

POTENTIAL ECONOMIC VALUE OF DROUGHT INFORMATION TO SUPPORT EARLY WARNING IN AFRICA

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Abstract

We present a methodology to estimate the economic value of advanced climate information for food production in Africa under climate change scenarios. The results aim to facilitate better choices in water resources management. The methodology includes 4 sequential steps. First two contrasting management strategies (with and without early warning) are defined. Second, the associated impacts of the management actions are estimated by calculating the effect of drought in crop productivity under climate change scenarios. Third, the optimal management option is calculated as a function of the drought information and risk aversion of potential information users. Finally we use these optimal management simulations to compute the economic value of enhanced water allocation rules to support stable food production in Africa. Our results show how a timely response to climate variations can help reduce loses in food production. The proposed framework is developed within the DEWFORA project (Early warning and forecasting systems to predict climate related drought vulnerability and risk in Africa) that aims to improve the knowledge on drought forecasting, warning and mitigation, and advance the understanding of climate related vulnerability to drought and to develop a prototype operational forecasting.

1 INTRODUCTION

Africa stands at a crucial juncture in terms of water management. Water security in the region is undermined by a lack of available technology and investments in the water sector (Vorosmarty et al. 2010). Additionally, increasing population pressures and development concerns are stressing available water resources (Funk et al. 2008). From the perspective of water managers, the process of negotiating between competing demands is becoming more complex.

In theory, water for irrigation should be given priority in low-income countries because of the high multiplier effect a prospering agricultural sector can have on a developing economy. But in the context of African water management, large-scale irrigation, inter-basin water transfer and high-technology desert-irrigation are not likely

to provide solutions to the issues of famine and food-aid dependence given the high-costs of such developments (Cooper et al. 2008, Collier and Gunning 1999). At the moment, only a small percentage of African crop yields are produced through irrigated agriculture and growing urban and industrial demands are already limiting the amount of water available for irrigation. Nevertheless, irrigated agriculture will need to be expanded in order to provide greater security to food production (Kurukulasuriya et al. 2006). This is likely to entail a progressive shift in water management priorities.

Over the past decades, available fresh water resources in Africa have greatly reduced due to severe and prolonged droughts (IPCC, 2007; Iglesias et al., 2009). This situation is expected to worsen in coming years as climate change impacts increase temperature even as they decrease precipitation over Africa (de Wit and Stanckiewicz 2006, Eriksen and Silva 2009, Hulme et al. 2001). Apart from changing harvest patterns, these climate changes will increase the frequency and intensity of droughts and have direct impacts on the agricultural sector (Lobell et al. 2011). Key strategies for reducing vulnerability to drought and water scarcity include increasing resilience through preparedness and adaptation, but also depend strongly on improved knowledge of drought onset and severity (Barros and Bowden, 2007).

The increase in variability and uncertainty of water supply implies the need for water managers to have access to climate information. Information is a factor that reduces uncertainty in decision processes (Johnson and Holt 1986). In the context of a changing climate where uncertainty is likely to increase, information will become increasingly valuable since climate change will affect farmers' decisions concerning when to plant or harvest, or which crops to produce, as well as decisions concerning investments in infrastructure or technology (Hansen et al. 2006). The value of climate information will depend on whether the information enables individuals to increase their utility relative to what it would be if that information was unavailable (Hill and Mjelde 2002). In other words, the value of information is the expected gain in a decision outcome from using additional information.

Determining whether the information is valuable to individuals requires an analysis of decision processes which is typically undertaken with the aid of decision theory, general equilibrium modelling, game theory, and mechanism design theory (Rubas et al. 2006). The insights that emerge from these analyses can greatly enhance agricultural management by informing the decisions that water managers take in terms of allocating scarce resources (Hill, Mjelde 2002).

In the case of many Africa countries the variability and its impacts are closely tied to the occurrence of El Niño events (Cane et al. 1994, Thomson et al. 2003). The fact that much climate information is provided at a scale that is irrelevant to farmers, points to a gap between the information routinely provided by climate predictions and the needs of agricultural decision makers (Hansen et al. 2006). Nevertheless, recent research suggests that regional seasonal forecasts are relevant at a local scale and that the predictability of crop yield response may be more predictable than seasonal climatic means (Cane et al. 1994, Gong et al. 2003, Hansen et al. 2004, Bharwani et al. 2005).

Advanced climate information is a key factor for investment aimed at improving water resources management for food production under climate change. The biggest benefits of food production in Africa will likely result from costly measures including expansion of irrigation. This requires substantial investment of governments and development organisations. Science may help in prioritising investment needs thought

the identification of high risk areas, a critical issue that has been addressed in a fragmented way to date. Here we focus on impacts of drought by 2080: a time period very relevant to large water resources management change. Our study seeks to assist African water managers in making decision concerning the most efficient allocation of water resources to improve agricultural production. Following this introduction, section 2 describes the methods for estimating the potential value of drought early warning systems, section 3 presents and discusses the results and section 4 outlines the main conclusions of the study.

2 METHODS

2.1 Geographical scope

Africa is generally considered a food insecure continent. For the purpose of this study we identify five major geographical areas with broadly similar agricultural production systems and climate change patterns by 2080 (Figure 1).

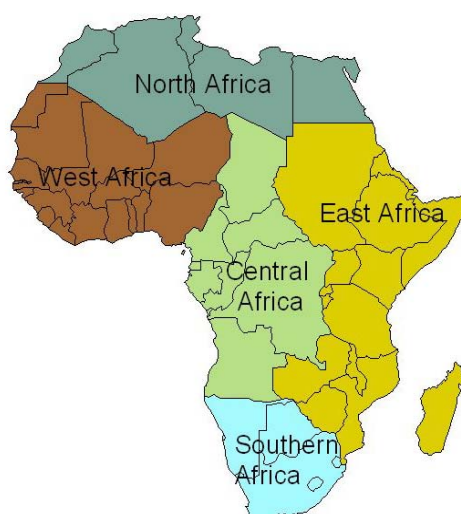


Figure 1. Geographical aggregation of countries in Africa according to production and climate scenario criteria

2.2 Facing drought under climate change

We analyse two options to face drought under climate change: with and without previous knowledge. We present a methodology to estimate the potential economic value of drought early warning. The structure of the decision problem is outlined in Table 1. Quantitative parameters for the decision problem are obtained from crop production estimates (section 2.4).

Table 1. Structure of the decision making problem

Action	State of Nature	
	Occurrence of extreme event (hydrological drought) ($\theta = 1$)	No extreme event (normal conditions) ($\theta = 0$)
Without early warning	Production loss due to the occurrence of a drought event (-L)	No production loss (0)
With early warning	Investment for the implementation and maintenance (-C)	Investment for the implementation and maintenance (-C)

Option 1: Without early warning systems. Under this alternative, the drought management begin when the drought event is occurring and water management cannot cope with the drought losses in the crop systems. In the case of hydrological drought the water failure leads to crop loss; the losses are determined by the effect of water decrease in crop yield. In all future climate scenarios analysed the supply reliability is reduced, and irrigators may be exposed to water scarcity during drought years. In normal years (no drought), agricultural production will be maintained at the current level, and there will be no net loss. In drought years, there will be water shortages, and agricultural production will be reduced accordingly. If Y is average crop yield for current water allocation in normal years, average crop yield during drought years will be a fraction of Y , kY , with $k < 1$. Under the occurrence of a drought event, farmers will take a production loss, L , equal to:

$$L = Y - kY = (1 - k)Y$$

In this case, farmers cannot implement adaptation measures such as reducing the cultivated land or changing crops as possible responses to reducing the impact of water shortages. This is because under this alternative, it is assumed that water shortage cannot be anticipated and the system fails to respond to an extreme event (drought). The yield loss for Alternative 1 is therefore higher.

The probability of having water shortages in any given year, P_θ , is computed as the drought frequency over the total period considered.

Option 2: Implementation of an early warning system. Under this alternative, the drought management begin in the pre-alert phase and water management can be planned in order to avoid major crop losses. Under this alternative, the implementation of an early warning system needs an investment to cover the cost of the implementation and maintenance characterised as a function of crop loss. In this case the economic cost is incurred both under normal and drought conditions. In this case, farmers will not be exposed to additional crop losses during drought years, because the correct management will be able to overcome the drought situation. However, the cost (C) will entail an additional production cost every year. This loss can be expressed as a fraction γ of the loss taken under alternative one: $C = \gamma L$.

In Alternative 2, farmers are assumed to attempt to adapt to the reduced water availability, which ensures that the economic loss is less than in Alternative 1 during

drought conditions. However, this economic loss is permanent and not associated to a particular extreme event.

2.3 Drought characterisation under climate change

Here we assess broadly which particular areas will be under increased risk of droughts under climate change scenarios. To estimate changing drought hazards, 26 climate change scenarios derived from two assumptions of representative concentration pathways (Moss et al., 2010) are used.

We explore the future by looking at the response of crop productivity to climate scenarios derived from representative concentrations pathways of global emissions for the 2080s: the A1B a scenarios with a balanced emphasis on all energy sources (574 ppm of CO₂) and the E1 scenarios representing stabilisation (458 ppm of CO₂). To address uncertainty we use several climate models driven by these representative concentration pathways: A1B: DMIEH5-4; A1B: HADGEM-1 and the E1: DMICM3-1; E1: DMICM3-2; E1: HADGEM2-1. The source of climate data is the University of East Anglia (Climate Cost project, publication in press). A1B represents a balanced emphasis on all energy sources with CO₂ level in 2080 of 712 ppmv. E1 is the so-called global “2 °C-stabilization” scenario that is characterized by an atmospheric concentrations of 498 ppmv CO₂ in the 2080s.

We use this last generation socio-economic scenarios derived from the ClimateCost project (Goodess, 2011, Climatecost project). Table 2 shows the climate scenarios considered in this paper.

Table 2. Climate change scenarios considered

Climate Scenarios for A1B RCP	Scenario code	Climate Scenarios for E1 RCP	Scenario code
A1B.BCM2_1_M.2080	A1B_1	E1.CNCM33_2_M.2080	E1_1
A1B.CNCM3_1_M.2080	A1B_2	E1.DMICM3_1_M.2080	E1_2
A1B.DMIEH5_4_M.2080	A1B_3	E1.DMICM3_2_M.2080	E1_3
A1B.EGMAM_1_M.2080	A1B_4	E1.EGMAM2_2_M.2080	E1_4
A1B.EGMAM_2_M.2080	A1B_5	E1.EGMAM2_3_M.2080	E1_5
A1B.EGMAM_3_M.2080	A1B_6	E1.HADCM3C_1_M.2080	E1_6
A1B.HADGEM_1_M.2080	A1B_7	E1.HADGEM2_1_M.2080	E1_7
A1B.INGVSX_1_M.2080	A1B_8	E1.INGVCE_1_M.2080	E1_8
A1B.IPCM4_1_M.2080	A1B_9	E1.IPCM4v2_1_M.2080	E1_9
A1B.MPEH5_1_M.2080	A1B_10	E1.IPCM4v2_2_M.2080	E1_10
A1B.MPEH5_2_M.2080	A1B_11	E1.IPCM4v2_3_M.2080	E1_11
A1B.MPEH5_3_M.2080	A1B_12	E1.MPEH5C_1_M.2080	E1_12
		E1.MPEH5C_2_M.2080	E1_13
		E1.MPEH5C_3_M.2080	E1_14

We evaluate the problem of drought under current climate using the data from CRED (2010). The classification of drought under climate change is complex and requires monthly time series of climate variables. All climate experts agree on the increase of drought hazard in Africa over the next century (IPCC 2007). Here we develop a very simple set of drought probability scenarios based on the thresholds defined in existing literature. The estimation of drought probabilities according to temperature and precipitation change thresholds in the climate change scenarios is based on drought characterisation thresholds computed by several drought indices (Rossi et al., 2003; Cancelliere et al., 2007; Tsakiris and Pangalou 2009)

Table 3. Estimation of drought probabilities according in the to temperature and precipitation thresholds in the climate change scenarios.

Change in the average annual temperature in the scenario 2080s (°C)	Change in the average growing season precipitation in the scenario 2080s (%)	Drought class	Probability of occurrence of drought in the 2080s
0 to 1.5	above 0	Near normal	0 to 10
0 to 1.5	-20 to 0	Mild drought	10 to 20
0 to 1.5	lower than -20	Mild drought	20 to 30
1.5 to 3	above 0	Mild drought	20 to 30
1.5 to 3	-20 to 0	Moderate drought	30 to 40
1.5 to 3	lower than -20	Severe drought	40 to 50
more than 3	above 0	Moderate drought	30 to 40
more than 3	-20 to 0	Severe drought	50 to 60
more than 3	lower than -20	Extreme drought	more than 60

2.4 Estimation of agricultural productivity changes

Expanding on a previous study (Ciscar et al. 2011) we have developed the ClimateCrop model (Iglesias et al., 2011) that estimates (a) changes in agroclimatic regions and (b) quantitative estimates of crop yield response linking productivity, management and climate variables; livestock production is not considered, except for the possible inference of crop productivity. The estimates take into account the regional adaptive capacity (Iglesias et al., 2010). We calculated the expected change in future crop productivity in Europe by applying the climate scenarios to the derived models.

2.5 Computing willingness to pay for the early warning system depending on risk attitudes

Our decision making problem has the same structure of the more general cost-loss ratio situation problem developed in earlier (Cerdá, Quiroga, 2011; Quiroga et al., 2011). Therefore, in order to use this methodology to evaluate the value of weather information it is necessary to know: (i) Information on the expenses matrix, (ii) climate information (probability of the extreme event) and, (iii) information about the risk aversion level. Assuming that the consequences of each combination of actions and

state of the world are known a priori the model allows for the representation of the decision maker's preferences (i.e. utilities associated with the future outcomes), and sets a decision rule by which an optimal strategy is selected once the expected utility of each decision is calculated (Meza et al., 2003).

In order to achieve a monetary value unchanging with linear utility transformations to compute the amount of money that farmers will pay for the insurance, we have considered the certainty equivalence approach. The certain equivalent (*CE*) can be defined as the amount of money for which the farmer is indifferent between the gamble and the certain amount *CE* (Mas-Colell et al., 1995), which is the amount of money producing the same utility without uncertainty as the expected utility when the risk exists.

The certain equivalent allows us to define a value of information in monetary terms. The optimal policy for the decision making problem with risk, defined in Table 1 was analysed in Cerdá and Quiroga (2011). The optimal farmer decision considering the maximization of the expected utility criterion is:

Alternative 1 if $A > P_\theta$, and in this case the expected utility is

$$EU(0) = -P_\theta \exp\{\rho L\} + P_\theta - 1$$

Alternative 2 if $A < P_\theta$, and the expected utility is $EU(1) = -\exp\{\rho \gamma L\}$

Indifference between both alternatives if $A = P_\theta$

$$\text{where } A = \frac{1 - \exp\{\rho \gamma L\}}{1 - \exp\{\rho L\}}.$$

Considering this optimal policy we can compute the farmers willingness to pay for the insurance (*C*) as the monetary amount that make the farmer to prefer the insurance option. That occurs if and only if:

$$\frac{1 - \exp\{\rho \gamma L\}}{1 - \exp\{\rho L\}} < P_\theta \Leftrightarrow \exp\{\rho \gamma L\} < 1 - P_\theta (1 - \exp\{\rho L\})$$

So we have that the maximum willingness to pay for the insurance can be computed as:

$$C = \gamma L < \frac{\ln[1 - P_\theta (1 - \exp\{\rho L\})]}{\rho}$$

If the cost of insurance (*C*) exceed this amount, farmers will prefer the Alternative 1 (without insurance). This threshold increases with the absolute risk aversion coefficient of Arrow-Pratt ρ . So, with a more risk adverse agent as expected the willingness to pay increases. Although individuals' risk tolerance varies, we assume that $\rho=0.5$ represents the risk aversion coefficient. Palacios-Huerta (2003) suggested that ρ typically ranges from 0.3 to 0.7, centred on 0.5.

3 RESULTS

3.1 Changes in crop productivity

Figure 2 illustrates crop productivity losses under climate change. North African countries are the most affected under A1B scenario although the impacts are not so significant under E1 scenario. The effects are quite consistent among scenarios but some agricultural areas have major changes among scenarios. This is mostly the case of North African countries. Figure 3 shows the average values and the standard deviation among scenarios for the considered agricultural areas.

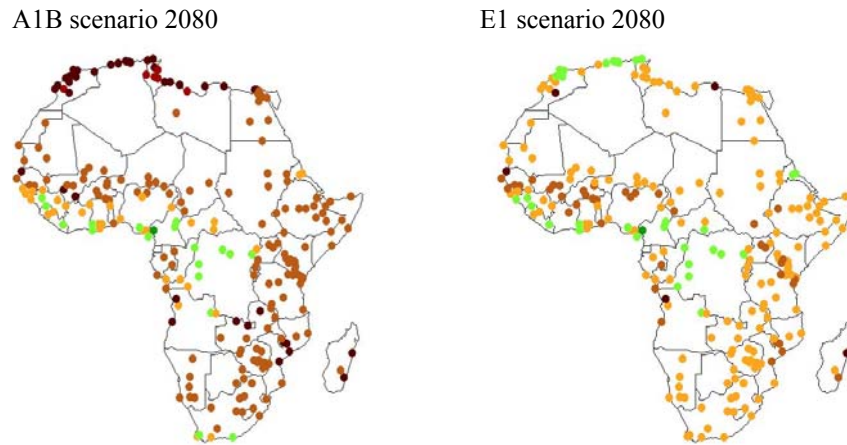


Figure 2. Crop productivity changes under the A1B and E1 averages scenarios for 2080a.

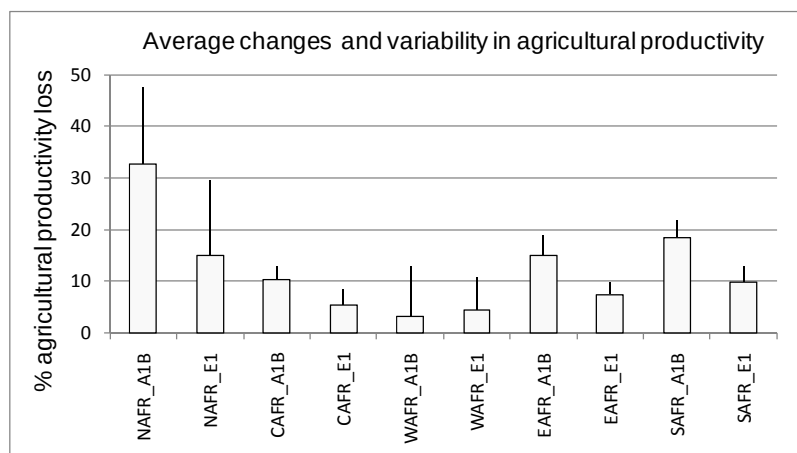


Figure 3. Crop productivity changes under the A1B and E1 averages scenarios for 2080a.

Table 4 shows the expected increase in drought probability considering the precipitation changes reported by the ClimateCost project (Goodess et al., 2011, Climatecost project) and the criteria exposed on Table 3. The Mediterranean countries are the most affected by drought risk increase due to climate change.

Table 4. Probability of drought (average and standard deviation) in the A1B and E1 scenarios in the African Regions

Scenario	North Africa	West Africa	East Africa	Central Africa	Southern Africa
A1B average	53	40	28	27	48
A1B standard deviation	9.85	12.79	8.35	4.92	9.37
E1 average	24	16	15	13	23
E1 standard deviation	12.84	12.84	10.92	9.94	12.04

3.2 Maximum benefit of early warning systems

Figure 4 shows in black the production loss from drought summarised for the considered agricultural areas and scenarios. Grey records show the maximum benefit of early warning computed as the maximum willingness to pay for the stakeholders considering different levels of absolute risk aversion coefficients (0.1, 0.3, 0.5 and 0.7) that is for different preferences to the risk. This maximum potential benefit is estimated as a percentage of crop productivity assuming that the early warning system allow the farmers to avoid the production loss from drought. So the better the risk management systems in an agroclimatic area, the nearest to the maximum potential benefit for the information system in this area.

North African and South African countries have higher drought probability and also higher losses reported for most of the climate change scenarios. In addition, the drought management and irrigation systems are more developed than in the rest of the African countries. All this factors make this two areas those with the most expected efficiency for investments on information systems (ie.early warning systems), while in the rest of areas the investment should increase first adaptive capacity to cope with drought management in order to achieve more effectiveness of information systems.

The role of risk aversion is higher in the more extreme scenarios where the farmers' willingness to pay can vary a lot depending on the farmers attitude to risk.

4 DISCUSSION

Drought is one of the major environmental disasters in Africa, and has resulted in extensive damage to the environment and economy. Recent climate change projections suggest this situation may worsen, and lead to an increased frequency and severity of this natural hazard. Advance warning of drought, and the implementation of effective drought management in response, offers the potential to mitigate adverse impacts. Drought preparedness and education can additionally increase resilience of affected societies, allowing these to cope better, and help break the disaster-response cycle.

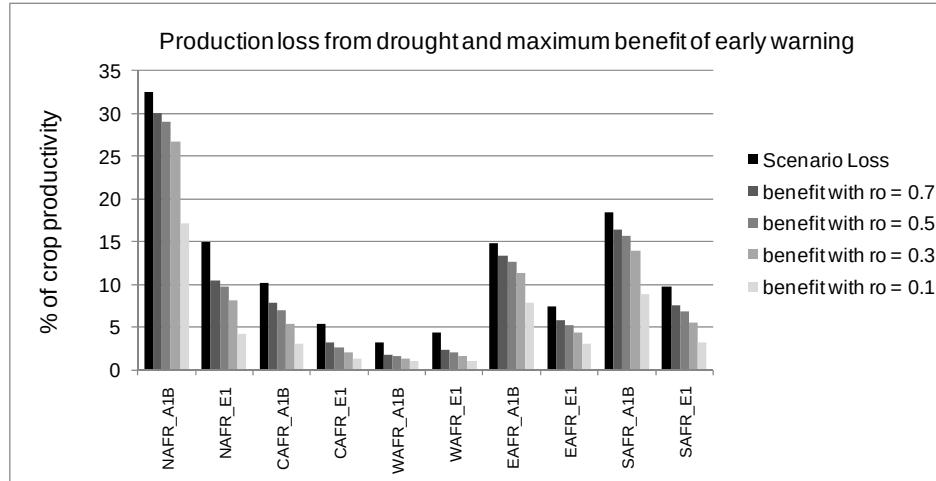


Figure 4. Production loss from drought and maximum benefit from early warning.

We estimate the increase in drought probability of a range of scenarios based on the definition of thresholds values. Our results lack the detail of indicators developed with more precise data but the strength is that include a continent-wide assessment and multiple scenarios; this may be useful to define priorities for drought management action. In spite of the simplicity of our drought evaluation, the results agree with previous studies that show that the frequency of drought has been increasing in Africa over the last three decades, which may be due to the changing climate (IPCC, 2007; Iglesias et al., 2009). The impacts of droughts are often related to agriculture and have serious societal and economic repercussions. The failure or lack of drought mitigation and management practices increases the vulnerability of food production due to drought hazards.

Key strategies for reducing vulnerability include increasing resilience through preparedness and adaptation, but also depend strongly on improved knowledge of drought early warning information (Barros and Bowden, 2007). We show that producing early warning is an effective drought mitigation measure in all countries and may be an effective adaptation strategy for climate change. The results may also be used to establish priorities for allocating water resources for agriculture and develop water management plans that are adapted to climate change.

Future climate change may render the current water management practices, current agricultural practices and current socio-economic circumstances unsustainable. In these cases, the effectiveness of drought early warning may decrease and preparedness and mitigation of drought may become common practice rather than a response to an extreme situation.

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