Forecasting Drought in Zimbabwe: Advances, Challenges, and Future Opportunities

Image source: IFRC

In Zimbabwe, agricultural activities are the primary source of income for 67% of the total population residing in rural areas. The agricultural productivity follows the rainfall patterns of the country, as most agriculture is rain-fed. This makes the farm productivity extremely susceptible to drought. Only 37% of the rural areas receive adequate rainfall for successful harvests. Climate change increases the frequency and intensity of drought. This means the impact of drought on the livelihood of people increases, significantly reducing community resilience.

510, the Data & Digital initiative of the Netherlands Red Cross, developed a drought trigger model with the Zimbabwe Red Cross Society, the Danish Red Cross, the Finnish Red Cross and other governmental partners in-country (part of Technical Working Group). Funded and technical support provided by Danish Red Cross and Finnish Red Cross. The trigger model development used the insights from co-design sessions with the relevant stakeholders.

Summary

- The Zimbabwe Red Cross Society is implementing drought anticipatory action in Zimbabwe.
- 510, the Data & Digital initiative of the Netherlands Red Cross, developed for this the drought trigger or impact-based forecasting model together with the Zimbabwe Red Cross Society, the Danish Red Cross, the Finnish Red Cross and in-country partners.
- Impact Based Forecasting (IBF) is a methodology to predict the impact of drought based on drought hazard forecast information as well as information on the vulnerability and exposure.
- Crop yield anomaly is currently selected as the impact-based forecast target for the activation of the Forecast Based Financing System (FbF) in Zimbabwe.
- The forecasted crop yield anomaly should be connected to the communities. That is the information needed by the decision makers to plan emergency operations.
- Staged forecasts triggers two sets of early actions. One in September and one in March.
- The prioritized drought impact selected in Zimbabwe to be addressed by early actions are identified as; 1. crop losses 2. drought induced mortality of livestock and 3. food insecurity as a result of crop or livestock losses.

'The development of an Impact Based Forecasting model by 510 has come at the right time as this will greatly improve drought monitoring at national and community level.'

David Muchatiza, AA specialist at Zimbabwe Red Cross

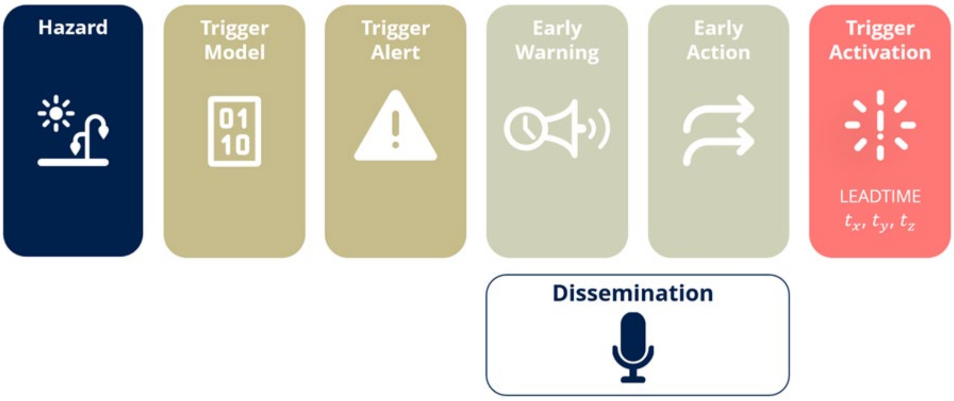


Figure 1: Key IBF components

Meteorological drought is defined as a prolonged period of low precipitation (rainfall, snowfall, or snowmelt) that can result in a water deficit (hydrological drought) and a soil moisture deficit (agricultural drought). Food insecurity, disease transmission, hunger and starvation, migration, and economic losses can also occur when communities do not have enough water for drinking, sanitation, and agriculture. Drought can also have an adverse effect on a country's power generation, transportation, and commercial or industrial demands. Between 1982 and 2011, drought has been the most recorded high-impact natural hazard occurring in Zimbabwe. It resulted in major natural disasters, such as the 2013 drought, which affected over 4 million people.

Forecast Based Financing

Forecast Based Financing (Fbf) is a program that enables access to humanitarian funding for early action based on in-depth forecast information and risk analysis. The goal of FbF is to anticipate disasters, prevent their impact, if possible, and reduce human suffering and losses. It consists out of three components: Triggers, Early Action and a Financial Mechanism.

Early Action are all the steps that protect people before a disaster strikes based on early warning or forecasts. Early Action is activated once a Trigger Model reaches a certain pre-determined threshold.

A Financial Mechanism is put in place to release the funding required once the trigger activates Early Action. The three components are summarized in an Early Action Protocol (EAP). The EAP serves as a guideline for National Societies and partners which delineates roles and responsibilities for quick action. The Drought Early Action Protocol (EAP) for the Zimbabwe Red Cross National Society (ZRCS) is a tool to guide the timely and effective implementation of early actions based on forecast and observational data, which predict meteorological hazards with a high likelihood of humanitarian impact.

Impact Based Forecasting

Impact Based Forecasting (IBF) enables Anticipatory Action in response to weather and climate events. It turns forecasts and warnings from descriptions of what the weather will be into assessments of what the

‘We try to deal with the insidious and complex nature of drought by triggering in phases for early actions and act with operation lead time that reduce drought impact.’

Marijke Panis, Data Team Lead at 510

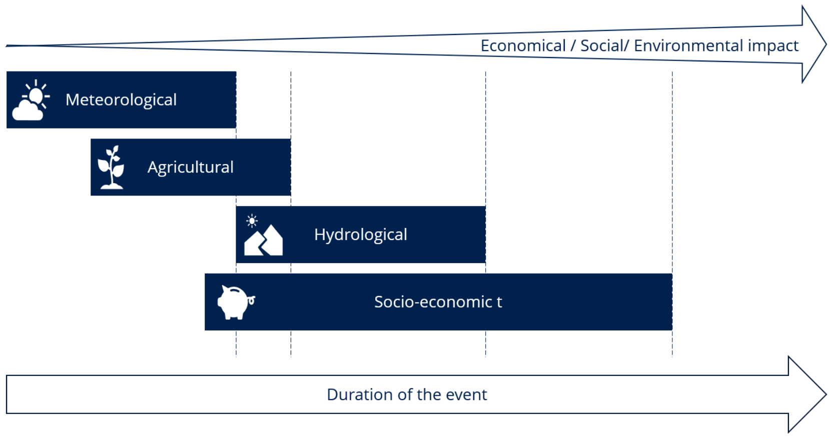


Figure 2: Characterizing drought and drought impacts (source)

weather will do and therefore enables organizations and individuals across the world to anticipate and take action to mitigate the impacts brought by weather and climate events. IBF is a crucial element of Forecast Based Financing.

The Key IBF components are: Hazard, Trigger Model, Trigger Alert, Early Warning, Early Action and the Trigger Activation. In the Early Warning and Early Action component Dissemination takes places (see figure 1).

Defining drought

The top four definitions deal with ways to measure drought as a physical phenomenon – while Socio-economical drought deals with drought in terms of supply and demand, tracking the effects of water shortfall as through socioeconomic systems.

Meteorological drought: Degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period, increased evapotranspiration (evaporation + transpiration), reduced infiltration runoff and groundwater recharge

Agriculture drought: Links various characteristics of meteorological drought to agricultural impacts, focusing on e.g. soil water deficits, plant water stress and reduced biomass and yield

Hydrological drought: Associated with the effects of periods of precipitation shortfalls on surface or subsurface water supply (i.e., reduced streamflow, reservoir and lake levels, groundwater).

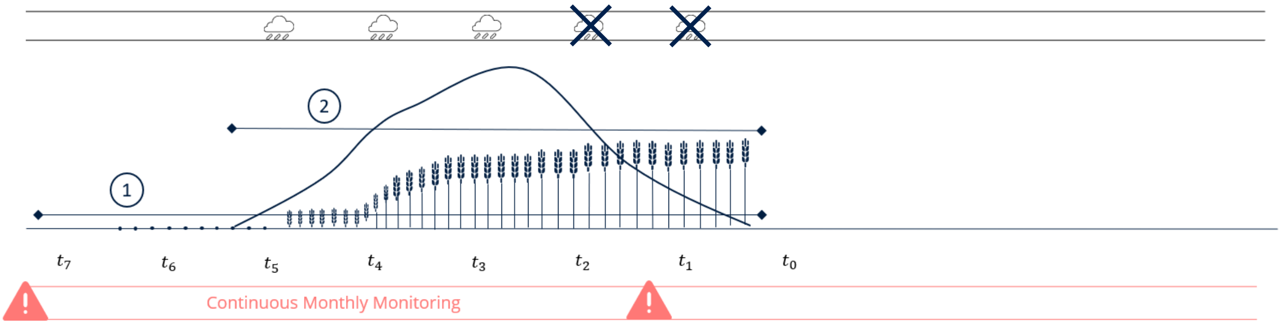
Socio-economic drought: When demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply.

Hydrological droughts follow the occurrence of meteorological and agricultural droughts as can seen in figure 2. There is a delay in response of the precipitation entering the hydrological systems, such as soil moisture, streamflow, and groundwater and reservoir levels. As a result, these impacts are delayed which impacts other ‘ economic’ sectors.

The need for IBF drought

The humanitarian implications of drought are profound, far-reaching, and cut across different sectors of the economy. Although drought impacts are initially most visible in the agricultural sector, indirect effects can cumulate into other sectors in a snowball effect. Droughts impact human populations in multiple ways by disrupting several key sectors that affect human livelihoods including agricultural production, food security, water management and public health.

Droughts are frequently observed and might cause severe impacts to communities. The impacts of drought include food insecurity, crop loss, livestock losses, soil erosion, dam failure, water pollution, and/or (child) malnutrition and stunting. The definition used in this research/methodology of risk is defined as the sum of hazard & exposure, lack of coping capacity and vulnerablity



SEPT	OCT	NOV	DEC	JAN	FEB	MRT	APRIL	MAY	JUNE	JULY	AUG
1st Phase Early Actions						**2nd Phase Early Action**					
	Beneficiary identification and registration	Distribution of Drought Tolerant Seeds									
		Purchase of dipping and dosing chemicals	Manning of dipping tanks and community mobilization				Identifcation of Boreholes	Repair and rehabilitation of boreholes			
						Beneficiary identification and registration	Confirm minimum expenditure basket	Initiate frame work contracts		Supplementary feeding to target schools & MPCT to target households	

Figure 3: IBF Trigger timeline for drought

(following the dimensions of the INFORM Risk Index).

Quantifying the different risk variables

Vulnerability to droughts can be quantified by social, economic, and infrastructural factors. For each of these indicators, proxies have been identified to quantify the level of vulnerability.

IBF Drought Methodology (general and Zimbabwe)

Drought is a complex slow-onset disaster, and its impact grows exponentially over time while the duration of the event can last for months or even years. These characteristics present one of many main challenges in the early action drought trigger development – but at the same time also give the opportunity to make use of that exponentially impact growth over time – to observe, monitor, forecast, and act when at that point the impact is still relatively low.

Drought affects the full hydrological cycle. The impact of drought is insidious and can be spread over large areas for extended periods (months-years). The current drought in eastern Africa, for example, is affecting around 13 million people in Kenya, Ethiopia, and Somalia.

We normally use indices to assess the intensity, magnitude, and severity of the drought hazard. A way of doing that is by using a drought index, which is often a standardized numerical value based on anomalies (deviating from the standard) of a selected parameter representing the availability of moisture or water (for example, precipitation, soil moisture, and streamflow) when compared with its long-term average.

Magnitude is a related term of severity. The difference between magnitude and severity is that magnitude is the absolute or relative size, extent or importance of something, while severity is the state of being severe.

IBF timeline for drought Zimbabwe

Drought is a slow onset disaster. Early actions are divided into two phases (see figure 3) based on the lead time, costs and reliability. The agrarian productivity follows the rainfall patterns of Zimbabwe, as most agriculture is rain-fed. This allows monitoring meteorological indicators along the agriculture timeline and using them as forecast features. In Zimbabwe, the following indicators are used in a stagged forecast; El Niño–Southern Oscillation index (ENSO) for long-lead climate fluctuation; rainfall (from CHIRPS), dry spell (mid-season rainfall summed in consecutive 14 days based on CHIRPS) for shorter-lead monitoring. In addition, biophysical indicator Vegetation Condition Index (VCI) can be used for assessing the growth of vegetation (i.e. crop, pasture) during the season.

The number 1 in the Figure 3 represents Long-lead climate forecast & observation (so all forecasts with a lead time between t5 and t7) and 2 represents Short-lead climate forecasts & observation (for all lead times between t0 and t5).

Outside period 1 and 2, monitoring of mid-season climate/weather forecast takes place.

IBF Drought Trigger Model Zimbabwe

The IBF Drought Trigger model exists of different components (see figure 4) to predict the likeliness of a drought to happen. Anticipating drought consists of constant monthly monitoring a forecasted or observed value of a biophysical or meteorological indicator (or multiple indicators) and making adequate calculations to know the impact to communities of such a forecasted or observed event. The forecast can be set up as a sequence of automated tasks feeding into each other that runs on a computer resulting in an alert when a predefined threshold is exceeded. This is called the IBF trigger model.

Understanding the Risk

Historical drought impact data is required to better understand the impact a drought hazard has on vulnerable communities. This can be done by historical timeserie analysis in relation to the reported droughts in the past. Here there might be a lot of factors: water losseDs, market drop, etc. It's important to know which factors link to each other and how. That is why together with the key in-country partners it is crucial to map the indicators, find and identify their correlation and see which have the highest reliability in forecasting the most severe impact of drought. The prioritised drought impact selected in Zimbabwe to be adressed by early actions are identified as; 1. crop losses (see figure 5) 2. drought induced mortality of livestock and 3. food insecurity as a result of crop or livestock losses

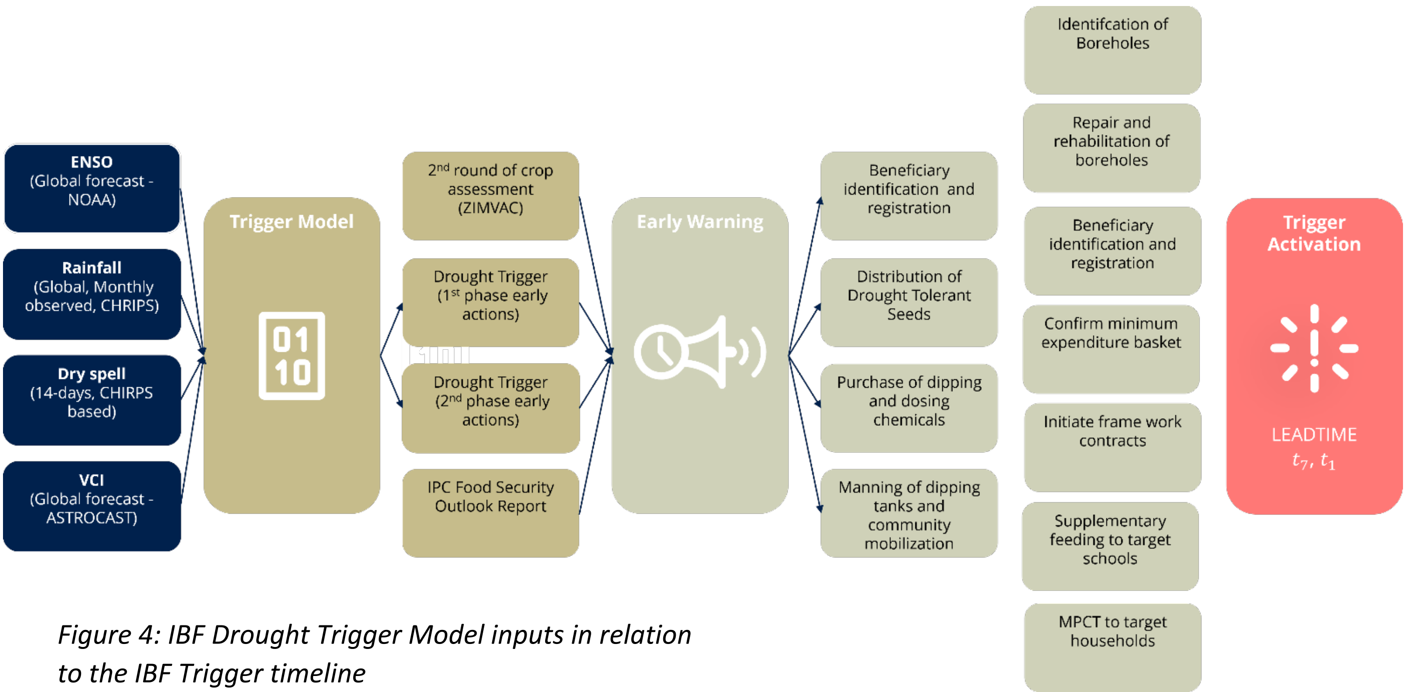


Figure 4: IBF Drought Trigger Model inputs in relation to the IBF Trigger timeline

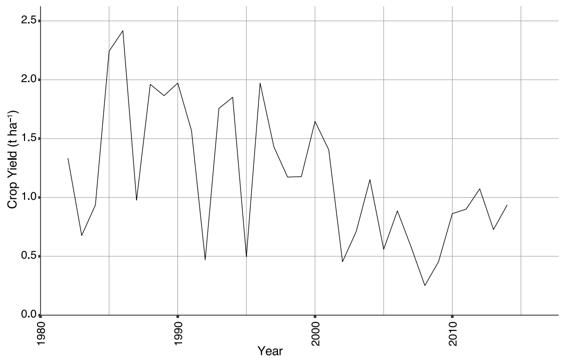
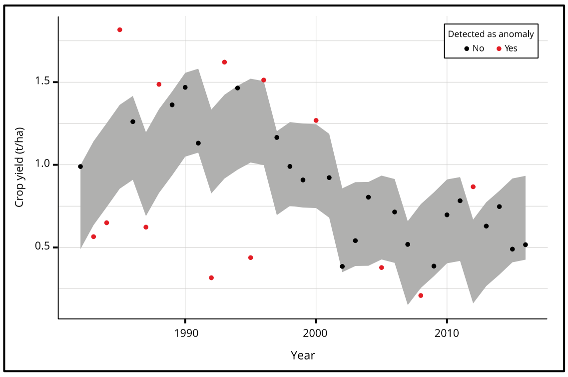


Figure 5: Crop growth (yield) in Zimbabwe over 20 years.

Anomaly Detection

As a second step, after analysing the historical impact data, anomaly detection is used to highlight the trend of the data, and shows the patterns over the years per district. Figure 6 shows the standardized anomalies of the crop yield data in the Bulawayo administrative district in Zimbabwe over the period 1981-2016. The grey area represents the range of normal average crop yield values All values falling outside this range were considered anomalies (red dots). Anomalies with a negative value were identified as droughts.



Fiigure 6: Anomaly detection of crop growth (yield) in Zimbabwe. Crop yield is measured in tons per hectare (t/h).

Train & evaluate trigger model

All of the historical information above feeds into the trigger model, which uses the machine learning model XGBoost. Specifically, all the meteorological, biophysical indicators and the binary crop loss anomaly per district in 2000-2016 are set respectively as model features and model target. Based on this data, the model is trained, tested, cross-validated and evaluated by performance scores.

Model Performance

The confusion matrix (consisting out of the FAR and Pod) determines the model performance, expressed in: 1. False Alarm Ratio (FAR) and 2. Probability of Detections (PoD). The FAR ranges from 0 to 1 with 0 being the highest performance model and 1 being the poorest perfomance. The PoD ranges from 0 to 1 with 0 being the poorest performance model and 1 being the highest perfomance (see figure 7). These values are important for decision makers indicating in which areas the model is performing well enough to make a decision on the activation of early actions (see figure 8).

The acceptable threshold of the model perfomances are determined by the Validation Committee of the Early Action Protocol. In Figure 7, the PoD is around 0.5 and the FAR is lower than 0.4 in most of the lead times. When closer to the season (lead time toward 0 months) with more information on observed selected indicators, the scores are getting better i.e. higher PoD and lower FAR.

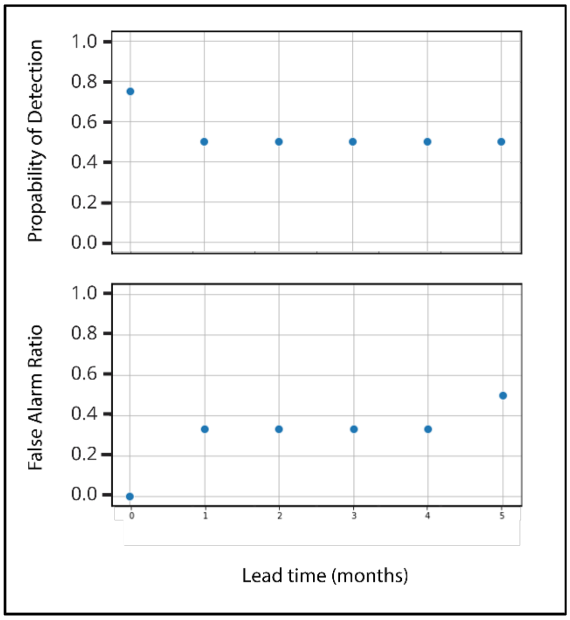


Figure 7: The PoD and FAR rates for Mashonaland Central for lead times 0-6

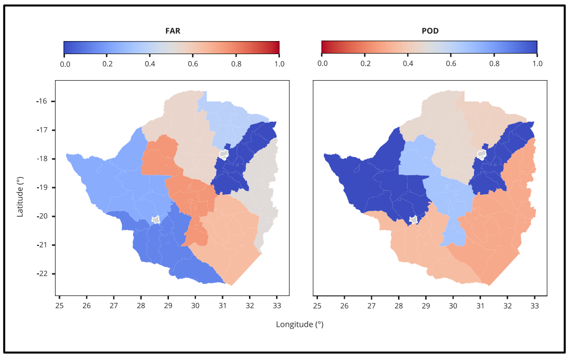


Figure 8: The performance of the model for lead time of 3 months. Shown as the FAR rate (left graph) and the PoD (right graph) for all administrative districts in Zimbabwe.

Drought Vulnerability Index

The Drought Vulnerability Index (DVI) looks at which provinces the probability of drought vulnerability is the highest. It takes indicators into account such as Labor-constrained households, child, women and elderly-headed households, and families with members who have disabilities. The DVI is used in deciding which areas to target for early actions.

$$vulnerability\ index = \sum_{k=1}^{n} (w_k \times x_k)$$

Drought vulnerability indicators	Sub-indicators
Labor-constrained households	• 7% unemployment rate 15+ • 7% economically non-active
Child, women and elderly-headed households	• 5% Head of Household (female) • 5% Head of Household (< 19 y. o.) • 5% Head of Household (> 65 y. o.)
Families with members who have disabilities	• 14% People with disabilities
Families with members who are chronically ill	(no data available)
Pregnant, breast-feeding women and children < 5 y. o.	• 5% pregnant women • 5% breast-feeding women • 5% children < 5 y. o.
Families with members who are malnourished	• 14 % Severe acute malnutrition
People living with HIV and those on ART treatment	• 7% HIV prevalence • 7% HIV ART Coverage
Households with a high dependency ratio	(no data available)
Limited access to productivity land or livestock	• 7% employment agriculture • 7% cattle per km^2

Figure 9 : Drought Vulnerability indicators used in calculating DVI Zimbabwe

Define the Early Actions

As part of the the Trigger Model development there is a process of defining early actions. The Technical Working Group (TWG) identifies via prioritization and ranking which early actions are prefered to be triggered including their leadtime of triggering.

Trigger Calendar

In Zimbabwe, the trigger model is staged; activating two sets op early actions within two different time periods. The first set of early actions is triggered with a lead time of 7 months to the harvest (September) and the second trigger releasing the second set of early actions with a lead time of 1 month to the harvest (March).

Loss of agricultural crops *1. Drought Early Warning Communication* *2. Distribution of drought tolerant short season certified seeds (in-kind)* ***Mortality of livestock (due to lack of grazing and water supplies)*** *3. Drought early warning communication.4. Water point rehab and construction of drinking troughs* *5. Livestock dosing and dipping support* ***Food Insecurity as a result of crop or livestock losses*** *6. Cash / Voucher Assistance for food purchases* *7. Nutrition Education* *8. Supplementary school feeding*

Table 1: Proposed set of early actions

IBF Portal: Drought Trigger Model

The trigger model and early actions are visualised in one location, which is the IBF Portal. The portal integrates and presents the data in a non-alert stage and an alert stage. This is how the IBF Portal looks like in a non alert level in which the map of Zimbabwe is shown. On the right-hand side, the different static data layers, such as locations of Red Cross and Red Crescent branches, water points, etc. The situational overview is located in the middle with its indicators and chatbox.

Non-triggered state (Annex 1):

• Primary color is dark blue.

• No Early Action Protocol (EAP) actions are displayed.

• Exposed population is not shown

Triggered state (Annex 2):

• Primary color is purple.

• Actions from the Early Action Protocol (EAP) are displayed. (in the situational overview)
• Explosed population is shown.
Right column: Shows an explanation message from the IBF and the current trigger state

IBF Portal Alert
The EAP will be triggered with a lead time of 1 month of up to 7 months. The EAP is complemented by an automated early warning system (the IBF System). This is an automatic system that monitors the forecasts, generates the intervention map and sends an alert message when the trigger is reached. The system shows information from the EAP relevant in each phase of the early warning early action response.

Monitor upcoming droughts (monthly)
• Dashboard will give an overview of the situation in-country and visualize the scale of the drought within the set lead time.
Receive notifications
• Notification email once the trigger is reached.
• The trigger statement
• When the event may take place
• How many people may be exposed
• Where the event may take place
• Link to the dashboard and to the approved EAP
• Link to a WhatsApp group
• Visual of the drought extent
Lead time of the upcoming drought

Conclusion
Drought hazard creates considerable impact on people's livelihoods and on community resilience., The Early Action Protocol includes an overview of all the activities to be done before a disaster strikes. can be implemented in order to minimize the hazard impacts. EAP is activated once a Trigger Model reaches a certain pre-determined threshold.

510 developed this IBF Drought Trigger Model for Disaster Managers of Zimbabwe Red Cross. 510's IBF Portal for Drought visualizes this Trigger Model and gives clear actionable steps for a National Society. The next steps for Zimbabwe will be to validate the EAP and monitor over the the first season in 2023.
In Ethiopia, Kenya, Uganda and Southern Africa region (Namibia, Lesotho and Mozambique) 510 started drought project as well. The development of the trigger model has not yet started but the scoping is completed.

Prioritization of drought impacts based on area and interests of National Societies is highly important. By doing so, it enables identifying the prioritized impact(s) as drought proxy and relevant indicators which contribute to the development of the drought forecast model. It is necessary to collaborate with partners and share knowledge to improve the knowledge on this topic in the wider humanitarian context. 510 supports collaboration with partners who are developing similar approaches to improve drought forecast models, resulting in more accurate forecasts and reduced humanitarian suffering.

Reach out to us

Marijke Panis (mpanis@redcross.nl)

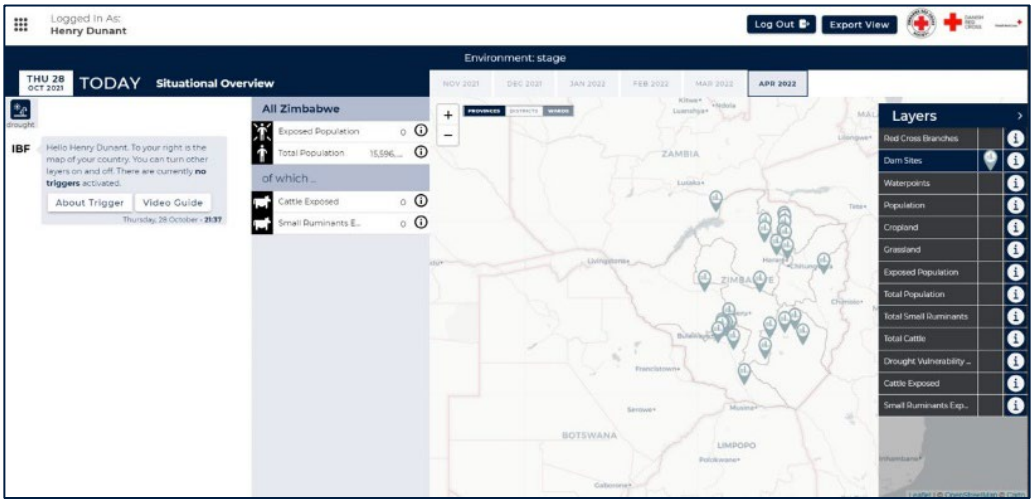
Or contact our Anticipatory Action coordinators:
Marc van den Homberg (mvandenhomberg@redcross.nl)
Aklilu Teklesadik (ateklesadik@redcross.nl)

A big thank you to all contributors!

Funding: Danish Red Cross & Finnish Red Cross
Zimbabwe Red Cross: David Muchatiza, Gwenzi Mhondoro, Rujeko Tokotore & Richard Muchena
Red Cross Red Crescent Climate Centre: Guigma Kiswendsida
510: Phuoc Phùng, Bouke Ottow, Aklilu Teklesadik, Jacopo Margutti, Orla Canavan, Marc van den Homberg & Marijke Panis
Volunteers: Misha Klein, Daniele Castellana, Behrouz Eslami Mossallam, Davide Francesco Lodato, Elisabeth Tschavgova & Tal Rosenthal
Other partners:
WFP: Dr. Gabriela Nobre,
TAMSAT: Dr. Vicky Boult and Professor Emily Black
Astrocast: Andrew Bowell and Pedram Rowhani
MSD

Annex 1:

IBF Portal Drought in Non-triggered state



Annex 2:

IBF Portal Drought in Triggered state