinary Services Directorate
DGFIOP – Directorate for Finance, Investment, and Professional Organizations
DGPA – Agricultural Production Directorate
DGRE – Water Resources Directorate
INM – National Meteorological Institute (Min. of Transportation)
OC – Office of Cereals
OEP – Office of Animal Husbandry and Pastures
SONEDE – National Water Exploitation and Distribution Company (national water supply utility)
UTAP – Tunisian (National) Union of Farmers and Fishers (CSO)
Synagri – Farmers' Syndicate[8] (CSO)

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[6]All acronyms are in the original language with the full name translated into English
[7] Unless otherwise noted, all organizations are part of the Ministry of Agriculture, Water Resources, and Fisheries
[8] Synagri is a relatively recently-established farmers' union in Tunisia that is present in several but not all regions.

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ODESYPANO – Sylvo-pastoral development authority of the North-West

Lebanon:
CNRS – National Center for Scientific Research
MOEW – Ministry of Energy and Water
LRA – Litani River Authority (Ministry of Electricity and Water)
LARI – Lebanese Agricultural Research Institute (Ministry of Water)
LAEC – Lebanese Atomic Energy Commission
DGCA – Directorate for Civil Aviation (Ministry of Transportation)
MOA – Ministry of Agriculture
MOE – Ministry of the Environment

Jordan:
JMD – Jordanian Meteorological Department (Ministry of Transportation)
JVA – Jordan Valley Authority (Ministry of Water and Irrigation)
MOA – Ministry of Agriculture
MOE – Ministry of the Environment
MWI – Ministry of Water and Irrigation
NCARE – National Center for Agriculture Research and Extension (Ministry of Agriculture)
RJGC – Royal Jordanian Geographic Centre
WAJ – Water Authority of Jordan (Ministry of Water and Irrigation)

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Tables

Table 1. Interview descriptions by country.

	Total # of engagements	Central government ministries/agencies (and # of directorates)	Regional government agencies	CSOs.	Research organizations	Private sector	International institutions	Local collaborative group
Morocco[9]	10	5 (10)	0	1	1	0	1	2
Tunisia[10]	58	4 (25)	7[11]	10	3	6	3	2
Lebanon[12]	35	4 (14)	10	6	2	2	3	0
Jordan[13]	34	3 (14)	5	7[14]	2	1	3	1

Table 2. Drought impacts described by participants.

Hydrological	**Agricultural**	**Ecological**	**Socio-economic**
• Decreased surface water flows and reservoir levels • Reduced snowpack, earlier and more rapid melt • Reduced groundwater recharge and spring discharge • Increased salinity of surface and groundwater • Other surface and groundwater chemistry changes • Shifted seasonality & intensity of precipitation • Increased rate of seawater intrusion in	• Increased water demand & irrigation rates • Increased crop and livestock disease rates & exacerbated impacts • Shift in cropping seasonality and crops cultivated • Increased reliance on irrigation for crop survival • Reduced cultivated/harvested areas and crop yields • Reduced crop output quality	• Increased number and intensity of forest fires • Presence and intensity of specific pest species • Bird migration pattern shifts • Marginal improvement in honey quality but reduced quantity • Honey bee location shift and reduced activity • Increase in arid species in semi-arid rangelands • Shift in areas suitable for specific crops • Altitudinal shift in plant species (up-mountain)	• Decreased hydropower production and higher energy demand • Inter-sectoral water conflicts and increase in illegal water sales • Localized increase in human disease and malnutrition • Farmer income declines and reduced agricultural loan repayment • Migration (temporary and long-term) from countryside to cities • Fodder, feed and agricultural input market disruptions and speculation • Insurance, compensation and subsidy payouts; increased imports

9 One interview and one workshop were introductory and project scoping focused; all engagements were in Rabat and Casablanca and focused on national concerns.

10 Five engagements and one workshop were introductory and project scoping focused; 19 engagements were outside of Tunis and focused on regional issues.

11 This table includes only the six CRDAs visited and the regional development organization, ODESPYANO. The table does not include the number of directorates represented in interviews at each CRDA.

12 One interview was introductory and project scoping focused; 19 engagements were outside of greater Beirut and focused on regional issues.

13 Four interviews were introductory and project scoping focused; 10 engagements were outside of Amman and focused on regional issues;

14 Of these meetings, 3 were with regional representatives from the same organization in different governorates.

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groundwater & shifts in its seasonality • Changes in frost frequency and timing • Increased evapotranspiration rates and soil water reserves deficits	• Increased reliance on purchased feed and fodder • Soil degradation, desiccation and loss • Livestock fecundity and birth weights decrease • Crop phenology shifts	• Tree decline and mortality (especially young ones) • Wetland and *sabkha* extent and biodiversity decrease • Soil degradation	• Household-level water and food security compromises • Increase in transhumance and territorial grazing conflicts • Increased time and cost for water provision

Table 3. Reported highest-ranking drought impacts from written workshop surveys.

Country *(number of respondents)*	Tunisia *(18)*	Jordan *(22)*	Morocco *(3)*	Lebanon *(28)*
Priority drought impacts from ranked results	• Shifting irrigation practices (e.g. to irrigation from rainfed; from surface to groundwater, etc.), • increased water demand, • reduced crop yields, and • increased demand for stored surface water.	• Decreased water availability tied to delay in rains, • increased frost risk during times of low winter precipitation, • reduced reservoir storage, • groundwater over-abstraction, • reduced groundwater levels and recharge, • spring heat waves, and • plant pests (mainly insects.	• Water scarcity, • overall reduced economic performance, and • changes in employment opportunities.	• Decreased municipal water availability, • surface water quality degradation, • increased irrigation required to maintain agricultural output, • increased groundwater pumping (and over-abstraction), • reduced spring outflow discharge, and • reduced reservoir levels.

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Table 4. Climatic and hydrological monitoring network and vegetative state monitoring; acronyms shown in Appendix 1.

	Climate monitoring	Hydrological monitoring	Vegetation Condition monitoring
Morocco	**DMN:** 42 synoptic, 206 automatic climate stations (Badi and Kasmi 2016) **Other institutions:** ~370 climate stations (Baubion et al. 2017)	**DGE/ABHs**: 265 principal surface water measuring stations and ~700 gauge stations (Baubion et al. 2017); 128 groundwater wells with automated groundwater data recording (Moumen et al. 2014)	**INRA/DMN/Dir. of SS:** Crop Growth Monitoring System for seasonal prediction, monitoring and modeling grain yields (Balaghi 2014); **CRTS:** Production of CDI (Bijaber 2017)
Tunisia	**DGRE:** ~850 precipitation stations (Mansour 2016) **INM:** 26 synoptic, 31 agro-meteorological, 29 climatic, ~200 precipitation (Louati et al. 2005)	**DGRE:** 60 principal surface water stations and 74 gauge stations (Mansour 2016) ; ~3,700 groundwater monitoring wells (Horriche and Besbes 2006)	**CNCT, DGPA, DGF:** NDVI and related indices for land cover/state, ex-post cereals yield estimation (BenSalah 2016)
Lebanon (CNRS 2015; MOEW 2014)	**DGCA:** 36 weather stations (some synoptic); **LARI:** 55 agro-meteorological stations (various types); **CNRS:** 17 weather stations (various types) **LAEC:** 16 weather stations	**LRA:** 51 gauge stations (of which 9 are spring discharge) **MOEW:** 13 groundwater monitoring wells **CNRS:** 3 snow monitoring stations	No official ongoing monitoring of vegetative state.
Jordan	**JMD:** 13 synoptic, 8 agro-meteorological, 25 climate, ~50 precipitation stations (Semawi 2006).	**MWI/JVA**: 47 surface water monitoring stations; ~600 spring discharge gauge stations; 222 groundwater monitoring wells (Hajahjeh 2006, Hayajeneh 2012,Nait 2015).	**MOA/NCARE**: NDVI and related indices such as VCI (Saba 2016)

Table 5. Agricultural, ecological and socio-economic drought monitoring indicators[15].

	Agricultural	Ecological	Socio-economic
All countries:	Cultivated area*; irrigation & crop zone demarcation*; livestock conditions & sale weight*; plant disease	Rangeland*, forest*, and pest conditions	Municipal water availability*; inter-sectoral water conflicts
Tunisia	**DGPA/DGSVA/OC:** Livestock birth weights & mortality rates*; Cereals harvestable area (April census)	**DGPA/DGF:** Rangeland extent and condition*	**SONEDE/OEP/OC/DGFIOP:** Agricultural input & feed prices*; livestock & produce sale prices; intervention/subsidy costs*
Lebanon	**MOA/LARI:** Pest presence	**MOE/LARI/MOE:** soil conditions*; forest fire intensity; bee productivity Crop phenology changes	**MOA/Water Establishments/LRA/ Min. of Econ. & Trade/ Min. of Public Health:** Hydropower production*; agricultural markets data & produce prices*; export statistics*; energy prices
Morocco	**MAPM/ONCA**: Livestock birth weights & mortality rates*	**MAPM/HCEFLCF/CRTS:** Forest fire intensity; invasive & arid species extent	**MAPM/DRPE/ONEE/ABH:** Agricultural input & produce prices*; hydropower production
Jordan	**MOA:** Crop quality / productivity* livestock & plant diseases*	**NCARE/MOA/MOE:** Rangeland conditions*; pest conditions; livestock & plant	**WAJ/MWI/MOA/Min. of Industry/Min. of Health:** Livestock sale & meat prices*; fodder subsidy usage*; incidence of human disease

[15] According to interviewees, indicators marked by an asterisk (*) are components of formal drought monitoring programs that connect directly with meteorological, hydrological, and vegetative state monitoring shown in Table 4, whereas the others help characterize and contextualize drought monitoring efforts and findings.

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		diseases*; forest condition; wetland degradation	

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Table 6. Reported drought monitoring needs.

	Drought definitions	Information sharing	Technical capacity	Knowledge gaps	CDI development	Inter-sectoral engagement
Morocco	• Indicators for tiered drought definitions and interventions	• Address drought data purchase & political sensitivity barriers • Improve data availability for technical analysts • Data-sharing platform	• Uniform data standards including periodicity	• Integrate drought monitoring with seasonal forecasting, rainfall runoff, and groundwater recharge models	• Validate CDI beyond rainfed crops and in more geographic areas	• Develop network of CDI evaluators
Tunisia	• Clear technical definitions for drought beyond seasonal precipitation deficit	• Formalize information-sharing regimes; • Data-sharing platform • Timeliness of data provision • Improved local to central government communication	• Validate and ground-truth remote sensing data • Production of locally-relevant data • Connect to crop planning and guidance	• Link with groundwater resources impacts, climate change adaptation, and specific crop connections	• CDI and input layers openly available • Production of locally-relevant data	• Two-way communication between the government and farmers, CSOs, and agricultural inputs stores • Government should use civil society/private sector effectively • Expand and formalize training role of CSOs
Lebanon	• Create definitions for triggers of drought management or declaration mechanisms	• Formalize information networks • Data-sharing platform;	• Ground-truth remote sensing data • Increase capacity for extension services to use information • Data quality improvements	• Understand drought-crop connection • Improve understanding of connections between snowpack and drought	• Host should easily share information and act as data clearinghouse • Host should have strong GIS and RS skills	• Create political demand and policy role for drought monitoring data • Find avenues to reach farmers and affected populations • Boost public awareness of drought
Jordan	• Clear technical definitions for drought • Government-wide consensus on indicators	• Formally regularize data-sharing agreements • Data-sharing platform • Data purchase barriers	• Improve technical capacity to use existing models and data • validate remote-sensing data	• Links with groundwater recharge and discharge • Link to crop planting and irrigation advice • Link to climate change adaptation and finance sector • Link to water pricing regimes	• Host in agency with remote sensing and GIS capacity • Link with end-users • Open-source data • Appropriate time scales • Train other agencies and decision-makers to interpret CDI • CDI and input layers freely available	• Intra-governmental cooperative environment and coordination • Provide channels for two-way communication with farming organizations;

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Figures

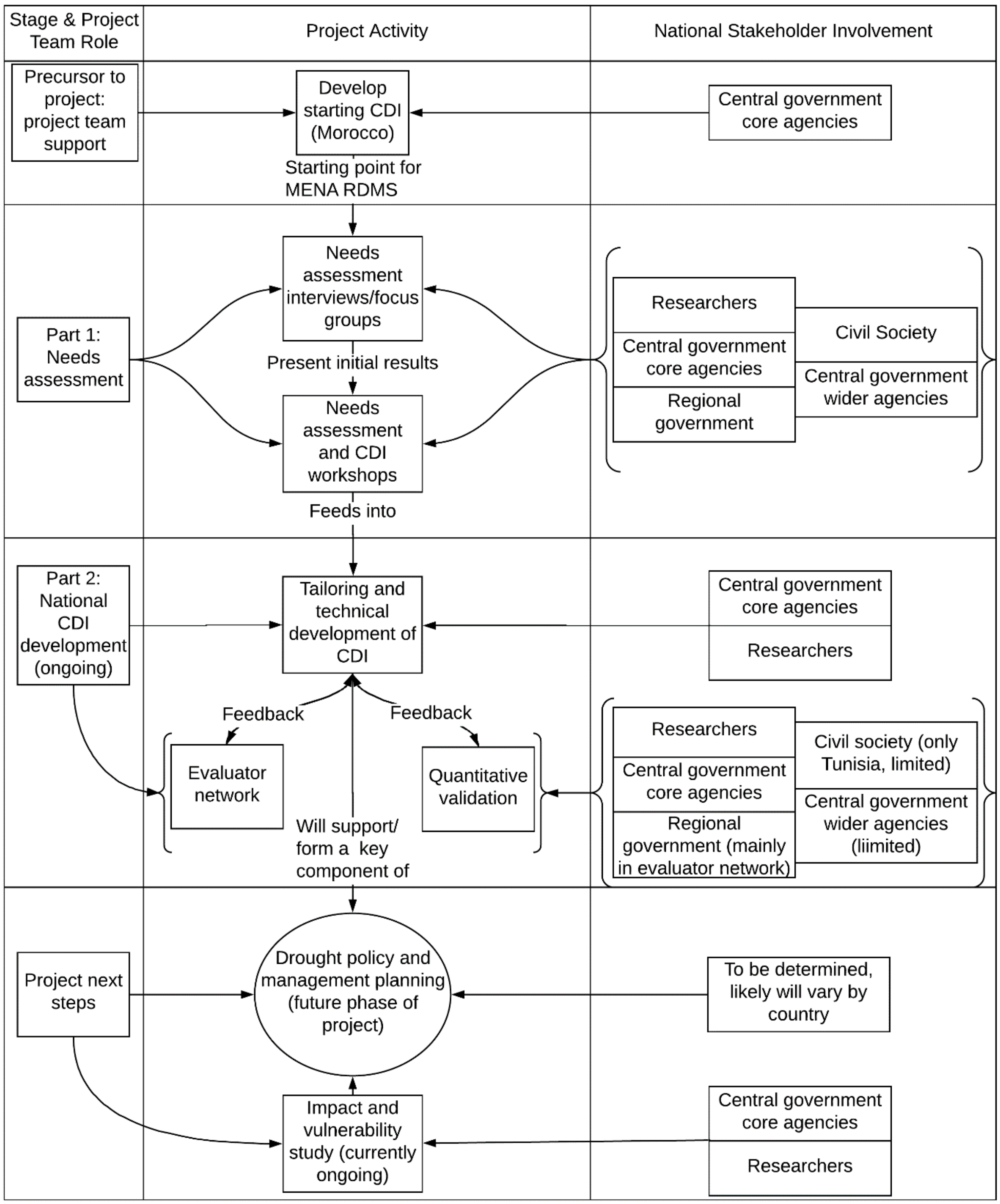

Figure 1 - MENA RDMS project structure.

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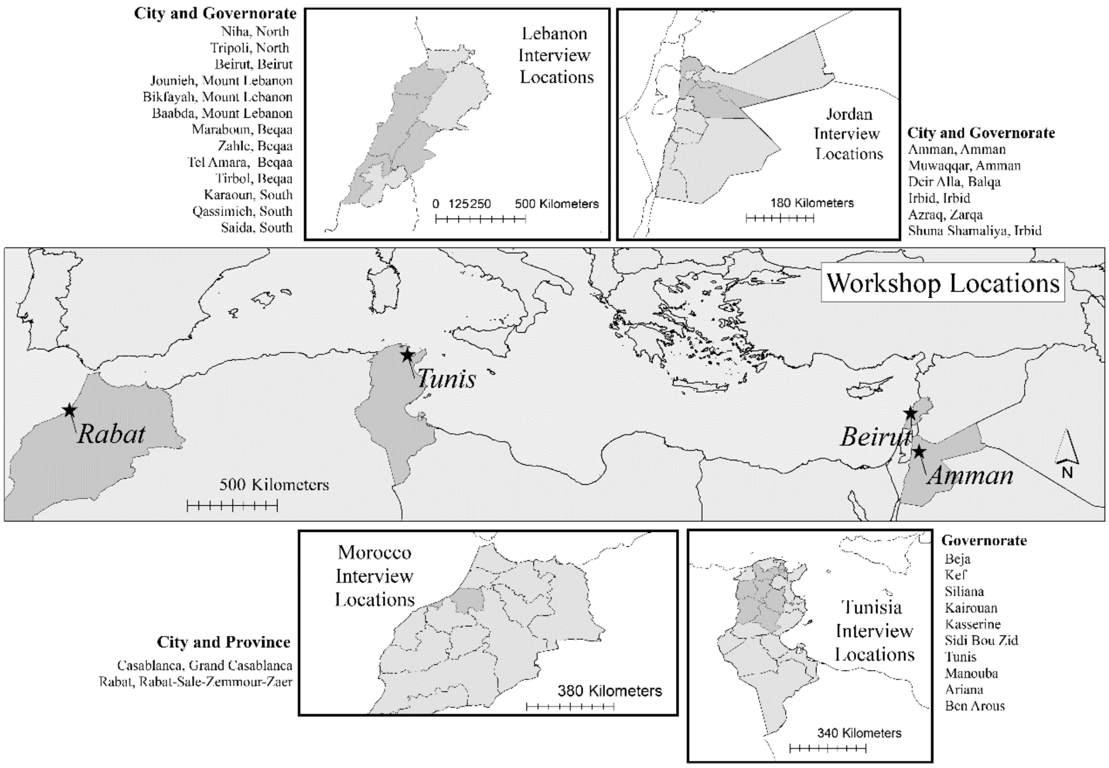

Figure 2. Interview, focus group and participatory workshop locations by country. Focal countries and provinces are depicted in greyscale. Workshop locations are starred and displayed in italics. Sources: the authors; GIS data layers from North American Cartographic Information Society's Natural Earth database,[16] and the GADM database of Global Administrative Areas.[17] These maps provide a general overview of the location of interviews and workshops, and they are neither a political statement nor a reflection of the authors' position regarding the delineation of each country.

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[16]http://www.naturalearthdata.com/
[17]http://www.gadm.org/

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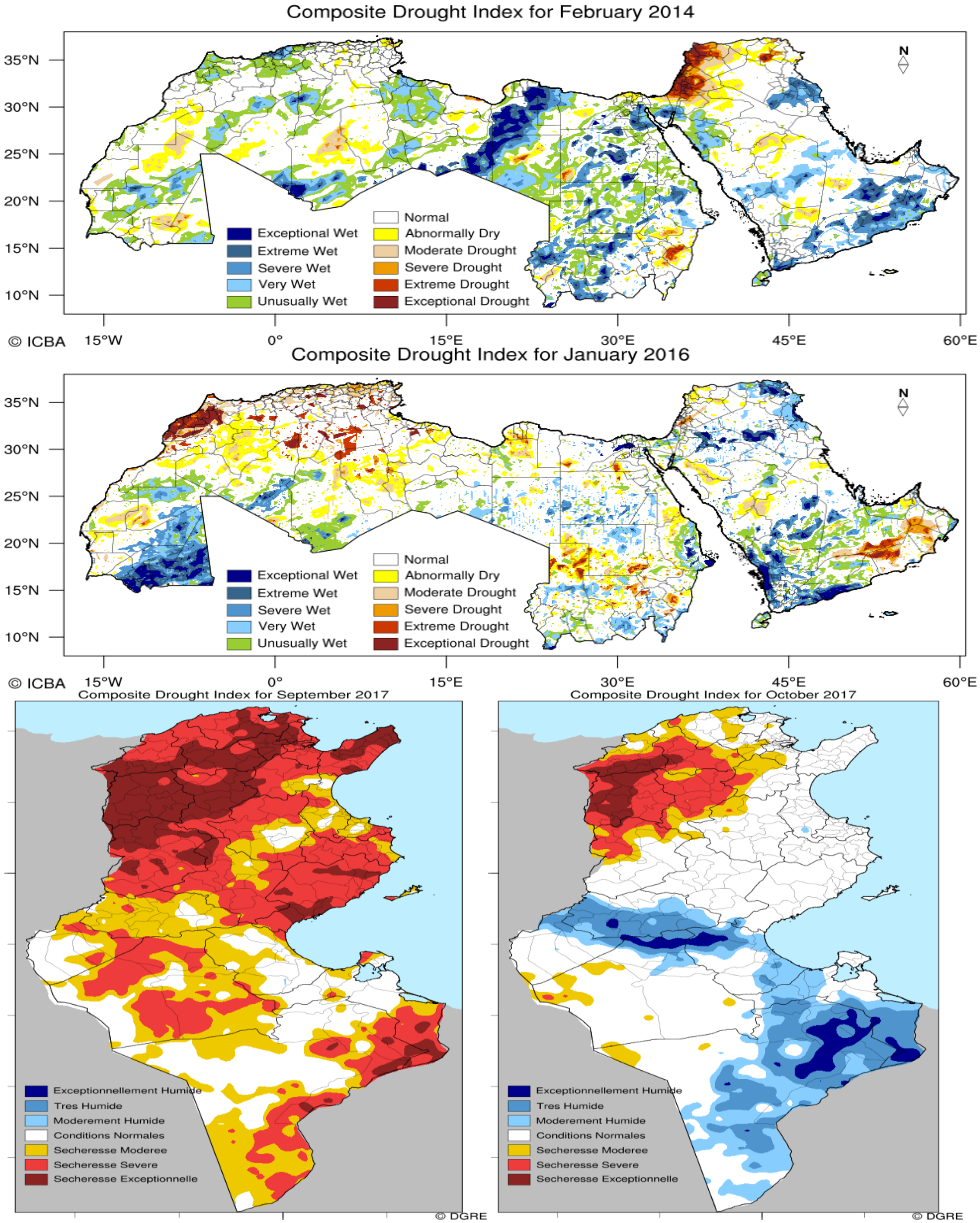

Figure 3. MENA CDI for February 2014 (top) and January 2016 (second from top); Tunisia CDI for September 2017 (bottom left) and October 2017 (bottom right). Source: Khemira and Jlassi (2018).

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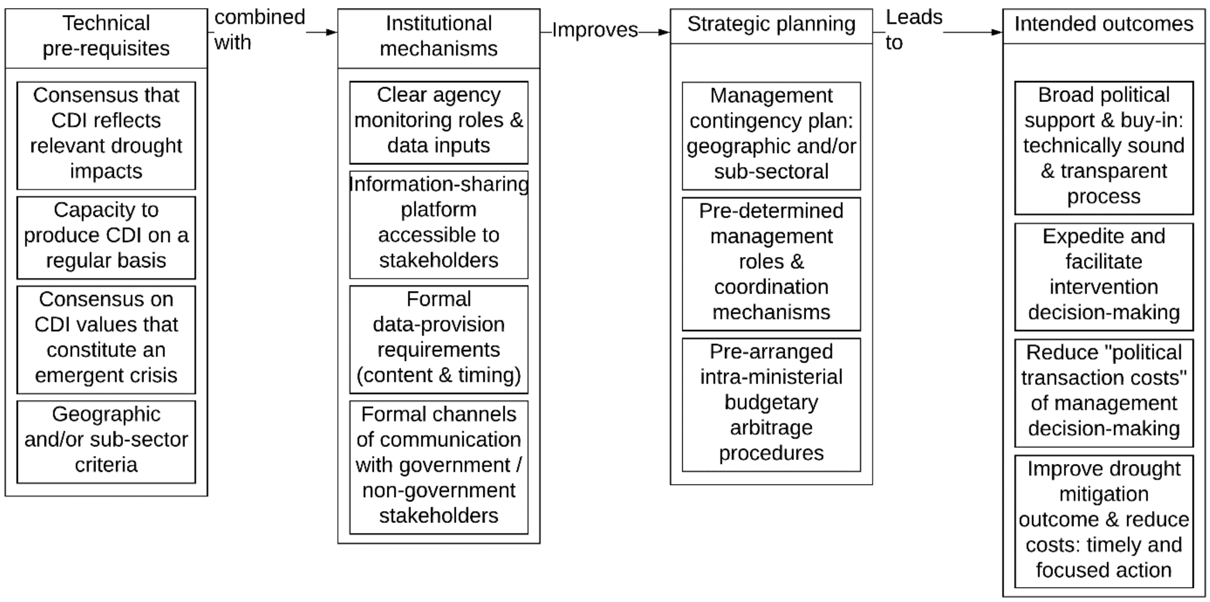

Figure 4. Synthesis of drought monitoring to management components.

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