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Predicting DROUGHT

Piotr Wolski explains the complexities of developing an early warning system for drought

"Predictions are difficult, particularly about the future," the saying goes. It's meant to be humorous, of course, but it's also very apt. So much depends on whether we are able to foretell, forecast, foresee the future, yet we are strongly constrained in our ability to do so. Without knowing how COVID-19 will spread in the coming months, for example, we cannot plan our social gatherings or sports events, and considering an overseas holiday or business trip would seem to require a crystal ball!

While pandemics are very rare, advance knowledge of many other phenomena can save lives and money. Drought is one such phenomenon, familiar to most South Africans. Broadly defined as a persistent deficit of water in the environment, drought can be differentiated on the basis of its impact into:

- meteorological drought, when there's a prolonged period of dry weather,
- hydrological drought, when a decline in river flows, dam storage or groundwater levels limits water supply,
- agricultural drought, when crops become affected by inadequate soil moisture, or
- socio-economic drought, when demand for goods exceeds supply due to the water shortages, causing economic losses and societal impacts such as famine.

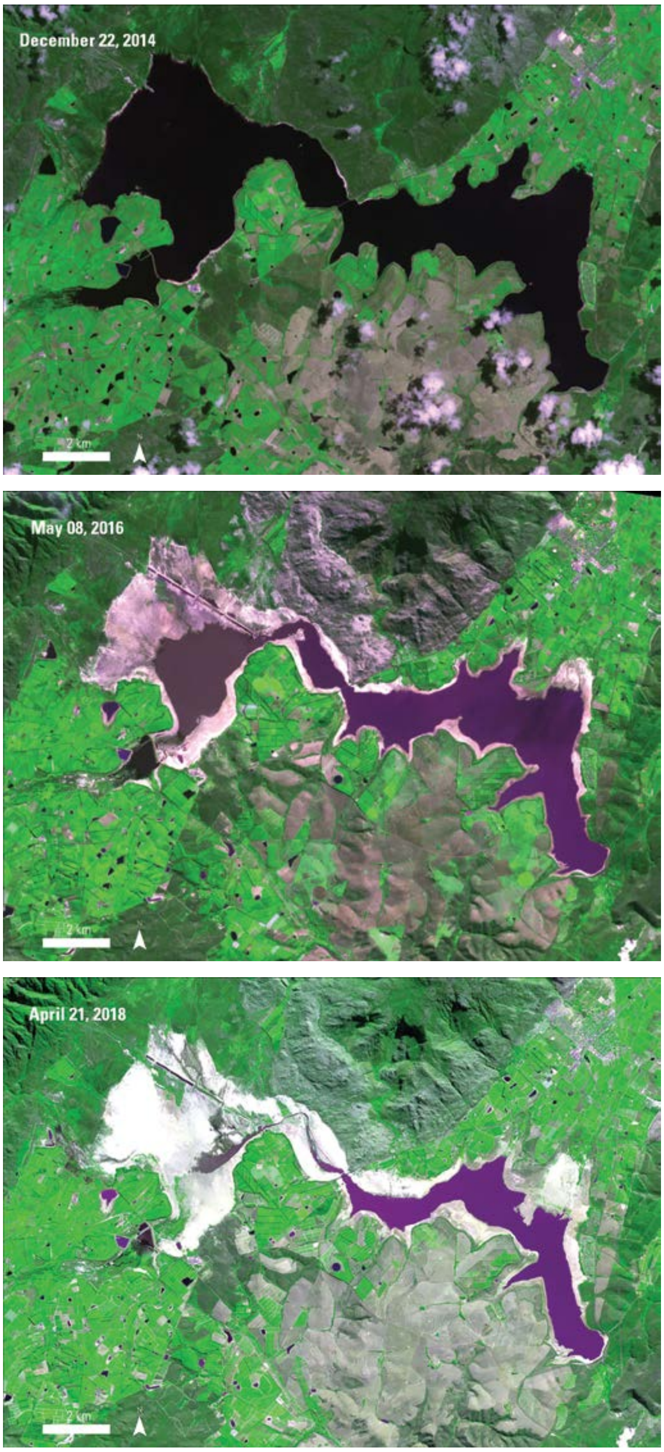
Whatever the type, a drought usually involves low rainfall, but it is a relatively slowly evolving event of considerable duration. We won't be talking about drought if there is no rain for a couple of days, and we won't be talking about drought in June in Limpopo, because it does not normally rain in June in that part of South Africa. We will have a drought, though, if rainfall over several weeks, months or even years is considerably lower than expected.

Drought episodes cause a decrease in agricultural yields, but drought-induced water shortages also constrain production and activities in many other economic sectors, from industry to tourism. Drought impacts our health too – for example, diarrhea cases tend to rise because water shortages mean more limited access to safe drinking water, increased use of grey water, and a reduction in personal hygiene practices, such as handwashing and bathing.

However, many negative impacts of drought can be reduced by appropriate actions prior to and during the drought. Dam operators can change water-release patterns in anticipation of the drought, or water restrictions can be introduced to 'stretch' the available resources, or augmentation projects like groundwater extraction or desalination plants can be fast-tracked. But any such action requires a reliable early warning of the coming drought.

To issue a warning, one has to predict the drought – a complex, multi-factor phenomenon – months in advance. Can we do that?

Let's start with a rainfall forecast. We are all familiar with weather forecasts, which are predictions of weather in the next couple of days, and are usually quite reliable. These are based on computer models of the global climate system. A rainfall forecast for the next months, or a seasonal forecast, can be obtained in a similar way, simply by running the climate model longer into the future. A climate model-based forecast is called a numerical or a dynamical forecast. But forecasts can also be statistical, based on historically observed relationships between rainfall and some driving variables.



NASA & USGS

Satellite images reveal the dramatic effect of the Western Cape drought on Theewaterskloof Dam, Cape Town's main water source.

Unfortunately, climate is usually poorly predictable at the timescale of several months – we can make a prediction by whatever means, but that prediction will not be very accurate. This is mostly due to the inherent nature of the climate system, but also because of imperfections of the computer models and limitations in our understanding of climate processes.

Nothing illustrates the challenge of forecasting better than the well-known Cape Town 'Day Zero' drought. As the crisis was emerging, in April 2017, the community of climatologists in South Africa held a meeting aimed at formulating a message to the authorities about the forthcoming rainy season in the Western Cape. The experts looked at several numerical forecasts coming from reputable global and local institutions: the European Centre for Medium Range Weather Forecast (ECMWF), the USA's National Oceanic and Atmospheric Administration (NOAA), the South African Weather Service (SAWS) and the University of Pretoria. There was no consensus between them – some forecasted a wetter season, some forecasted drought. The experts discussed the state of the climate system and indications it could give about what to expect. And they could not agree either. The consensus message of that meeting was as follows:

"*...the Western Cape needs to consider the full range of possibilities, which comprise that the 2017 winter season may be drier than normal (which may greatly exacerbate the current situation) or normal (which may fail to relieve the current situation) or wetter than normal (which may bring relief to the current situation).*"

We now know that the Cape Town's rainy season of 2017 turned out to be the driest on record.

However, a seasonal forecast might work reasonably well in certain locations, seasons and conditions. In South Africa, for example, seasonal rainfall is predictable in the northern part of the country, but only in the December-February period, and only in certain years. This is because that region is strongly affected by the El Niño-Southern Oscillation (ENSO) cycle – the deviations from normal sea surface temperatures in the equatorial Pacific that propagate through the climate system. If there's a (warm) El Niño phase we can expect drought, but if there's a (cool) La Niña phase we expect a wet year. The key word here, however, is 'expect'. There are El Niño years that happen to be wet or average, and La Niña years that are dry or average. And when there are neutral ENSO conditions – in other words, neither El Niño nor La Niña – anything can happen!

But forecasting rainfall is only one part of the story. The other part is how to translate that forecast into an 'actionable' drought warning. To act, we need to know not just how severe the meteorological drought is going to be, but also the likely consequences. A strong rainfall deficit will not necessarily translate into a hydrological drought, and a strong hydrological drought will not definitely result in a shortage of water resources, which may or may not translate into a disaster. But in particular conditions, even a moderate rainfall deficit can cause a severe hydrological drought.

So climate science has to engage other disciplines: hydrology, agriculture, health or financial planning. Unfortunately, each of those disciplines speaks another 'language' and is based on a slightly different set of concepts, hampering the interaction. This means that predicting the implications of meteorological drought is very difficult.

Take hydrology, for example. Our ability to forecast river flows or groundwater recharge is affected by our level of knowledge of rainfall and temperature, as well as parameters describing the hydrological system. The implication is that, providing we had perfect knowledge

A hydrological drought may cause perennial rivers to cease flowing, or prolong the period that intermittent rivers remain dry.

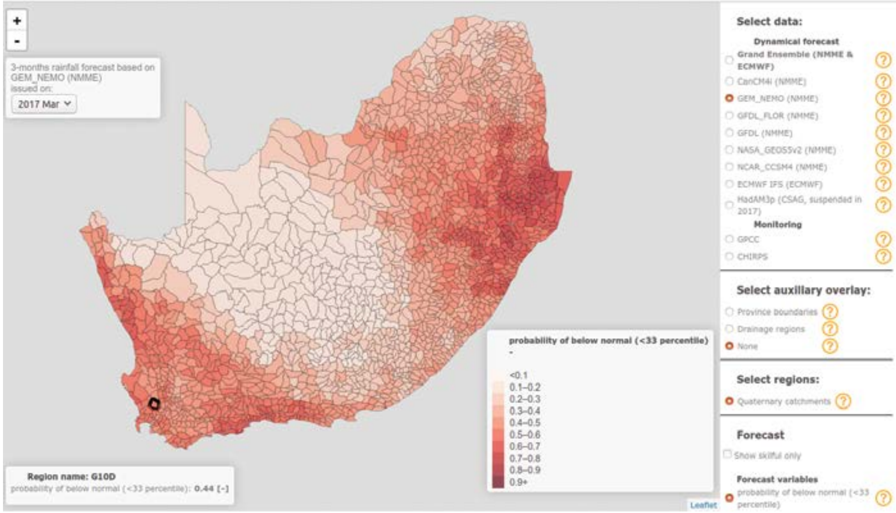
of these, we would be able to issue a perfect forecast – in other words, a forecast that is always correct. Yet climate forecasting will still be highly uncertain, even if we had a full and perfect knowledge of the system, due to the chaotic nature of that system and the 'internal variability', as well as other sources of uncertainty.

Then there is the practicality of handling climate forecast data, and implementing models and analyses. Climate forecasts are available from various institutions around the world, and the 'state-of-the-art' approach is to integrate and combine various pieces of information from these sources into what is called an 'ensemble' forecast, rather than attempt to single out the 'best' forecast. But climate modellers use different computer operating systems, different file formats, different nomenclature (or rather, jargon) to those used by hydrological or water resource modellers. How are the hydrologists to negotiate that unbelievably large global data and information landscape?

Yet another important aspect is the issue of forecast skill. One has to remember that whatever forecasting system one looks at, the numbers will be there. But are they believable… and are they correct? And how does one measure 'correct? Climate forecasts are typically formulated as: "there is a 60% probability of drought". Such a forecast is 'correct' irrespective of whether the event actually occurs (the forecast will never be for 100%), and thus there is always only a certain probability associated with the actual observed outcome (60% of drought, but then 40% of 'no-drought'). Of course, there are strict mathematical ways of expressing the level of correctness, or skill, of such a probabilistic forecast. But they are usually rather complex and not very transparent to someone who is not a specialist in forecasting.

And this brings us to the last aspect – communicating the forecast and its uncertainty, and formulating the eventual drought warning. Here, one has to find a balance between two ends of the spectrum. On the one side is the "here is the data, explore and make your own interpretation" approach. In that case, an early warning system presents a wide range of basic forecast data and skill measures, perhaps with some information about the context, and leaves the interpretation of those to 'decision makers' or 'users', under the assumption that they will best be able to interpret these results in their specific context. On the other end of the spectrum is the "here is a warning, trust us" approach; the interpretation of all the information is done by the 'analyst', or a forecaster, distilling all the complex information into a straightforward message.

The first of those approaches bears the risk that the recipients will find it difficult to engage with the process; the second, that the nuance of a particular context is overlooked, the message appears definitive and thus might clearly be wrong, and the recipients will dismiss it on the basis of inaccuracy. Emerging in recent years are approaches that evolve around 'co-exploration' and learning, where the proverbial 'analyst' and the 'users'



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The drought early warning system developed as part of a Water Research Commission project shows the three-month rainfall forecast in March 2017 according to the North American Multi-Model Ensemble's (NMME) GEM_NEMO model. The darker the area, the higher the probability of below normal rainfall.

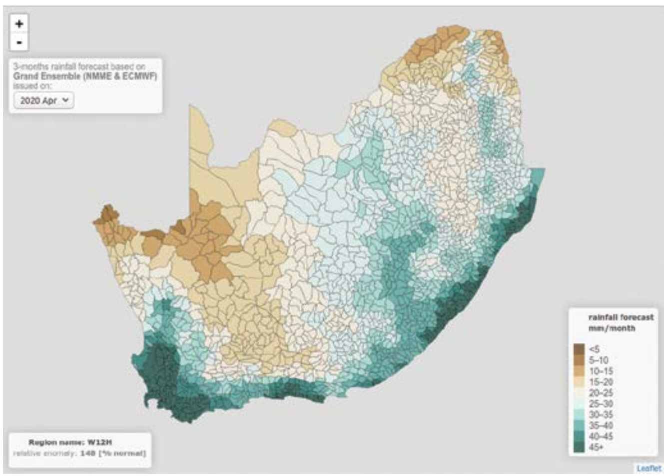
are jointly engaged in the process of generating the forecast and creating an in-depth and context-relevant understanding of the outcome.

As a consequence, creating an 'actionable' drought warning is a rather demanding task that requires analysing and processing a large amount of data from a number of global sources in a multidisciplinary setting, mixed with a substantial dose of creativity and contextual expertise in presenting the information. Perhaps that's the reason for the very few such operational systems in South Africa?

In this complex landscape, a number of hydrologists and climatologists came together for a Water Research Commission funded project, titled 'The development of an integrated (early warning) system for adaptation and mitigation to hydrological drought in South Africa'. The focus is on the climatological and hydrological forecast, at the spatial level of quaternary catchments, and it involves linking a hydrological model with a suite of dynamical and statistical seasonal forecasts. The system recognises limitations of quality and availability of climate and hydrological data and involves:

- dynamical climate forecasts from the European ECMWF, the US-based Climate Forecast System (CFS) and the North American Multi-Model Ensemble (NMME),
- a statistical forecast based on relationships between seasonal rainfall and phenomena such as ENSO, Atlantic Multidecadal Oscillation (AMO) and Indian Ocean Dipole (IOD), and
- a forecast of end-of-season rainfall anomaly, based on rainfall monitoring and the persistence of the emerging rainfall anomaly.

The results from this suite of forecasts are synthesised in terms of probability of meteorological and hydrological drought of various levels of drought severity, highlighting the level of agreement of the different forecast systems and models. The skill of the individual models, and that of the entire ensemble of models, is clearly articulated. Results are presented through a publicly accessible website at two levels of complexity – basic, with simple, straightforward messages, and advanced, allowing exploration of nuances of the procedure and underlying models. The page will be available through the website of the Climate Systems Analysis Group: www.csag.uct.ac.za.



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A three-month 'Grand Ensemble' rainfall forecast, issued in April 2020. Quaternary catchments shaded dark teal are predicted to receive rainfall in excess of 45 mm per month.

GLOSSARY

Anomaly: something that deviates from what is standard, normal or expected.

Dynamical forecast: relies on a mathematical model that describes the change in state of phenomena, and interactions between variables, over time.

Quaternary catchment: the fourth level in the hierarchy of catchment size, after primary, secondary and tertiary, and the basic unit of water resource management in South Africa.

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