

# Local early warning systems for drought – Could they add value to nationally disseminated seasonal climate forecasts?

Lotta Andersson<sup>a,\*</sup>, Julie Wilk<sup>b</sup>, L. Phil Graham<sup>a</sup>, Jacob Wikner<sup>c</sup>, Suzan Mokwatlo<sup>d</sup>, Brilliant Petja<sup>e,f</sup>

<sup>a</sup> National Centre for Climate Adaptation, Swedish Meteorological and Hydrological Institute, SE-601 76, Norrköping, Sweden

<sup>b</sup> Department of Thematic Studies, Environmental Change Unit, Linköping University, SE-581 83, Linköping, Sweden

<sup>c</sup> Department of Electrical Engineering, Linköping University, SE-581 83, Linköping, Sweden

<sup>d</sup> Research Directorate, Limpopo Department of Agriculture and Rural Development, Limpopo Province, Private Bag 9487, Polokwane, 0700, South Africa

<sup>e</sup> Water Research Commission, Pretoria, South Africa

<sup>f</sup> Risk and Vulnerability Science Centre, University of Limpopo, Turfloop, South Africa

## ARTICLE INFO

### Keywords:

Drought  
Seasonal climate forecasts  
Local EWS  
Indigenous climate indicators  
Resilience

## ABSTRACT

Limited application and use of forecast information restrict smallholder farmers' ability to deal with drought in proactive ways. This paper explores the barriers that impede use and uptake of seasonal climate forecasts (SCF) in two pilot communities in Limpopo Province. Current interpretation, translation and mediation of national SCF to the local context is weak. A local early warning system (EWS) was developed that incorporated hydrological modelled information based on national SCF, locally monitored rainfall and soil moisture by a wireless sensor network, and signs from indigenous climate indicators. We assessed to what degree this local EWS could improve interpretation of SCF and increase understanding and uptake by farmers. Local extension staff and champion farmers were found to play important knowledge brokering roles that could be strengthened to increase trust of SCF. The local EWS provided added value to national SCF by involving community members in local monitoring, enacting knowledge interplay with indigenous knowledge and simplifying and tailoring SCF and hydrological information to the local context. It also helped farmers mentally prepare for upcoming conditions even if many do not currently have the adaptive mindsets, economic resources or pre-conditions to positively respond to SCF information.

## 1. Introduction

Climate-related stress, including drought, is a major obstacle to poverty reduction. It is expected to worsen in many parts of the world because of climate change. The number of drought days could increase by more than 20 percent in most of the world by 2080, and the number of people exposed to droughts could increase by 9–17 percent in 2030 and 50–90 percent in 2080 (Hallegatte et al., 2016). Severe droughts can lead to primary impacts such as acute food shortages, loss of livestock, as well as malnutrition and other health-related issues (Hales et al., 2014). Secondary impacts such as school drop-outs and migration from rural to urban areas (Eriksen et al., 2005; Dercon and Porter, 2014) also negatively affect household resilience in rural areas. Depression and anxiety can further limit the ability of individuals and households to recover

after a drought (Manning and Clayton, 2018). The overall impacts of drought are critically dependent on the degree of vulnerability in households and communities. Most households in South-African rural areas depend on small-scale farming and/or pastoralism as their main livelihood, often with a focus on growing sufficient food to feed their families. The fact that these households have limited options for alternative livelihood sources during droughts is one factor critically reducing their resilience (Baudoin et al., 2016).

Drought differs from other natural hazards, due to its slow onset and long duration. In spite of this, there is a tendency to focus drought management on reactive actions (Wilk et al., 2017). If seasonal climatological forecasts (SCF) or early warning systems (EWS) indicate drought conditions, there are opportunities to take response actions to mitigate damages and even reduce vulnerabilities. These could include,

\* Corresponding author.

E-mail addresses: [lotta.andersson@smhi.se](mailto:lotta.andersson@smhi.se) (L. Andersson), [julie.wilk@liu.se](mailto:julie.wilk@liu.se) (J. Wilk), [phil.graham@smhi.se](mailto:phil.graham@smhi.se) (L.P. Graham), [jacob.wikner@liu.se](mailto:jacob.wikner@liu.se) (J. Wikner), [MokwatloS@agric.limpopo.gov.za](mailto:MokwatloS@agric.limpopo.gov.za) (S. Mokwatlo), [petjamb@gmail.com](mailto:petjamb@gmail.com) (B. Petja).

<https://doi.org/10.1016/j.wace.2019.100241>

Received 24 March 2019; Received in revised form 5 November 2019; Accepted 25 November 2019

Available online 25 November 2019

2212-0947/© 2019 The Authors.

Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

e.g., maintaining water storage reserves, stocking of food supplies, ensuring social support, focusing on home gardens, adapting and diversifying production, obtaining insurance, forward selling, and providing government subsidies (Henly-Shepard et al., 2014).

Seasonal climatological forecasts estimate how rainfall and other meteorological variables may develop over time scales of one to several months or more. These are typically provided at relatively large spatial scales. The El Niño Southern Oscillation (ENSO) is known to be a key driver for African rainfall variability and dynamical prediction systems have become increasingly skilled in predicting this (e.g., Pomposi et al., 2018). Within the World Meteorological Organization (WMO) cooperation, a number of international forecasting centres now provide global seasonal forecasts as a regular part of their prediction products under the designation of Global Producing Centres for long-range forecasts. SCF are routinely produced in South Africa, e.g., by the South-African Council for Scientific and Industrial Research (CSIR South African Weather Service (SAWS) and Climate System Analysis Group (CSAG).

Theoretically, increased access to SCF would make it possible, both for authorities and farmers, to take early actions to lessen negative impacts. However, despite progress in forecast capability, practical use of SCF at local and regional levels is limited, due to factors such as lack of awareness, engagement and communication between producers and users, tailoring to make information locally relevant, e.g., by providing information at the right time, including relevant indices that relate to hydrological and agricultural drought, and credibility, e.g., by ensuring local validation and presenting information in a language and format to which users can relate (e.g., Hammer et al., 2001; Orindi et al., 2007; Soares and Dessai, 2016).

Consequently, SCF are only one component in an Early Warning System (EWS). There are several definitions of EWS however, most include components related to detecting risks, informing those concerned about the risks and assisting people in enabling actions to reduce harm (e.g., UNISDR, 2009; Basher, 2006). EWS are usually managed as national services, with dissemination in a chain from regional to local authorities, and finally to end-users. The focus is often biased to technical capacities and the SCF itself, with limitations in engagement with local recipients and development of response capacities (Glantz and Baudoin, 2014; Baudoin and Wolde-Georgis, 2015; Baudoin et al., 2016).

It has been argued that national EWS are relevant for forecasting slowly emerging long-term events such as droughts while local EWS better relate to rapidly manifesting events as flash-floods (Glantz, 1994). However, it has gradually been recognised that drought-related EWS have the potential to be beneficial at local level if they are part of a context where it is possible for farmers to merge information with their own realities, capacities and knowledge, and have opportunities to make appropriate response actions (Bauer and Smith, 2015; Mugi-Ngenga et al., 2016). Successful applications of EWS on the local level will, however, require a shift of defining communication with end-users as a “last mile approach” to a “first mile approach” (Kelman and Glantz, 2014). Although it is not always possible to provide all the information requested by potential users, a common discussion of what is most useful is a prerequisite (Bauer and Smith, 2015). EWS must also be based on understanding the room of action of rural communities, as well as of measures that could extend that room (O’Brien et al., 2000). EWS thus depend on an institutional framework that enables actions (Wilk et al., 2017) and should enable resources so that those at risk can act on the received information to reduce damage (Ziervogel and Downing, 2004).

Although to some degree lost due to rapid societal change (Baudoin et al., 2016), indigenous knowledge is still used to forecast droughts and other climate-related phenomena by interpreting the behaviour and conditions of plants, animals, insects and meteorological and astronomical phenomena (e.g., wind, rain, stars and the moon). These predictions have in some cases been shown to correlate well with scientific assessments. Chisadza et al. (2015) found correlation between traditional plant and tree indicators and resulting conditions captured as

NDVI and SPI in a Zimbabwean catchment of the Limpopo Basin. They emphasised the importance of including indigenous knowledge, especially for predictions at local scale and recommended further validation be carried out for a number of seasons, in order to standardise the indicators.

The merging of knowledge from signs of indigenous climate indicators and SCF has been shown to facilitate the use and uptake of EWS (Orlove et al., 2010). Inclusion of local knowledge in an EWS can make it perceived as more locally relevant which increases the trust of inhabitants (Plotz et al., 2017). Although local knowledge can increase preparedness to drought, some traditions might also work against appropriate response actions. The maintenance of livestock among many rural Africans as savings reduces their willingness to reduce herds in spite of their high vulnerability to droughts (Nkedianye et al., 2011).

Another important component of an EWS is local monitoring of emerging drought conditions and its impacts. Access to locally monitored information makes it possible to update and verify forecasts against what actually is happening on the ground. In addition, it can be a way to ensure that authorities responsible for drought-relief have documentation of the level of drought that a community has experienced. It could also be a way to, in addition to SCFs, contribute to early detection of drier-than-usual conditions to farmers and authorities. Wireless sensor networks (WSN) are promising technologies to survey rural areas and obtain higher spatial and temporal monitoring of drought indices, such as soil moisture or water levels. Masinde (2015) recommended a drought EWS based on the integration of WSN and other technologies with indigenous knowledge. The modules should preferably be inexpensive, not only in terms of hardware cost, but also in terms of calibration, maintenance, etc. to ensure better spatial coverage and minimize data loss if the units are damaged. In summary, the current shortcomings of EWS undermine their use for risk reduction at the community level and there is a need for a shift from top-down EWS towards a more participatory approach, as suggested by, e.g., Baudoin et al. (2016).

The objectives of this study are, based on a pilot study in the Limpopo Province, South Africa, to evaluate the potential of a local participatory EWS to increase smallholder farmers’ preparedness to drought. The EWS focused on forecasts of the hydrological variables requested by farmers in the pilot communities, each relating to a different type of drought. They are: rainfall (meteorological drought), soil moisture (agricultural drought) and streamflow (hydrological drought).

Limpopo province is characterized by high climatic variability and is one of the driest regions in South Africa. It is prone to flood events and severe droughts and experiences high intra-seasonal variability during the rainy season. Rainfall varies significantly between years and occurs on a few isolated rain days seldom exceeding 50 rain days per year (FAO, 2004). Rainfall variability can expose communities to floods, as well as to a range of mild to severe drought, resulting in reduced crop yields in small-scale farmer areas, as maize production is entirely rain-fed (Bouagila and Sushama, 2013). Climate change impact in the basin remains uncertain, with indications of an impact on precipitation variability rather than on average precipitation (Tadross et al., 2005).

SCF, their communication, mediation and dissemination by Limpopo Department of Agriculture and Rural Development (LDARD) Extension and Advisory Services and Disaster Management Services Directorates at provincial, district and local municipality as well as service centre level, were explored in this paper. The local EWS system is based on an integration of forecast and current local conditions in two communities incorporating information from models (meteorological SCF linked to a hydrological model), signs from indigenous climate indicators, and a network of sensors measuring rainfall and soil moisture. An assessment was made of the added value of establishing a local EWS and the opportunities, constraints and recommendations for establishing and developing the system for future pilot communities in Limpopo Province.

## 2. Analytical framework

The usability of science knowledge relates to the degree that it is problem-driven and to which users are involved in the production process (Kirchhoff et al., 2015). Participation involving stakeholders that are affected by a particular issue or event and that must take related decisions, has been found to positively influence good responsive management. This is especially relevant when there are complex relationships and a lack of synchronization between groups and individuals, cultural and local traditions (Pahl-Wostl, 2009), existing and potential policies, and planning and implementation (Jonsson et al., 2015). Participatory processes have been found to contribute to more relevant and accepted outcomes by users (Wilk et al., 2018; Wilk and Jonsson, 2013).

Potential use of EWS information by smallholder farmers relies on the degree to which a number of factors identified in previous studies of knowledge systems, SCF usage and climate adaptation are fulfilled. Different strategies are useful for narrowing the usability gap involving varying levels of interaction, customization, packaging and selling of existing knowledge to meet users' needs (Lemos et al., 2012). For knowledge systems to be useful to users, Cash et al. (2003) highlighted the importance of creating processes and outcomes that are credible (contain sufficient scientific adequacy), salient (are relevant to decision makers' needs) and legitimate (are unbiased, fair and respectful of stakeholders' diverse values and beliefs). Lemos et al. (2012) also identified a number of processes and factors in previous studies that could prove useful for bridging the gap between what producers of climate information hope is useful and what users need and ask for. They categorized the main barriers and enablers of the use of SCF into: fit, interplay and interaction. *Fit* is the accuracy, reliability, relevance and usability of provided information. *Interplay* is how the information relates to and interacts with other form of available information. *Interaction* is the type and quality of relationship and collaboration between producers and users.

Boundary organizations are often needed and increasingly relied upon by producers to act as intermediaries between the arenas of science and policy. They have been found to play an important role in mediating the space between providers and users and as knowledge brokers that translate information and assist with communication (e.g. Kirchhoff et al., 2015; Lemos et al., 2012). This is linked to (i) specialized roles within the organization for managing the boundary space (ii) clear lines of responsibility and accountability to distinct social arenas on opposite sides of the boundary; and (iii) forums in which information can be co-produced (Guston, 1999). Effective climate knowledge brokering was found related to: *filtered information* (limiting it to an appropriate amount), *tailored information* (corresponding to user needs), *information access* (containing perceivable interfaces), *outreach* (increasing awareness and understanding among endusers) and *feedback to producers* (communicating the quality of provided information) (Bauer and Smith, 2015). The organizational settings, practises and routines are also aspects that can promote SCF usage among organizations (Bolson and Broad, 2013). Boundary organizations can be non-governmental organizations but also designated parts of organizations that have been given responsibility for this role.

Besides access to credible and legitimate information translated and communicated in ways that users can grasp, users may require resources to be able to act upon the information they receive (Ziervogel and Downing, 2004). This is especially true among smallholders in African contexts. In KwaZulu-Natal, South Africa, access to land, water, economic resources and knowledge, and adaptive mind-sets were found to influence farmers' abilities to adapt to climate variability and change through appropriate response actions (Wilk et al., 2012).

Based on the studies summarized above, we chose a number of factors relevant for assessing current SCF, their dissemination and use in our pilot communities and the local EWS developed in this study. The factors are organized into the themes: communication and mediation,

translation, and adaptive capacity (Fig. 1).

## 3. Methods and study area

A local participatory EWS for local drought monitoring and forecasts was developed and evaluated for two pilot communities during two growing seasons (2013/2014 and 2014/2015). The EWS included: SCF coupled to a hydrological model (to enable forecasts of meteorological (rainfall), agricultural (soil moisture) and hydrological (streamflow) drought), signs of indigenous climate indicators and sensor-monitored rainfall and soil moisture (Fig. 2). Participatory workshops were carried out with LDARD staff at provincial, district and service centre level to discuss the dissemination, content and use of SCF and common farmer responses and collect information to inform the design and assessment of the local EWS system. Community workshops were held with farmers in the two pilot communities to disseminate the local forecasts, discuss their planning and performance of farming activities during the two growing seasons of the study. Field-trials were carried out by LDARD in collaboration with local women champions to demonstrate crop yields resulting from different inputs and farm practices, e.g., fertilizer amounts, drought-tolerant seeds, mulching, etc.

### 3.1. The pilot communities

The pilot studies were carried out in two smallholder farming communities in Limpopo province within the Limpopo River Basin: Lambani (Luvuvhu sub-catchment in the Thulamela local municipality of the Vhembe district municipality) and Mokwakwaila (Letaba sub-catchment in the Letaba local municipality of the Mopani district municipality). Limpopo province is one of the driest regions in South Africa. The Luvuvhu and Letaba sub-catchments receive an average annual rainfall of approximately 610 mm, with a mean annual potential evaporation of approximately 1 670 mm. The Luvuvhu sub-catchment has slightly lower rainfall and higher evaporation than the Letaba sub-catchment. Agricultural drought is a recurring problem in both communities. Lower than normal rainfall (meteorological drought) results in agricultural drought (dry soils) and eventually also hydrological drought (reduced streamflow or water in rivers). This causes negative effects on agricultural activities, livestock herds, drinking water access, yields and seed availability (Mpandeli, 2014). The Lambani community has also suffered from recurrent high intensity rainfall events and flash floods that caused soil erosion, damage to water and road infrastructure and loss of planted crops.

Lambani inhabitants belong to the Venda ethnic group and Mokwakwaila inhabitants to Northern Sotho/Pedi and Tsonga groups. When this study was carried out, 525 households resided in each community (StatsSA 2016). Smallholder farmers in both communities undertake dryland agriculture and cultivate maize and some vegetables. The average farm size is 1 ha or less. Both villages received piped household water (from a dam in Mokwakwaila and a river in Lambani), although without regular daily access. In Lambani, during 2013/2014 wet season, the pipes collapsed and inhabitants took water directly from the river or bought it. In Mokwakwaila tap-water was used for irrigation of home gardens, as well as rainfall water harvested on rooftops and tanks. A minority of households owned small numbers of cattle, sheep or goats. Most farmers are over 60 years of age. Many younger people have moved to urban areas or continue to live with older relatives in the communities without participating in farming activities.

### 3.2. Hydro-climatological seasonal forecasts

SCF used in the local EWS were obtained from the South African Council for Scientific and Industrial Research (CSIR) around the 15th of each month. Contrary to the official SAWS forecasts distributed by LDARD that are probabilistic and present predicted statistical deviations from average conditions, the CSIR forecasts are deterministic and

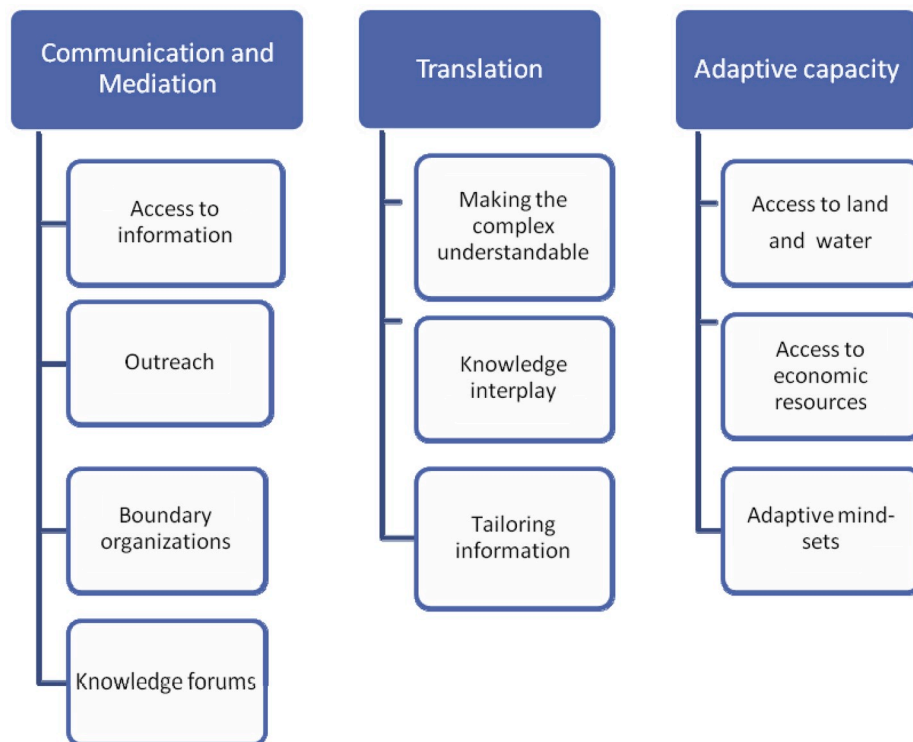


Fig. 1. Analytical framework containing factors linked to improving the usability of climate information.

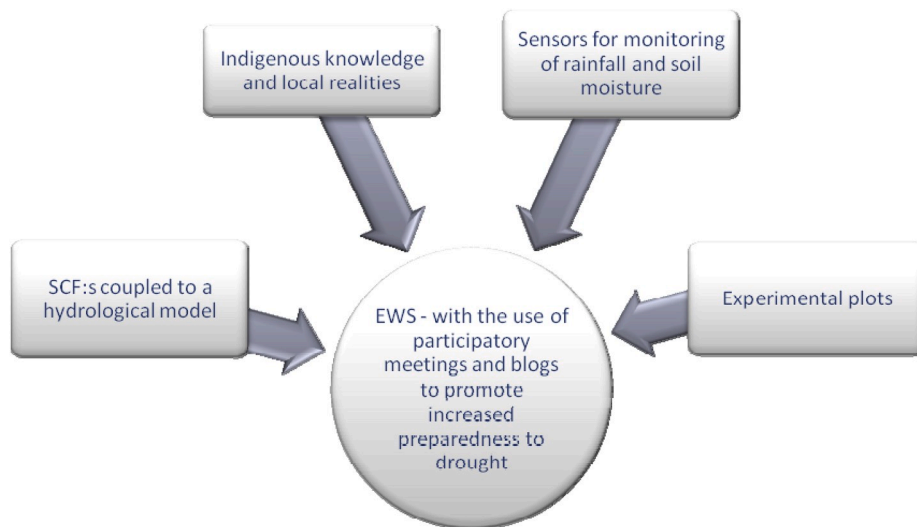


Fig. 2. The main components of the local EWS.

present deviations (mm) from normal rainfall. Raw data in the form of forecasted rainfall anomalies, i.e. deviation from climatological means, were provided on the CSIR ftp server. These were produced from an ensemble of global seasonal forecasts using the CCAM (Conformal Cubic Atmospheric Model; McGregor and Dix, 2008) global forecast model at a horizontal resolution of  $1 \times 1^\circ$ . The forecasted rainfall anomalies represent the ensemble mean of the CCAM model outputs.

As the seasonal forecast information came from a global model with a rather coarse spatial resolution, it cannot adequately reflect local drought conditions, such as local soil moisture deficits or low (if any) water flow in local streams or rivers. We therefore employed a “proxy” approach that combines the SCF with hydrological model simulations that use observed rainfall to produce evapotranspiration, soil moisture,

and river flow. The proxy forecast of agricultural drought (soil moisture) and hydrological drought (streamflow) for upcoming five-month periods was produced by selecting observed rainy seasons representative of the forecasted rainfall anomalies and analysing the relevant outputs from the hydrological model for the Luvuvhu and Letaba sub-catchments of the Limpopo River Basin.

We used the ACRU hydrological model (Warburton et al., 2010), which was calibrated for the Luvuvhu River and for the upstream portions of the Letaba River. Available historical rainfall and temperature observations for the 1961–1999 period were used to run the model. Output variables from ACRU included river runoff, evapotranspiration and soil moisture. These hydrological results provided a database that was used to represent conditions based on forecast-typical values.



The proxy approach is based on historical years that have similar characteristics to the seasonal forecast according to the forecasted rainfall anomaly values. Hydrological model outputs for these “analogue” years were then used as the basis for the proxy forecasts of local rainfall (meteorological drought), local soil moisture (agricultural drought) and local streamflow (hydrological drought). The observed rainfall anomaly was calculated as the difference between rainfall during the year in question to the climatological average rainfall for the area. To choose analogue years, rainfall anomalies over three-month periods were compared to the forecasted rainfall anomalies over corresponding three-month periods. The central analogue year was that which came closest to matching the forecasted rainfall anomaly. Analogue years lying on both sides of the central year were added based on the sorting order of the historical rainfall differences. We used five analogue years, the central year plus two years on each side according to the sorted order. The final proxy hydrological forecast shows the median and spread from the five analogue years for the variables of interest. The proxy methodology is described in more detail in Graham et al. (manuscript).

### 3.3. Sensor networks

Sensor development aimed to provide a system that is (i) inexpensive, with replaceable sensors, (ii) flexible and easy to install for a local representative, (iii) based on inter-communication between sensors, so that not all nodes need direct communication with, e.g. GSM, and (iv) based on consuming little power. Sensors were installed at three sites in each community to monitor rainfall and soil moisture. The design of the sensor network was based on reducing vulnerability due to malfunction or vandalism. The sensors were located in home-gardens or fields of trusted members of a community or in schoolyards. Lambani and Mokwakwaila residents, together with extension officers and researchers determined the locations where the sensors were installed and suitable soil depths for monitoring soil moisture. Maintenance and uploading of the data were carried out by community members and the extension officers assigned to the two communities.

### 3.4. Participatory workshops and blog

Seven half-day community workshops were held in Mokwakwaila and Lambani to present hydro-climatological SCF, record signs of indigenous climate indicators (Table 1), identify potential and actual responses and discuss reasons for taking response actions to SCFs or not. Extension service staff recruited the participants, facilitated the workshops and translated between English and local languages. A mix of different data collection methods was undertaken. Quantitative exercises assessed actions participants planned to take in response to presented SCF at the onset of the rainy season, and those that had been undertaken at the end of the season. Participants could choose from a list of suggested actions or add their own. Additional exercises were performed to assess the management practices farmers would prioritize if they had sufficient resources to respond to the climate/weather situation to which they were exposed. Farmers could choose a maximum of three of response actions (from offered suggestions or by adding their own) to wetter and drier conditions respectively. We counted and recorded the responses. Qualitative information was also collected by asking farmers open questions about their planned and performed farming activities and how their choices related to the forecasts. We noted their responses and estimated to what degree others agreed with the statements.

Three workshops were held with invited LDARD representatives including Research Services, Disaster Management Services Directorates (provincial head office and district offices) and Extension and Advisory Services from the Letaba and Thulamela local municipalities and service centres, the Agricultural Research Council, University of Limpopo, University of Venda, and the non-government organization, Association

for Water and Rural Development (Table 1). The workshops presented the project as it progressed and contained exercises to collect empirical information on: i) availability, communication and use of SCF by LDARD at the provincial to the extension service level as well as among the smallholder farmers; ii) prevalence, communication and use of indigenous climate indicators by farmers; iii) types of information e.g., rainfall, soil moisture, river discharge that is useful for farmers, including critical levels of hydrological variables and responses by farmers to cope with wet and dry seasons; iv) possibilities to act on information.

Two workshops were arranged for LDARD extension and advisory officers at service centre level for Thulamela and Letaba local municipalities, to assess existing and potential use of SCF in their work, as well as discuss current barriers and opportunities (Table 1). Notes were taken at the workshops and the content later coded and categorized according to main themes. Hands-on training on the proxy approach to creating hydro-climatological seasonal forecasts and the installation and maintenance of sensors and interpretation of the data was provided.

During the growing (rainy) season, monthly updates of hydro-climatological seasonal forecasts were provided to LDARD staff, as well as other interested organizations on an open access blog (<http://limpopo-dewd.blogspot.com/p/home.html>). Farmers received the information via their extension service officers.

## 4. Results and discussion

This section is organized according to factors that contribute to making knowledge systems useful to users (Fig. 1). We summarize and discuss information at workshops with: LDARD staff at provincial, district and service centre level, farmers, researchers, and civil society (Table 1). In Section 4.1 we describe and discuss the CSIR forecasts, process of dissemination and mediation, signs of indigenous climate indicators, SCF user needs and experiences from the local EWS (Table 1). Section 4.2 explores and discusses factors that determine usability in addition to forecasts. Results from quantitative exercises are expressed as percentages. Results from group interviews or discussions are expressed as an estimation of the number of extension staff or farmers that made or agreed with a statement or question. We have noted this by “one farmer”, “a few farmers”, “some farmers”, “many farmers” or “the majority of farmers” or similar statements with equivalent expressions for the case of extension officers.

### 4.1. Seasonal climate forecasts and dissemination

#### 4.1.1. Communication and mediation

**4.1.1.1. Access to information.** At the time of study, the South African Weather Service (SAWS) official forecasts and warnings were delivered approximately once a month. The provincial departments of LDARD compiled reports and Extension and Advisory Services were responsible for interpreting and communicating the information and recommending responses to smallholder farmers. Although formal channels to disseminate SCF from provincial to extension service level existed, they were lengthy, with many risks for bottlenecks (Wilk et al., 2017). Only 22 percent of the 76 extension officers that participated in service centre workshops in Thohoyandou and Tzaneen (Table 1), stated that they regularly received SCFs, which was attributed to a lack of laptops or weak and irregular internet access (Wilk et al., 2017).

**4.1.1.2. Outreach.** LDARD extension staff have the main role in communicating SCF to farmers. They are aided by Disaster Management Co-ordinators<sup>1</sup> who also disseminate forecast information at farmer

<sup>1</sup> Designated LDARD staff at District or service centre level that have extra duties related to Disaster Management.

**Table 1**

Workshops and other activities during which information related to the design and evaluation of the EWS were collected. The content of the workshops is described after the colon (:). The location of each meeting is followed by the number of participants in brackets.

Date	Community activities	Regional activities
Oct 2012	Field visits as part of decision of pilot areas	Meetings at LDARD provincial office: agreement on project design and choice of pilot communities
June 2013	Half-day community workshops: project presentation, strategies, indigenous forecast signs, information that would assist decisions; Lambani (10) and Mokwakwaila (20); Installation of sensors	Two-day workshop with provincial and community level extension staff: Presentation of the project, use and experiences of SCF, use of indigenous forecast signs, identification of meteorological, agricultural and hydrological drought indicators. Training in the use and maintenance of sensors Polokwane (25).
Sept 2013	Half-day community workshop: discussion of strategies, indigenous forecast signs, SCF; Lambani (5) and Mokwakwaila (35); Installation of sensors	Half-day workshops: definition of risks and identification of indicators. At Univ. of Limpopo also lectures held for students; University of Venda (10) and University of Limpopo (10).
May 2014	Half-day community workshops: experiences from the growing season; Lambani (19) and Mokwakwaila (20)	Half-day workshop with LDARD staff at provincial/service centre level: regional presentations, discussions of experiences; Polokwane (20)
Sept 2014	Half-day community workshops: discussions of indigenous forecast signs, locally monitored sensor data and SCF from previous season; Lambani (47) and Mokwakwaila (30)	
Oct 2014	Half-day community workshops: discussions of indigenous forecast signs, strategies for planning wet and dry years, handling uncertainties; Lambani (19) and Mokwakwaila (20)	
Nov 2014	Half-day community workshops: measures undertaken last (wet) year; exercises on planned actions and prioritised actions if economic resources were available; Lambani (28) and Mokwakwaila (31)	
April 2015	Informal discussions about experiences. Planning for final meetings.	
June 2015	Half-day community workshops: experiences from the dry season and actions taken. Final conclusions. Dissemination of results to students in local schools; Lambani (39) and Mokwakwaila (34)	Two one-day workshops with LDARD Advisory and Extension staff: barriers and opportunities for change in the communication, current existing and potential use of SCF in extension work; Thohoyandou (45) and Tzaneen (31) for Thulamela and Letaba local municipalities, respectively. One-day workshop with LDARD provincial/service centre staff level: final conclusions and way forward; Polokwane (20)
Oct 2015		Half-day field-trip to Mokwakwaila (24) One-day hands-on training: creating hydro-climatological SCF; Polokwane (12)

days. During community workshops, the majority of participating smallholder farmers said that they were unaware of the current SAWS forecasts. Some extension staff at a service centre workshop reported that when SCF are communicated, farmers often confuse them with short-term weather forecasts.

Extension staff from the two pilot communities reported that even when they receive a SCF and understand it, they do not always have time to disseminate it to a large number of farmers (Wilk et al., 2017). The bulk of knowledge exchange and discussions are undertaken in community meetings, that some, but far from all farmers, attend. The extension officers assigned to the pilot communities stressed that meetings of this type do not substitute for additional meetings with farmers, individually or in smaller groups. They have to revisit farmers and repeat information in order to build trust, especially with new types of information, technologies or recommended actions, such as forecasts.

**4.1.1.3. Roles and responsibility for boundary organizations.** A close and ongoing relationship between boundary organizations and users is a contributing factor in supporting SCF usage (Soares and Dessai, 2016). Although service centre extension staff function as the main boundary partner within LDARD, the majority of officers at the service centre workshop did not, at the time of the study, consider it their responsibility to interpret, filter and tailor SCF for local conditions. The Disaster Management Coordinators could play an important role in mediating and acting as knowledge brokers between provincial and service centre staff. However, at the time of the study, the coordinators' duties mainly pertained to reactive reporting of damages from disasters rather than in proactive risk management (Wilk et al., 2017). Previous positive experiences with innovation have been found to make climate forecast use more likely (Lemos et al., 2012). Champion farmers in every community, who already collaborate in the performance and dissemination of the results of LDARD field trials, could assume the role of community boundary partners or knowledge brokers. After SCF training, they would have the capacity to relay information in a way that

fellow farmers understand and be involved in the establishment of additional local EWS pilots.

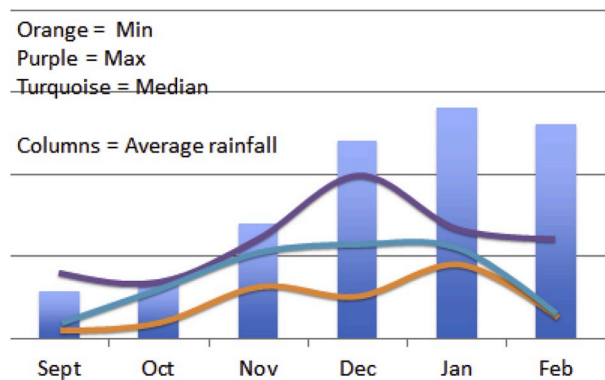
**4.1.1.4. Knowledge forums.** Two-way information enhances understanding between of one another's contexts, needs and limitations (Lemos et al., 2012) even within the same organization.

Forums for exchange of information and co-production of knowledge among different levels of LDARD staff did not exist at the time of the study. Written reports with information of emerging field conditions passed through a long chain of administrative levels thus hindering timeliness of response actions (Wilk et al., 2017). The majority of service centre extension staff expressed that forums are needed where they can give feedback on SCF and communicate signs of emerging drought conditions and where they can receive relevant site-specific recommendations. Although they are the ones who observe field conditions first-hand, extension staff are not included in discussions or consulted or well represented at district and provincial forums when important strategies and policies of drought management are made. Many said that they do not always find that the instructions they receive from higher administrative levels are relevant or timely for the problems they observe or that the grounds on which the decisions are based are understandable.

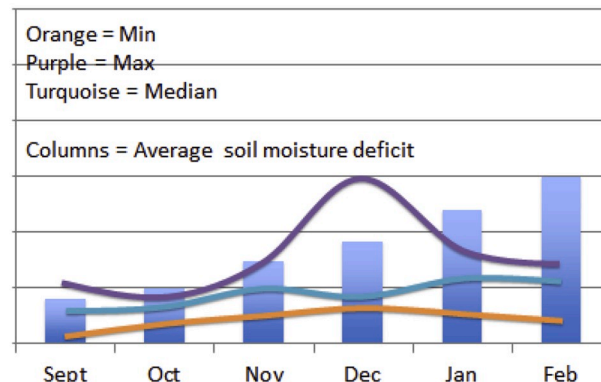
**4.1.1.5. Communication and mediation assisted by the local EWS.** The regularly updated open-access blog contained information of local rainfall, soil moisture and streamflow conditions from the latest SCF. The information was displayed in graphs with accompanying texts (see Fig. 3 and more information below) in addition to short summaries of the observed and predicted climate conditions for each pilot community. A similar regularly updated information source, with filtered and tailored information could increase local relevance.

The project workshops attended by provincial and service centre extension staff provided a channel for both top-down and bottom-up communication about interpreting SCF, current gaps in

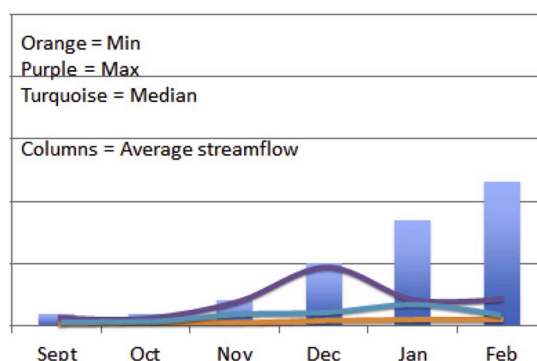
## Rainfall forecast: Letaba 2014-2015



## Soil Moisture Deficit forecast: Letaba 2014-2015



## Streamflow forecast: Letaba 2014-2015



**Fig. 3.** Graphs exemplifying the EWS forecasts shown at community workshops, showing rainfall, soil moisture deficit and streamflow forecasts for the 2014–2015 growing season, compared to average values from available historical records.

communication pertaining to EWS and drought management and suggestions for improvements. The majority of participants expressed in discussions that it is not a lack of willingness to meet and discuss SCF, their fit and salience but rather a lack of organized forums in which such discussions could take place. Many provincial divisions are involved in issues that relate to drought management, e.g., Disaster Management Services, Extension and Advisory Services, Crop and Animal Production Services, and there was a lack of directive or decision at the time of the study on who could take the lead and organize such forums on a regular basis. The study, undertaken with the backing of LDARD at provincial level, allowed extension staff at service centre level to prioritize study workshops over other duties.

#### 4.1.2. Translation

**4.1.2.1. Making the complex understandable.** The majority of extension officers found the currently disseminated SCF difficult to understand, especially the probabilistic statements. Sometimes both above and below normal conditions (with different probabilities) were shown for the same location. One participant gave an example where “probability of 40 percent” was interpreted as an expectation of 40 mm of rainfall. In the workshops, the majority of service centre extension staff agreed that the uncertainty of SCF must be clearly explained to farmers to prevent confusion. If farmers were to believe that the forecasts are “true” predictions and the forecasts proved to be wrong, this would negatively impact on their trust in future forecasts.

**4.1.2.2. Knowledge interplay.** During workshops with LDARD staff from

all administrative levels, there was consensus among participants that a respect of indigenous knowledge would likely increase trust and openness to other types of knowledge and technology, such as SCF, especially if different sources of information pointed in the same direction regarding drought forecasting (as was the case in the two years of our study). At community workshops, a few farmers reported and discussed recently noted signs from indigenous forecast indicators (Table 2). Although the two communities are situated approximately 140 km apart and inhabitants are of different ethnic groups, the noted signs and interpretations during the two years of study were similar. The only noticeable difference was the interpretation of signs related to number and sex of calves (Table 2). A few farmers said that less people interpret and use indigenous forecast signs to guide their farming activities than previously. Knowledge interplay is important so that interpretation of indigenous forecast indicators does not only rely on certain individuals and can withstand the loss of this expertise (Plotz et al., 2017). When new types of knowledge are introduced, value is added to the decision-making process (Lemos et al., 2012). Many farmers expressed that they plan their farming activities according to radio weather forecasts. If the radio reports and signs from indigenous climate indicators forecast similar conditions, farmers are more likely to trust in and plan according to the signs from indigenous climate indicators as they provide more site-specific information. Some farmers noted that in recent years rain patterns had become more unreliable, with a higher uncertainty of when the first rains would begin. Indigenous forecast signs had also been less certain. One farmer spoke about a particular type of tree in Mokwakwaila with a heavy load of fruit. While formerly this would have indicated that rains would soon begin and that most often had been the

**Table 2**

Signs from indigenous climate indicators in nature observed by people in Lambani and Mokwakwaila communities during the growing seasons of 2013/2014 (above average rainfall) and 2014/2015 (below average rainfall). Interpretation of whether the sign indicated higher, normal or lower wet/dry conditions is shown in brackets.

	2013/2014		2014/2015	
	Lambani	Mokwakwaila	Lambani	Mokwakwaila
Trees	Many fruits and shoots on the Motoma tree (higher)	Motoma, Marakarakane, Motakahoma and Mothokolo, Motika and wild fig trees had many fruits (higher)	The Motoma trees had a normal amount of fruit (normal)	The Motoma and Morukwe trees had normal/high amount of fruit (normal)
Astronomic				The moon was not covered with thin cloud and clouds (during day) were not chased away by winds (lower)
Wild animals		Large numbers of Sifenenefene worms in October (higher) Singing of the Hlahlamedupe bird in Oct/Nov (lower)		
Livestock	Calves came unnoticed; more female calves (higher)	More calves and kids (goats) (lower)		Normal number of calves and kids (normal)

case, in recent years the rains had not begun early despite the same sign. Findings from other areas have also indicated that indigenous signs do not correlate as strongly with weather phenomena as previously because of climate change (Plotz et al., 2017).

**4.1.2.3. Tailoring information.** During service centre level workshops, the majority of participants agreed that the currently distributed SCF information cannot be understood by smallholder farmers and that information must be tailored to increase understanding and uptake. The information should be locally relevant, relate to what really matters to farmers and be presented in a way so farmers can understand in what way e.g., forecasted rainfall, soil moisture or river flow might impact on their farming systems and households. The information should be disseminated in local languages and phrased in a similar manner as farmers speak. For example, one could express “get ready for dry conditions” instead of “it is likely that it will be drier than normal”. Without more tailored information, forecasts might confuse farmers rather than help them.

**4.1.2.4. Translation assisted by the local EWS.** The extension staff assigned to Mokwakwaila and Lambani perceived the locally monitored soil moisture and rainfall information to be useful for farmers as it is relevant information and monitored locally therefore farmers viewed it as trustworthy. They considered local monitoring a complementary tool that could validate both SCF and signs from indigenous forecast indicators. One extension officer also pointed out the value to capacity building if soil moisture levels could be measured and compared over longer time periods to enable early identification of deviations from normal conditions as a basis for reporting on risks for agricultural drought.

SCF in the local EWS had a deterministic approach so uncertainty

was presented at the workshops as a range with lines showing minimum, median and maximum levels compared to bar charts with average monthly amounts. In order to avoid debates about exact numbers, no absolute numbers were shown, only the predicted ranges compared to the historical average (Fig. 3). Although simplified, i.e., filtered and tailored for the community workshops, the graphs were however still challenging for some of the extension officers assigned to the communities to understand without clarification. Once they were explained, all the extension staff expressed that they gave added value to the currently disseminated SCF for preparing their work. After the EWS forecasts had been presented in a series of community workshops, one extension officer observed that farmers were increasingly more accustomed to discussing the forecasts, what they might mean for their community and contrasting them with the signs from indigenous climate indicators. During the two-year study, the two sources of information indicated similar forecasted conditions which corresponded with actual conditions once verified by local observations (Table 2) and the community sensor data (manuscript, Graham et al.). This time period is however too short to test or confirm any relationship between signs from indigenous climate indicators and SCF. The information would have to be compared for a number of years that include excessively wet and dry as well as normal conditions.

#### 4.2. Adaptive capacity

At provincial level workshops, some LDARD participants expressed that the majority of smallholder farmers do not respond to forecasts of extreme weather by undertaking management recommendations until conditions become critical. They did not perceive this to be due to a lack of knowledge but rather a lack of resources or ability to respond, and to some degree a lack of adaptive mind-sets. They listed a number of response actions that farmers could take to mitigate damages and decrease vulnerabilities which included: timely land preparations, selection of crop varieties, amounts and planting locations, increase or reduction of livestock, fodder purchase, pesticides, performance of dipping, vaccinations and other precautions against potential outbreak of diseases among livestock and crops, water harvesting, hiring of tractors, selection of cattle breeds, and dredging of dams.

##### 4.2.1. Access to land and water

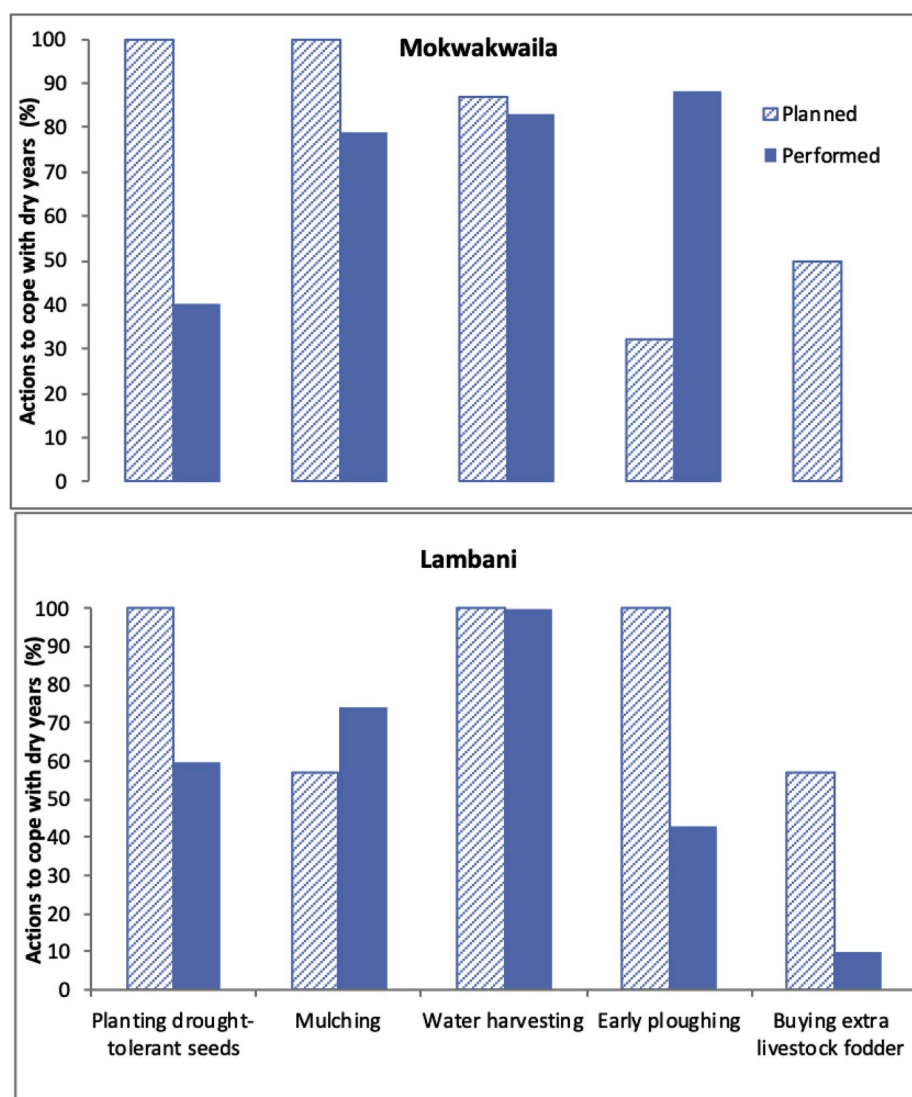
Water harvesting for households and home gardens was the action that showed the least discrepancy between planned and performed actions in both communities for the 2014/2015 growing season (Fig. 4). All farmers with home gardens had planned and undertook water harvesting for this purpose. This refers to small rooftop tanks so the economic and labour costs are low. However, farmers harvested such small amounts of water that it was only sufficient for household purposes, and not home gardens so most vegetables perished.

No farmers, at the time of the study, had constructed dams to water their crops or livestock. Their small plots of 1–2 ha do not allow much space for such purposes as they try to maximize crop production. Under dry conditions, as in 2014/2015 the animals had to walk long distances to reach water reserves. Some farmers suggested that they could also harvest water in their fields as they do in their home gardens by digging holes in the ground. However, one farmer said that this would only be possible if they cooperated because of the large amount of labour required and because the results would impact on land owned by several farmers.

##### 4.2.2. Access to economic resources

Many farmers at the community workshops stated that they could not take appropriate response actions to SCF because they lacked economic resources. This could be partially confirmed by the discrepancy between the planned and performed actions reported for the 2014/2015 growing season when conditions were drier than usual (Fig. 4), as well as the discrepancy between actions that they would prioritize if





**Fig. 4.** The discrepancy between the percentage of farmers that planned and performed actions to cope with the 2014/2015 growing season when conditions were drier than usual. The results are based on farmer reports during workshops before and after the 2014/2015 rainy season (cf Table 1, workshops in Nov 2014 and June 2015).

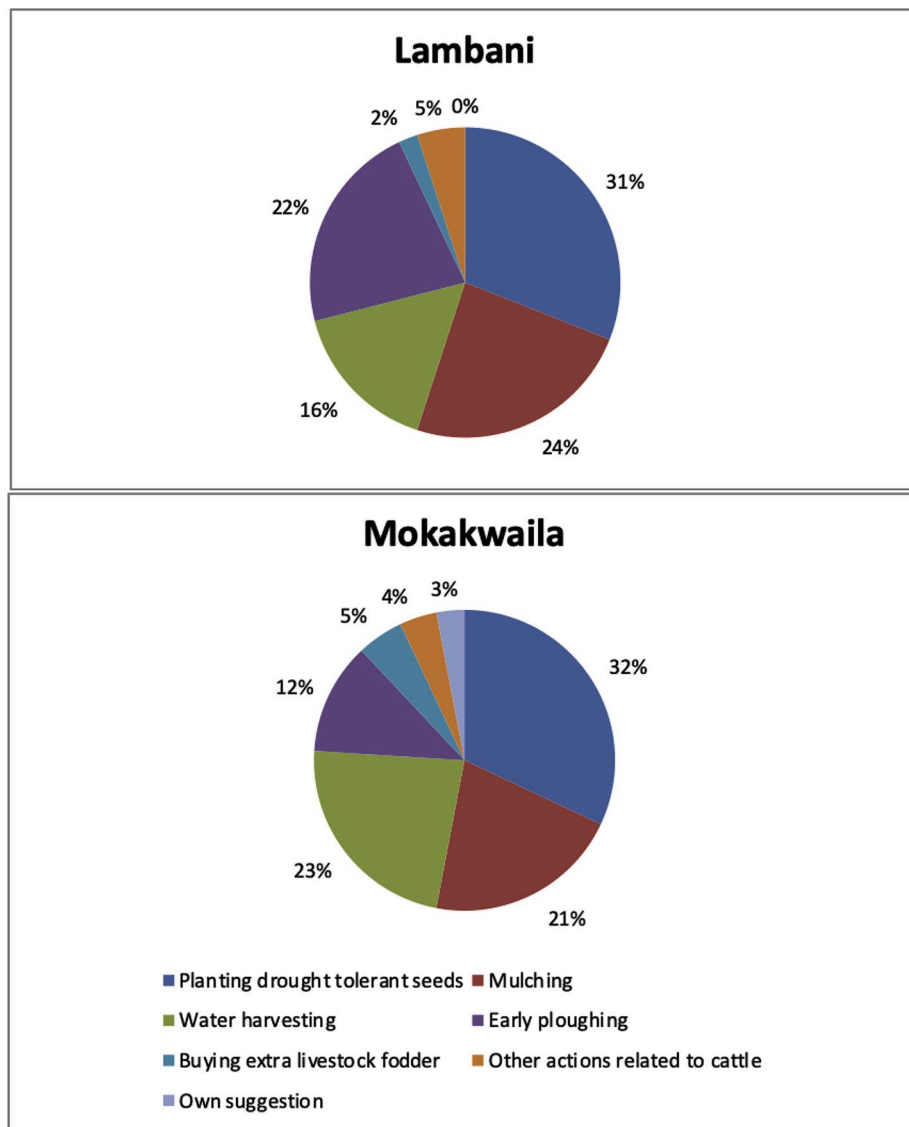
resources were available and the actual actions that they undertook (Fig. 5).

Although participants in both community workshops stated that they planned to plant drought-tolerant seeds as dry conditions had been indicated from the SCF, the number that actually performed the action was much smaller (60% in Mokwakwaila and 40% in Lambani). Drought-tolerant seeds are more expensive than indigenous and cannot be stored so they must be purchased each year. Use of drought-tolerant seeds was the measure that farmers most prioritised if resources were available (Fig. 5).

Farmers planned to perform mulching to reduce evaporation losses in response to the dry forecast (100% in Mokwakwaila and 57% in Lambani). At the end of the growing season approximately 75% in both communities reported that they had performed the practice. Mulching is done manually and so requires more physical capital than economic resources.

Early ploughing was the second-most prioritised measure if resources were available (Fig. 5). However, in reality, access to resources was a significant constraint for action. In Mokwakwaila many more farmers carried out early ploughing (88%) than planned (32%) after they received SCF indicating dry conditions. This could be linked to the government subsidy of free ploughing at Mokwakwaila in 2014/2015

(Wilk et al., 2017). In Lambani, however, although all farmers had planned to undertake early ploughing, only about half of them actually did so. No ploughing subsidy was available in Lambani for the same year (Wilk et al., 2017). The costs, availability and organization of tractors and ploughing equipment often cause long queues and delays, even up to two months. One farmer said that after waiting for a long time, he instead ploughed with donkeys, a very labour intensive activity. Actions related to cattle management under dry conditions were not highly prioritised by farmers even if they had sufficient resources available (Fig. 5). Although approximately 50% of the farmers said that they planned to buy extra fodder, very few (0% in Mokwakwaila and 10% in Lambani) actually did so (Fig. 4). The amount of cattle fodder needed in a long dry season is very expensive for smallholder farmers. Government subsidies sometimes cover costs but only for a limited amount (Wilk et al., 2017) and some farmers in both communities reported that they did not know of the subsidy program. Instead of buying extra fodder, they told that they take their cattle to graze in distant places during long dry spells, which strains the animals. A few farmers reported selling their animals, but reducing their herds is often a “last resort action”. If they wait too long to sell in dry periods, animals are in poor body condition, prices low and the queues to abattoirs long.



**Fig. 5.** Farmers' prioritization of actions to cope with dry conditions if economic resources were available. The percentage of suggested actions is shown for the two pilot communities, based on exercises held during workshops in the two pilot communities in November 2014 (cf. Table 1). Each farmer could choose a maximum of three response actions from the suggestions above, or by adding their own suggestions. The only added suggestion was "save money instead of investing in farming during a dry year".

#### 4.2.3. Adaptive mind-sets

At community workshops at the end of the growing seasons, the majority of farmers said that they remembered the forecasts that had been presented and they had found them helpful though they could not say explicitly why. However, a smaller number had or could proactively respond to the forecast information. Some, in 2014/2015, contrary to how they usually acted, planted at the first rains. A few said that they planted drought-tolerant seeds, even when they were not distributed in government programs. Generally, farmers expressed that they plan for favourable conditions, despite what the forecasts say, as one farmer expressed "we do not want to stay hungry but instead try our luck and hope for the best". In 2014/2015, forecasted as dry, many farmers planted their entire fields instead of reducing the planted areas as well as seed and manual inputs, as a response to this hope. The forecasts, however, could also be seen as a way to help farmers mentally prepare for emerging harsh conditions rather than solely influencing their farming actions.

Some extension staff indicated that many smallholder farmers have become so accustomed to government subsidies that they are sometimes reluctant to undertake their own management activities, despite recommendations. While no-till is a well proven method in water and soil conservation, farmers, who have received free ploughing from the government for several years, do adopt the practice on their own when

subsidies are not provided. Others expressed that younger farmers are often quicker to adopt new technologies and measures, although they are few in number in the two communities as most have moved to urban centres. Older farmers tend to have more difficulty in undertaking labour-intensive measures, e.g., mulching and drainage, which may influence them to wait for government actions such as free ploughing, even if the rains have come and the tractors are delayed. Larger actions, including large-scale drainage and dam construction for crop and livestock watering demand significant economic or labour investments. Farmers would have to collaborate and plan together which might require a new mind-set but also effective organization. Smallholder farmers in another South African study linked collective efforts to indecisiveness, conservativeness and even conflict (Wilk et al., 2012).

## 5. Conclusions

A majority of LDARD extension staff found the official SAWS forecasts hard to understand. They suggested increased translation, communication and mediation by filtering and tailoring the language (e. g., by reducing non-technical language and translating SCF to local languages), clearly communicating uncertainty and clarifying roles and responsibilities of LDARD staff at different administrative levels. Effective two-way communication channels and increased representation of

extension officers in provincial and district forums could also help relay information about local conditions and emerging signs of drought upwards to compare against the forecasted conditions and also help them take early actions to lessen negative impacts. Strengthening the boundary roles played by LDARD Extension and Advisory Services staff and champion farmers would hasten SCF dissemination and encourage farmer uptake. Extension staff and Disaster Risk Coordinators at local and district level already play important roles in mediation between SCF producers and users and they could be further supported with additional time and resources to ensure they understand SCF and are aware of appropriate and site-specific actions to relay to farmers. Field trials and demonstrations undertaken by LDARD are important opportunities to concretely illustrate the effects of different response actions that might encourage greater usage and trust in SCF and more adaptive mindsets. Champion farmers involved in these activities could be supported as SCF mediators and knowledge brokers to increase usage of positive response actions in their communities. These recommendations do not negate the important role that LDARD staff already plays in SCF dissemination and as a boundary organization.

The local EWS, including information from hydrological modelling of nationally distributed SCF, signs of indigenous climate indicators and locally situated sensors, did provide added value to smallholder farmers. Locally monitored soil moisture and rainfall, from a wide spatial coverage of wireless sensors, added site-specific information. Inclusion of local champions and LDARD extension staff in the installation and maintenance of monitoring equipment and uploading and transferring the retrieved information increased trust in the forecasts. The trust was further enhanced by inclusion of noted signs from indigenous forecast indicators in the SCF knowledge interplay. The creation of the local EWS also gave farmers and extension staff opportunity to discuss the combined forecast information, its implications and relevant responses for farmers. Although we acknowledge that the findings are based on the local context of the two pilot communities, they could inform the process of developing other local EWS in new pilot locations.

Even if smallholder farmers tend to do “business as usual” in spite of forecasted droughts, a local EWS could aid them to mentally prepare for coming conditions. In the 2014/2015 dry year, farmers planned for and performed actions with lower economic investment and higher benefits (e.g., mulching, water harvesting for home gardens). Greater discrepancies were found between plans and actions when higher economic resources were required (e.g., hiring tractors for early ploughing, buying drought-tolerant seeds and animal fodder). Prioritised actions that require both a coordination of labour and economic resources, e.g., water harvesting for crops, were rarely undertaken.

## Declaration of competing interest

There are no known conflicts of interest.

## Acknowledgements

We gratefully thank community participants from Mokwakwaila and Lambani and staff of LDARD and other organizations that participated in and contributed to project workshops and the information in this project. The project was funded by the Swedish International Development Agency by grant 348-2013-6285.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.wace.2019.100241>.

## References

Baudoin, M.A., Henly-Shepard, S., Fernando, N., Sitati, A., Zommers, Z., 2016. From top-down to “Community-Centric” approaches to early warning systems: exploring

- pathways to improve disaster risk reduction through community participation. <https://doi.org/10.1007/s13753-016-0085-6>.
- Baudoin, M.A., Wolde-Georgis, T., 2015. Disaster risk reduction efforts in the greater horn of Africa. *Int. J. Disaster Risk Sci.* 7 (6.1), 163–174, 49–61.
- Basher, R., 2006. Global early warning systems for natural hazards: systematic and people-centred. *Phil. Trans. R. Soc. A Math. Phys. Eng. Sci.* 364 (1845), 2167–2182.
- Bauer, F., Smith, J. (Eds.), 2015. The Climate Knowledge Brokers Manifesto. Renewable Energy and Energy Efficiency Partnership (REEEP) on behalf of CKB Vienna International Centre, ISBN 978-3-200-04206-3.
- Bolson, J.J., Broad, K.B., 2013. Early adoption of climate information: lessons learned from South Florida water resource management. *Weather Clim. Soc.* 5 (3), 266–28.
- Bouagila, B., Sushama, L., 2013. On the current and future dry spell characteristics over Africa. *Atmosphere* 4, 272–298.
- Cash, D.W., Clark, W.C., Alcock, F., Dickshon, N.M., Eckely, Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci. U.S.A.* 100 (14), 8086–8091.
- Chisadzwa, B., Tumbare, M.J., Nyabeze, W.R., Nhapi, I., 2015. Linkages between local knowledge drought forecasting indicators and scientific drought forecasting parameters in the Limpopo River Basin in Southern Africa. *Int. J. Disaster Risk Reduct.* 12, 226–233.
- Dercon, S., Porter, C., 2014. Live aid revisited: long-term impacts of the 1984 Ethiopian famine on children. *J. Eur. Econ. Assoc.* 12 (4), 927–948.
- Eriksen, S.H., Brown, K., Kelly, M., 2005. The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. *Geogr. J.* 171 (4), 287–305.
- Food and Agricultural Organisation (FAO), 2004. Drought Impact, Mitigation and Prevention in the Limpopo Basin: A Situation Analyses, Land and Water Discussion Paper. FAO, Rome.
- Glantz, M.H., 1994. Creeping Environmental Phenomena: Are Societies Equipped to Deal with Them? Workshop On Creeping Environmental Phenomena and Societal Responses to Them, 7–9 February 1994. National Center for Atmospheric Research, Boulder, Colorado, USA.
- Glantz, M.H., Baudoin, M.A., 2014. Working with a Changing Climate, Not against It—Hydro-Meteorological Disaster Risk Reduction: A Survey of Lessons Learned for Resilient Adaptation to a Changing Climate. Consortium for Capacity Building, Boulder.
- Guston, D.H., 1999. Stabilizing the boundary between US politics and science. *Soc. Stud. Sci.* 29 (1), 87–111.
- Hales, S., Kovats, S., Lloyd, S., Campbell-Lendrum, D., 2014. Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s. World Health Organization.
- Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., Vogt-Schilb, A., 2016. Shock Waves: Managing the Impacts of Climate Change on Poverty. Climate Change and Development Series. World Bank, Washington, DC. <https://doi.org/10.1596/978-1-4648-0673-5>. License: Creative Commons Attribution CC BY 3.0 IGO.
- Hammer, G.L., Hansen, J.W., Phillips, J.G., Mjeldec, J.W., Hill, H., Love, A., Potgieter, A., 2001. Advances in application of climate prediction in agriculture. *Agric. Syst.* 70, 515–553.
- Henly-Shepard, S., Anderson, C., Burnett, K., Cox, L.J., Kittinger, N.L., Ka’auomoana, M., 2014. Quantifying Household Social Resilience: A Place-Based.
- Jonsson, A., Rydham, B., Wilk, J., Feroz, A.R., Rani, A., Kumar, A., 2015. Climate change adaptation in urban India: The inclusive formulation of local adaptation strategies. *Global Nest Journal* 17 (1), 61–71.
- Kelman, I., Glantz, M.H., 2014. Early warning systems defined. In: Singh, A., Zommers, Z. (Eds.), *Reducing Disaster: Early Warning Systems for Climate Change*. Springer, London, pp. 89–108.
- Kirchhoff, C.J., Esselman, R., Brown, D., 2015. Boundary organizations to boundary chains: prospects for advancing climate science application. *Clim. Risk Manag.* 9, 20–29.
- Lemos, M.C., Kirchhoff, C.J., Ramprasad, V., 2012. Narrowing the climate information usability gap. *Nat. Clim. Chang.* 2, 789–794.
- Manning, C., Clayton, S., 2018. Threats to mental health and wellbeing associated with climate change. In: *Psychology and Climate Change Human Perceptions, Impacts, and Responses*, Chapter 9. Academic Press, pp. 217–244.
- Masinde, M., 2015. An innovative drought early warning system for sub-Saharan Africa: integrating modern and indigenous approaches. *Afr. J. Sci. Technol. Innovation Dev.* 7 (1), 8–25.
- McGregor, J.L., Dix, M.R., 2008. An Updated Description of the Conformal-Cubic Atmospheric. High Resolution Numerical Modelling of the Atmosphere and Ocean. Springer, New York.
- Mpandeli, S., 2014. Evaluation of crop production practices by farmers in Tshakhuma, Tshiombo and Rabali areas in Limpopo province of South Africa. *J. Agric. Sci.* 6 (8), 10–18.
- Mugi-Ngenga, E.W., Mucheru-Muna, M.W., Mugwe, J.N., Ngetich, F.K., Mairura, F.S., Mugendi, D.N., 2016. Household’s socio-economic factors influencing the level of adaptation to climate variability in the dry zones of Eastern Kenya. *J. Rural Stud.* 43, 49–60.
- Nkedianye, D., de Leeuw, J., Ogutu, J.O., Said, M.Y., Saidimu, T.L., Kifugo, S.C., Reid, R. S., 2011. Mobility and livestock mortality in communally used pastoral areas: the impact of the 2005–2006 drought on livestock mortality in Maasailand. *Pastoralism: Res. Policy Pract.* 1, 17.
- O’Brien, K., Sygna, L., Næss, L.O., Kingamkono, R., Hochobeb, B., 2000. Is Information Enough? User Responses to Seasonal Climate Forecasts in Southern Africa. Oslo University. CICERO. Report 2003:3.
- Orindi, V.A., Nyong, A., Herrero, M., 2007. Pastoral Livelihood Adaptation to Drought and Institutional Interventions in Kenya. *Fighting Climate Change: Human Solidarity*

- in a Divided World. UNDP. Human Development Report Office OCCASIONAL PAPER 2007/54.
- Orlove, B., Roncoli, C., Kabugo, M., 2010. Indigenous climate knowledge in southern Uganda: the multiple components of a dynamic regional system. *Clim. Change* 100, 243–265.
- Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change* 19 (3), 354–365.
- Plotz, R.D., Chambers, L.E., Finn, C.K., 2017. The best of both worlds: a decision-making framework for combining traditional and contemporary forecast systems. *J. Appl. Meteorol. Climatol.* 56 (8), 2377–2392.
- Pomposi, C., Funk, C., Shukla, S., Harrison, L., Magadzire, T., 2018. Distinguishing southern Africa precipitation response by strength of El Nino events and implications for decision-making. *Environ. Res. Lett.* 13, 074015.
- Soares, M.B., Dessai, S., 2016. Barriers and enablers to the use of seasonal climate forecasts amongst organizations in Europe. *Clim. Change* 137 (1–2), 89–103.
- StatsSA (Statistics South Africa), 2016. Statistics by place. <http://www.statssa.gov.za> (Accessed 8 July 2016).
- Tadross, M., Jack, C., Hewitson, B., 2005. On RCM-based projections of change in southern African summer climate. *Geophys. Res. Lett.* 32, L23713.
- UNISDR (United Nations International Strategy for Disaster Reduction), 2009. Terminology on Disaster Risk Reduction. UNISDR, Geneva.
- Warburton, M.L., Schulze, R.E., Jewitt, G.W.P., 2010. Confirmation of ACRU model results for applications in land use and climate change studies. *Hydrol. Earth Syst. Sci.* 14, 2399–2414.
- Wilk, J., Andersson, L., Warburton, M.L., 2012. Adaptation to climate change and other stressors among commercial and small-scale South African farmers. *Reg. Environ. Chang.* 13, 273–286.
- Wilk, J., Andersson, L., Graham, L.P., Wikner, J.J., Mkwato, S., Petja, B., 2017. From forecasts to action – what is needed to make seasonal forecasts useful for South African smallholder farmers? *Int. J. Disaster Risk Reduct.* 25, 202–211, 2017.
- Wilk, J., Jonsson, A., 2013. From Water Poverty to Water Prosperity—A More Participatory Approach to Studying Local Water Resources Management. *Water resources management* 27 (3), 695–713.
- Wilk, J., Jonsson, A.C., Rydhagen, B., del Callejo, I., Cerruto, N., Chila, G., Rani, A., 2018. Assessing vulnerability in Cochabamba, Bolivia and Kota, India: how do stakeholder processes affect suggested climate adaptation interventions? *Int. J. Urban Sustain. Dev.* 10 (1), 32–48.
- Ziervogel, G., Downing, T.E., 2004. Stakeholder networks: improving seasonal climate forecasts. *Clim. Change* 65, 73. <https://doi.org/10.1023/B:CLIM.0000037492.18679.9e>.