Supplement of

The effects of commercial export farms on drought risk and impact of agropastoral communities in the drylands of Kenya

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S1. ODD+D Protocol

This ODD+D protocol is based on the ADOPT model from Wens et al., 2020, and previous version of ADOPT-AP in Streefkerk et al., 2023.

I. Overview

I.i Purpose

What is the purpose of the model?

The purpose of ADOPT-AP is to improve drought risk assessments through including the complex adaptive behaviour of agropastoralists in dryland areas. The ADOPT-AP model simulates the uptake of adaptation measures of representative agropastoral households over time as a function of climate effects on agricultural and livestock production, mitigated by implemented adaptation measures, and simulates the adoption of such measures as a function of economic, social and psychological household characteristics. Understanding the two-way feedback between households' adaptation decisions and drought risks over time will help optimize future drought impact estimations and allow for the testing of drought management policies. Indeed, the model can be used to evaluate the effect of possible climate change and (non-)governmental policies on drought risk of agropastoral communities, scrutinizing the heterogeneous effect of these external factors on the changes in vulnerability of the agropastoralists.

For whom is the model designed?

The model can allow scientists to increase understanding of the socio-hydrological reality of drought risk and drought adaptation in a rural and dryland context, while it can help decision makers to design drought policies that target the right rural household and evaluate their effect on their drought risk.

I.ii Entities, state variables, and scales

What kinds of entities are in the model?

The agents in are representative individual agropastoral households that have crop land and/or a livestock herd of varying size and potentially an external income source.

By what attributes are these entities characterized?

Agropastoral households (see Supplementary Figure 1) have, other than crop land and s livestock herd with a specific size, a family size, a household head (male/female) with a certain age and education level, financial assets (wealth, expressed in USD), alternative employment, and expenses. Household heads have a memory regarding past drought impacts, have a perception about their own capacity and in varying degrees, have information about potential adaptation measures.

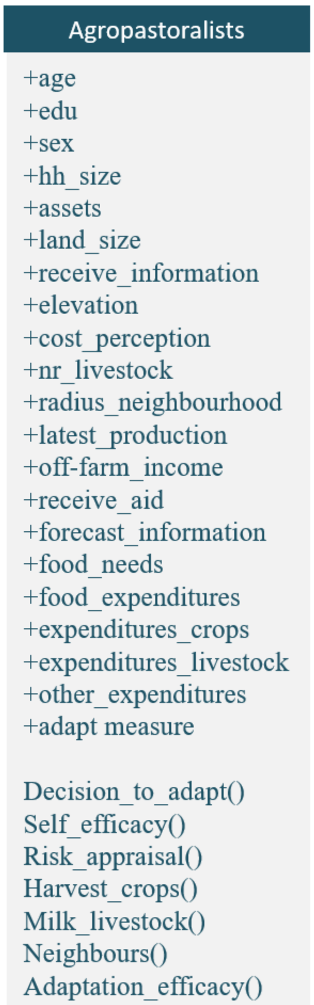


Figure S1: UML diagram with characteristics and functions of the agents.

What are the exogenous factors / drivers of the model?

The exogenous factor that influences the household system is the climate which affects the frequency of droughts (therefore also crop and livestock production). In addition, there are commercial export farms that follow water allocation rules and modify the water balance.

How is space included in the model?

Space is included as spatially explicit 1 by 1 km gridded cells on a catchment scale in the context of East Africa (Ewaso Ng'iro North). On this level, agricultural water management decisions (adaptation) interact with rainfall variability (drought hazard) and neighbouring agents.

What are the temporal resolution and extent of the model?

One time step of agent's decision making model represents one year; decisions are made on yearly basis However, crop and livestock- related decisions are made in different times of the year. Livestock-related decisions by the agropastoral households to eventually adopt new adaptation measures are only made in the long dry season, around September. For crop-related decisions this is just before the March-April-May season. The socio-hydrological model part runs on a daily basis, producing updated water availability and livestock and crop production. The model runs for over 32 years (January 1990- June 2023), with the period of 1990 to 2001 as the initialisation period.

I.iii Process overview and scheduling

What entity does what, and in what order?

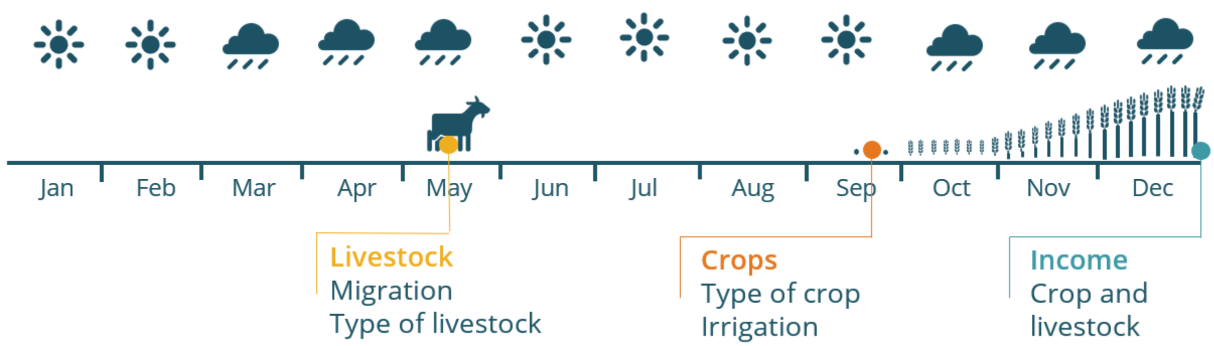


Figure S2: Timeline of key moments in model.

Every year, income of the households is updated with the crop harvest and milk products. This harvest depends on the size of the crop land and livestock herds of the households. The crop and livestock production may be affected by a drought and may be mitigated by implemented drought adaptation measures. Food needs of the own household (depended on household size) are subtracted from the production (subsistence is prioritized over selling). This income, together with a potential (fixed) external income, and with agricultural and livestock expenses (depended on crop land and livestock size), alter the assets of all agropastoral households. The agropastoral households' memory about drought impacts (risk perception) is updated, and they interact with their network of neighbours exchanging information on adaptation measures.

Risk appraisal includes the perceived probability of the drought risk by the farmers. The perception is high just after a drought event, and then decreases over time Therefore, risk appraisal increases in relation to the drought damage but decreases if no drought damage occurs. It is expressed as follows:

$$RiskAppraisal_t = RiskAppraisal_{t-1} + DroughtDamage - 0.125 \cdot RiskAppraisal_{t-1} \quad (2a)$$

The $RiskAppraisal_t$ variable is initialized as a random value between zero and one [0;1], and the memory is the risk appraisal of the previous time step t-1. DroughtDamage (Eq. 2b) is computed as the relative loss in livestock or crop production in a specific year compared to the average production of the previous 10 years (Di Baldassarre et al., 2013). DroughtDamage is calculated as follows:

$$DroughtDamage = 1\ e^{-loss} \quad (2b)$$

The perceived ability to adapt (Coping appraisal) also influences the decision-making process. This is determined by three components: (a) household characteristics such as education level, household size, age, network and gender determine the self-efficacy. (b) households have to believe they can pay for the costs: the perceived adaptation costs, expressed as the relative cost of the adaptation measure compared to the agent's liquidity) (Van Duinen et al., 2015). (c) the perceived degree to which the adaptation options are likely to have an effect (adaptation efficacy). The $CopingAppraisal_t$ is thus a combination of these three factors:

$$CopingAppraisal_t = \gamma \cdot SelfEfficacy + \delta \cdot AdaptationEfficacy + \varepsilon \cdot AdaptationCosts \quad (3)$$

Twice a year, the household heads decides whether to adopt an adaptation measure or not (see Supplementary Figure 2). The livestock-related decisions are made in May, just before the long dry season. The second decision is related to crops and made in September at the start of the cropping season. Based on their memory of past drought impacts, their perception of the adaptation costs, the knowledge on adaptation measures through their networks and training, and based on their perception of their own capacity, they decide whether they to adopt a drought adaptation measure. The adoption of a measures changes the management of those agropastoral households, directly changes their wealth and influence crop and livestock production and vulnerability to drought – thus potential income - during the following year(s). Two measures have a lifespan of one year (migration and type of crop), and the other four (type of livestock, water harvesting, soil moisture conservation, and irrigation) have a lifespan of 10 years. The intention to adapt is converted to a variable that compares whether the intention to adopt will lead to actual behaviour, by correcting the intention to the lifespan of the measure. The calibration parameter determines whether the adaptation measure is implemented:

$$1 - (1 - \mathrm{PMT})^{1/\mathrm{lifespan}} > Threshold_{Intention\_to\_behavior}\ [0,1] \qquad \text{Eq. S.1}$$

II. Design Concepts

II.i Theoretical and Empirical Background

Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the sub-model(s) ?

The multi-disciplinary modelling approach of ADOPT-AP is rooted in quantitative socio-hydrology framework', where the human system both influences and adapts to the changing physical agricultural drought environment, and applies an agent-based approach to deal with heterogeneity in adaptive behaviour of households.

On what assumptions is/are the agents' decision model(s) based?

Simulating bounded rational rather than economic rational adaptation decisions, the Protection Motivation Theory (Rogers, 1983) is used as a way to include psychological factors in the heterogeneous adaptive behaviour of smallholder households.

Indeed, it is often stated that households' adaptive behaviour is bounded rational and embedded in the economic, technological, social and climatic context of the household (Gebrehiwot & Van Der Veen, 2015; Mandleni & Anim, 2011). Knowing the risk is not enough to adapt; households should also believe the adaptation measure will be effective, be convinced that they have the ability to implement the measure and be able to reasonably pay the costs (Van Duinen et al. 2015). Financial or knowledge constraints may limit economic rational decisions. The perceived ability to do something (Coping Appraisal) influences the decision making process (Eiser 2012). This coping appraisal can be subject to intrinsic factors such as education level, sources of income, farm size, family size, gender, confidence and beliefs, risk-aversion, and age (Shikuku, 2017; Eiser 2012, Van Duinen 2015; Zheng & Dallimer, 2016). In order to understand the observed adaptive behaviour of Kenya's households, it is critical to incorporate such social-economic factors in the decision-making framework of drought adaptation models (Lalani et al., 2016; Gbetibouo, 2009; Deressa et al. 2011; Gebrehiwot & Van Der Veen, 2013).

Why is a/are certain decision model(s) chosen?

Analysis of the past and intended behaviour of agropastoral households in the region (Wens et al. 2021; Schrieks et al., 2023) provided support for the choice of theory. Showing the effect of different assumptions about decision making in the first exploration of ADOPT (Wens et al. 2020), and with empiric evidence on the adaptive behaviour (Wens et al. 2021; Schrieks et al., 2023), the decision rules in ADOPT-AP are assumed be a good enough representation of the decision making process regarding drought adaptation in East African context.

At which level of aggregation were the data available?

Data from the survey by Wens et al. (2020) is available on individual household level.

II.ii Individual Decision Making

What are the subjects and objects of decision-making? On which level of aggregation is decision-making modelled?

In ADOPT-AP, individual agropastoral households make individual decisions about their water management by potentially adopting drought adaptation measures (changing crop types, apply irrigation, change livestock types, migrate livestock, soil conservation, water harvesting). There are no multiple levels of decision making included.

What is the basic rationality behind agents' decision-making in the model? Do agents pursue an explicit objective or have other success criteria?

Agropastoralists generally try to reduce their drought risk and thus try to maximise crop and livestock production given the capacity they have to adopt adaptation measures.

How do agents make their decisions?

In ADOPT-AP, the Protection Motivation Theory (Rogers 1983) (see II.i) is used to explain the decision making process of the households. PMT consists of two underlying cognitive mediating processes that cause individuals to adopt protective behaviours when faced with a hazard (Rogers 1983). These are the Risk-appraisal process forming a risk perception and the coping-appraisal process forming a perception of the adaptation-efficacy. This theory in able to include all factors described above and summarized them in terms of perceived risk, perceived adaptation efficiency, perceived self-efficacy and the adaptation costs. For each potential adaptation measures, agropastoral households develop an intention to adopt (protect). This intention can be seen as a likelihood to adopt – the actual adoption is stochastically derived from this. Households do not have any other objective or success criteria. A detailed description of how PMT is modelled can be found in Streefkerk et al. (2020).

Do the agents adapt their behaviour to changing endogenous and exogenous state variables? And if yes, how?

Exogenous factors influencing adaptation decisions in adopt include natural environment in which households exists. Drought induced crop and livestock losses steer a households' perception of the drought risks they face (Risk Appraisal). Besides, access to extension services (e.g. field demonstrations, trainings) - used as primary source of information, and other sources of information sharing (i.e. through the social network or NGOs) can have profound effect on whether or not individuals take proactive action (Shikuku et al., 2017). Endogenous factors, as explained above, include age, household size, education level, crop and livestock production and assets.

Do spatial aspects play a role in the decision process?

Agropastoral networks (connections with neighbours) exist and information on the adaptation measures is passed through this social network. Additionally, drought hazard can spatially differ.

Do temporal aspects play a role in the decision process?

Risk memory is based on the crop and livestock production variability of the accumulated past years and gives agropastoral households an expectation about the current production.

Do social norms or cultural values play a role in the decision-making process?

Social norms or cultural values do not play a role in the decision-making process.

To which extent and how is uncertainty included in the agents' decision rules ?

No.

II.iii Learning

Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?

Decision rules follow the PMT and are thus fixed, but some rules differ among type of households. Households that do not regularly receive extension services, are limited to only implement measures that their neighbours have installed as they are not aware of the existence of others. Besides, people who receive training will form their perception about the adaptation efficacy in a more objective way (as they have knowledge of average production under the adaptation measures while others estimate this based on production of their neighbours with such measure)

Is collective learning implemented in the model?

No.

II.iv Individual Sensing

What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?

Following the socio-hydrologic setup of the model, households with bounded rational behaviour are embedded in and interact with their social and natural environment. Changes in rainfall patterns during growing season will change households' risk perception; drought memory will influence the adaptive behaviour of these households. Besides, there is a diffusion of technology due to interactions and knowledge exchanges among agropastoral households as discussed above.

What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?

Households are aware of their assets, past crop and livestock (milk) production, income sources and their stability, and household food needs. Households know their own but also their neighbours current production and management practices. Households can also sense state variables of the environment. For example, whether there is water in the river or groundwater extraction point.

What is the spatial scale of sensing?

Individual sensing happens on household level. Households can sense their neighbours and environment based on their neighbourhood radius.

Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables?

Sensing happens locally and households have a simulated "contact" with the households in their network to exchange info on crop and livestock production and management strategies.

Are the costs for cognition and the costs for gathering information explicitly included in the model?

No.

I.v Individual Prediction

Which data uses the agent to predict future conditions?

By extrapolating from historic crop and livestock production experiences, agropastoralists have expectations about their crop and livestock production every year.

What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?

Households receiving extension services have knowledge about the average (future) crop and livestock production gain of adopting a new adaptation measure, which will influence their coping appraisal through the perceived adaptation efficacy.

Might agents be erroneous in the prediction process, and how is it implemented?

Households without this access to training will predict the yield gain based on the extra crop and livestock production of their neighbours who have already adopted the considered adaptation measure.

II.vi Interaction

Are interactions among agents and entities assumed as direct or indirect?

Agropastoralists learn from the other households in their social network about the implementation and benefits of drought adaptation measure through pioneer households' and family ties (Shikuku 2017). In ADOPT-AP, interventions with neighbours shape the perceived adaptation effectivity.

On what do the interactions depend?

Spatial distance (neighbourhood) at initialisation is the key driver for networks; it is assumed that (s)he would not walk more than her/his neighbourhood. This neighbourhood radius is part of the calibration procedure.

If the interactions involve communication, how are such communications represented?

Communication is not explicitly modelled.

If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?

No coordination network exists.

II.vii Collectives

Do the individuals form or belong to aggregations that affect, and are affected by, the individuals?

No

How are collectives represented?

Network sizes are set at the initialization phase and do not change over time.

II.viii Heterogeneity

Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?

Household agents are heterogeneous in terms of state variables (i.e. land and herd size, household size, assets), and their location – resulting in different environmental drivers.

Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?

Shikuku (2017) – among others - found that state variables such as age, beliefs. gender, education of the household head and the household size have significant effects on this risk- attitude; and these factors are included in the model application of the Protection Motivation Theory through the self-efficacy factor.

II.ix Stochasticity

What processes (including initialization) are modelled by assuming they are random or partly random?

The initialisation of the agents characteristics (see Supplementary Figure 1) are based on a fitted distribution of survey data. The characteristics are stochastically determined from that distribution. Although the number of groundwater abstraction points are calibrated, the locations of these points are randomly generated.

II.x Observation

What data are collected from the ABM for testing, understanding and analysing it, and how and when are they collected?

Average household coping and risk appraisal, adopted measures and crop and livestock production are tracked over the model years.

What key results, outputs or characteristics of the model are emerging from the individuals

The adoption of adaptation measures and how this influenced drought hazard is emerging from the model.

III. Details

II.i Implementation

How has the model been implemented?

The model is coded in Python, which is able to link the sub model (DRYP 2.3) which is written in Python as well.

Is the model accessible, and if so where?

The model code is publicly available in GitHub via https://github.com/istreefkerk/ADOPT-AP and http://doi.org/10.5281/zenodo.7447665.

III.ii Initialization

What is the initial state of the model world, i.e. at time t=0 of a simulation run?

At the initial stage, households and their characteristics are stochastically created based on the best-fitted distribution derived from the household dataset, obtained from a household survey in the case study area (Schrieks et al., 2023).

*= setting used for single run (but part of calibration)

Table S1: Initialisation parameters for agropastoral households in ADOPT-AP

Parameter	Explanation of initialization parameters for agropastoral households	Distribution	Value
Age	Age of the household head (Schrieks et al., 2023)	Genextreme	
Edu	Years of education of the household head (Schrieks et al., 2023)	Gamma	
Sex	Gender of the household head (Schrieks et al., 2023)	Random choice	[0, 1]
HH-size	Family size of the households (people living under same roof) (Schrieks et al., 2023)	Dweibull	
Assets	Household financial assets (USD) that can be spend (Schrieks et al., 2023)	Pareto	
Land-size	Size of the farm (in hectare) used for planting crops (Schrieks et al., 2023)	Random choice	[0.5, 1.5]
Receive extension	Whether or not household receive agricultural extension services	Random choice	[0, 1]
Elevation	Elevation of household [m]		
Cost_perception	Perceived cost per adaptation measure	Random choice	[0, 1, 2 ,3, 4 ,5]
Nr_livestock	Number of livestock of household; cattle/goats	Genextreme/ Burr	

Latest production	Memory of crop and livestock production (last 10 years)		
Off-farm income	Income from activities not on the own farm in USD (Schrieks et al., 2023)	Exponential	
Receive aid	Whether or not household receive aid from the government or NGO	Binary	
Forecast information	Whether or not household receive forecast information	Random choice	
Food needs	Kilogram of crop / litre of milk to fulfil daily caloric intake needs, per adult (Wens et al., 2021)		103 kg crop/year 0.25 l cowmilk/day 0.05 l goatmilk/day
Food expenditures	Expenditures for food by the household (USD/hh size/ year) (Schrieks et al., 2023)	Gompertz	
Expenditures crops/livestock	Expenditures for farm (USD/hectare/year) and livestock (USD/#livestock/year) made by the household (Schrieks et al., 2023)		130/hectare 12 USD/cow 3 USD/goat
Other expenditures	Other expenditures than agricultural and food related (Schrieks et al., 2023)	Burr	
Adapt_measure	Whether or not a household adopted a measure	Random choice	[0, 1]
Milk_price	Price (USD) for selling 1 litre of milk produce (goats/cows)		0.5/0.7
Crop_price	Price (USD) for selling 1 kg of crop produce		0.35
NR*	Neighbourhood radius (km)		3.63
CM*	Costs of adaptation measures (-)		2.68
AL*	α weight of risk and coping appraisal (-)		0.57
IM*	Threshold intention to adapt to implemented measure		0.68

Is initialization always the same, or is it allowed to vary among simulations?

Most initialisation parameters are stochastic and can thus vary among different simulations. However, to make a comparison between scenarios possible, the initialisation is the same in the scenario runs.

Are initial values chosen arbitrarily or based on data?

Household characteristics (age, income, etc) for agents are determined per climate zones (Figure 1 of article). We initialise gents located in climate zones I-IV (agriculture communities with data of Tegemeo Institute (2010). Agents in climate zone V (agropastoral communities) are initialized with Burat data of Schrieks et al. (in review). Agents in climate zones VI and VII (pastoral communities) are initialised with Oldonyiro data of Schrieks et al. (2023). These initial agent characteristics are based on the best-fitted statistical distribution (e.g. gamma distribution) of the sampled data of Tegemeo Institute (2010) and Schrieks et al. (2023).

III.iii Input Data

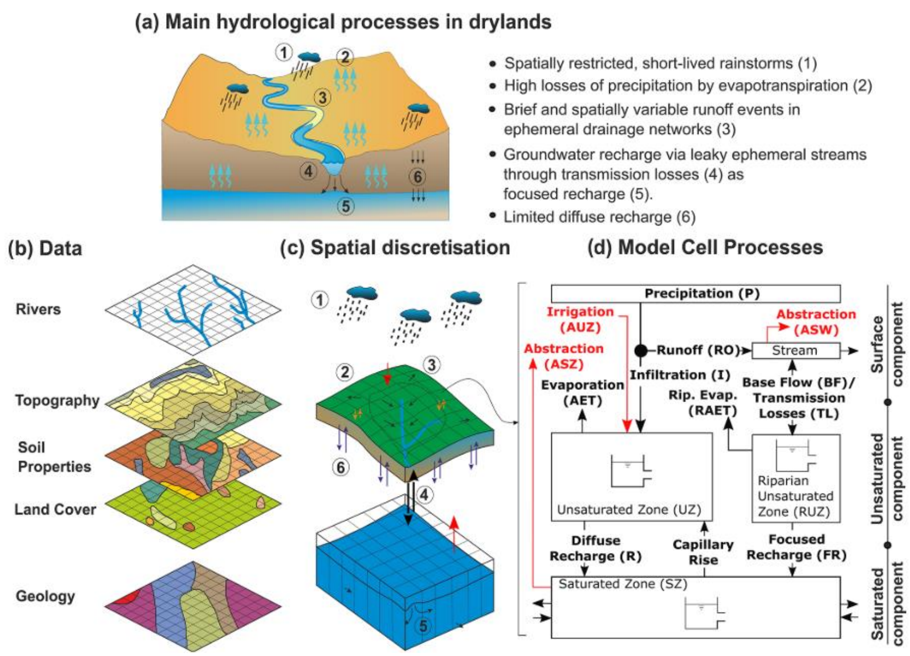
Does the model use input from external sources such as data files or other models to represent processes that change over time?

The daily weather conditions from January 1990 to June 2023 is used as input time series for the hydrological DRYP model.

III.iv Submodels

What, in detail, are the sub-models that represent the processes listed in 'Process overview and scheduling'?

The hydrological model DRYP (coded in Python by Andres Quichimbo (Quichimbo et al. 2021) calculates the drought hazard, based on hydro-climatologic conditions provided by the climate data. A conceptual diagram of the hydrological processes in DRYP can be seen in Supplementary Figure 3.



Supplementary Figure S3: DRYP 1.0 a) main hydrological processes, b) data, c) spatial discretisation, and d) model cell processes (Quichimbo et al. 2021).

Drought hazard is expressed in soil moisture, discharge and groundwater levels compared to normal conditions. Through socio-hydrological interactions crop and livestock productions are calculated based on water availability/severity of drought and the agricultural management of the households.

The socio-hydrolological interactions sub-module include the calculation of crop and grass yield. It follows Siebert and Döll (2010): the production is based on the ratio between the crop's actual (AET) and potential evapotranspiration (PET) ($Ratio_{crop\_yield}$). If the ratio is 1 (AET = PET), crop yield is at its maximum, while a lower AET reduces crop yield:

$$Ratio_{crop\_yield} = \left\{ \begin{array}{c} 1\ if\ a\frac{AET}{PET} + b > 1 \\ aP1 + b - \left|(P1 - \frac{AET}{PET}) * \frac{aP1 + b}{P1 - P0}\right|\ if\ P0 < \frac{AET}{PET} <\ P1 \\ 0\ if\ \frac{AET}{PET} \leq P0 \\ a\frac{AET}{PET} + 1\ else \end{array} \right\}$$

$$Yield_{crop} = \ Ratio_{crop\_yield} \cdot Yield_{crop\_max}$$

where a, b, P0 and P1 are crop-specific parameters statistically derived by Siebert and Döll (2010).

The decision sub-module in which households decide on their drought adaptation measures, is coded in Python as well. It is a model-application of the Protection Motivation theory as explained in section II.i. A more detailed explanation can be found in Wens et al 2020.

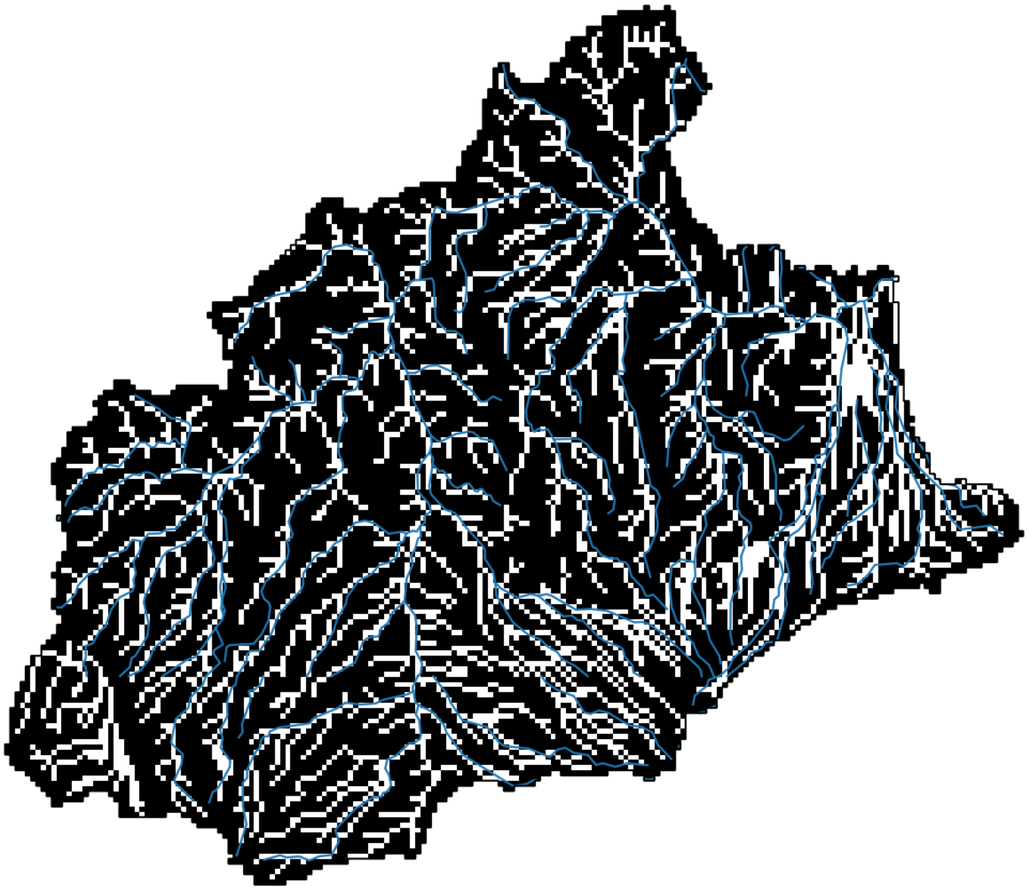
How were sub models designed or chosen, and how were they parameterized and then tested?

DRYP 1.0 was applied following Quichimbo et al. (2021) who both analysed and approved the functioning of this model to simulate water availability for dryland regions.

The decision sub model designed is described above in the sections about decision-making and theoretical foundations (II.ii). A more detailed description can be found in Wens et al 2020.

What are the model parameters, their dimensions and reference values?

The model parameters and input maps of different model components can be found in Table B, C, D and E. The maps (Table D and E) have no vales as the values are spatially heterogeneous. An example of the river network can be seen in Supplementary Figure 4.



Supplementary Figure S4: River network in DRYP, indicated by white grid cells. The blue lines indicate the river network for orientation purposes in the paper.

*= setting used for single run (but part of calibration)

Table S2: Parameters settings for DRYP in ADOPT-AP

Parameter	Explanation of calibration parameters for DRYP 1.0	Value
kDroot*	Rooting Depth factor	1.59
kKsat*	Saturated hydraulic conductivity factor	0.28
kT*	Recession time factor	0.23
kKsat_ch*	Saturated hydraulic conductivity factor (channel)	0.37
kKsat_sz*	Aquifer saturated hydraulic conductivity factor	19.29
kYield*	Aquifer specific yield factor	0.05

Table S3: Parameters for socio-hydrological interactions

Parameter	Explanation of (static) parameters for socio-hydrological interactions	Value
a, b, p0,p1	Crop specific parameters of maize and casava	1.29, 0.08, 0.1, 0.4 1, 0.1, 0.15, 0.5
$\boldsymbol{Yield_{crop\_max}}$	Maximum yield of maize and casava (*1000 kg/hectare)	2.4,4.0
Kg	Yield response factor of grass (-)	0.4
$\boldsymbol{G_{yield\_max}}$	Maximum yield of grass (*1000 kg/hectare)	3.5
$\boldsymbol{\eta_l^f}$	feed requirement of cattle and goats (kg/day)	7, 6
$\boldsymbol{\eta_l^r}$	Feed residue rate of cattle and goats	0.3 , 0.2
$\boldsymbol{r_{net}}$	Net birth rate of cattle and goats	0.15, 0.25
-	Livestock water demand of cows and goats (litre/day)	25, 9.6
-	Domestic water demand (litre/day)	50
-	Start long dry season date (day of the year)	140
-	Start long rainy season date (day of the year)	274
-	Harvest date (day of the year)	360
DA*	Distribution groundwater abstraction points (chance of abstraction point)	0.10
NR*	Neighbourhood radius (km)	3.63
IF*	Irrigation demand factor (-)	0.32

Table S4: Input maps needed for Environment

Parameter	Explanation
=============== **TERRAIN COMPONENTS** =================	
-	Topography (DEM)
-	Cell factor area
-	Basin Mask (catchment)
-	River length
fd	Flow Direction
========== **SOIL AND SUBSURFACE PARAMETERS** ==========	
-	Theta residual
AWC	Available Water content
-	sigma_Ksat
wp	Wilting Point
D	Soil Depth
b	Soil particle distribution parameter
-	Soil suction head
-	Saturated hydraulic conductivity
-	Soil porosity
==================== **INTERCEPTION** ====================	
Av	Vegetation fraction
SAVI	Soil Adjusted Vegetation Index
=== **GROUNDWATER PARAMETER AND BOUNDARY CONDITIONS** ===	
	Groundwater Boundary condition (domain)
Ksat_aq	Aquifer Sat. Hydraulic Conductivity
-	Specific Yield
-	Initial Conditions Water table elevation

Table S5: Input maps needed for Socio-hydrological interactions

Parameter	Explanation
Kc	Vegetation type
-	Land cover map
-	Population density

S2. Description of variables in regression model

Table S6: Description of variables in regression model

Variable name	Questions/Description	Coding	Mean	SD
Expected frequency Drought **(Perceived frequence)**	How often do you expect a drought to occur in the region where you live?	10-point Likert scale from 1: 'Once every 10 rainy seasons or less' to 10: 'Every rainy season'	8.96	1.01
Perceived relative impact **(Perceived severity)**	If you compare your family situation to the rest of the community, do droughts affect you less or more than an average family?	5-point Likert scale from 'A lot less than others' to 'A lot more than others'	3.18	0.70
Perceived self-efficacy	For each of the fifteen adaptation measures we asked: To what extent do you feel able implementing the following measure that reduces the impact of drought on your household?	5-point Likert scale from 'not able et all' to 'very able'	2.63	1.45
Perceived adaptation **efficacy**	For each of the fifteen adaptation measures we asked: How effective do you think the following adaptation measure is to reduce and possibly prevent the drought impacting your livestock, crop harvest, and your life?'	5-point Likert scale from 'not effective et all' to 'very effective'	3.92	1.15
Perceived costs	For each of the fifteen adaptation measures we asked: How high do you think the total costs would be for you to carry out this adaptation measure, in terms of financial costs as well as time and effort?	5-point Likert scale from 'not high et all' to 'very high'	4.02	1.15
Education level	What is your highest completed level of education?	0 = No formal education 1= primary (incomplete) 2= primary (complete) 3= secondary (incomplete) 4 = secondary (complete) 5 = tertiary (incomplete) 6 = tertiary (complete)	1.78	1.73
No knowledge	In case you did not implement some of the drought risk adaptation measures, what were the main three reasons for not implementing them?	1 if answer is "I don't know how" or "I don't know which" (N = 120) 0 otherwise (N = 364)		
Access government support or aid	To what extent do you feel that you have sufficient access to the following resources to cope with droughts? Government support or aid	4-point liker scale from (1) 'No access et all' to (4) 'More than sufficient access'	2.04	0.83

Access forecast info	To what extent do you feel that you have sufficient access to the following resources to cope with droughts? Forecast information and early warnings	4-point liker scale from (1) ‘No access et all’ to (4) ‘More than sufficient access’	1.83	0.92
Livestock keeper	Which of the following livelihood activities does your household engage in?	1 if livestock breeding is selected (N = 319), 0 if not (N = 132)		
Crop farmer	Which of the following livelihood activities does your household engage in?	1 if crop farming is selected (N= 89), 0 if not (N=362)		

S3. Regressions for self-efficacy

Table S7: Perceived self-efficacy per adaptation measure

	D.R. crops	Livestock diversification	Moving	Irrigation
(Intercept)	1.47 ***	1.29 ***	0.85 ***	1.06 ***
	(0.21)	(0.21)	(0.23)	(0.22)
Education level	-0.02	0.11 ***	0.07 **	0.08 **
	(0.03)	(0.03)	(0.04)	(0.04)
No knowledge	-0.25 *	-0.33 **	-0.42 ***	-0.44 ***
	(0.14)	(0.14)	(0.15)	(0.15)
Access gov support or aid	0.18 **	0.30 ***	0.03	0.11
	(0.07)	(0.07)	(0.08)	(0.07)
Access forecast info	0.39 ***	0.02	0.33 ***	0.35 ***
	(0.07)	(0.07)	(0.07)	(0.07)
Crop farmer	1.16 ***	0.73 ***	0.36 **	1.21 ***
	(0.15)	(0.15)	(0.16)	(0.16)
Livestock keeper	0.03	0.89 ***	0.97 ***	0.20
	(0.13)	(0.13)	(0.14)	(0.14)
N	490.00	491.00	472.00	463.00
AIC	1633.66	1620.18	1614.39	1560.37

*** p < 0.01; ** p < 0.05; * p < 0.1.

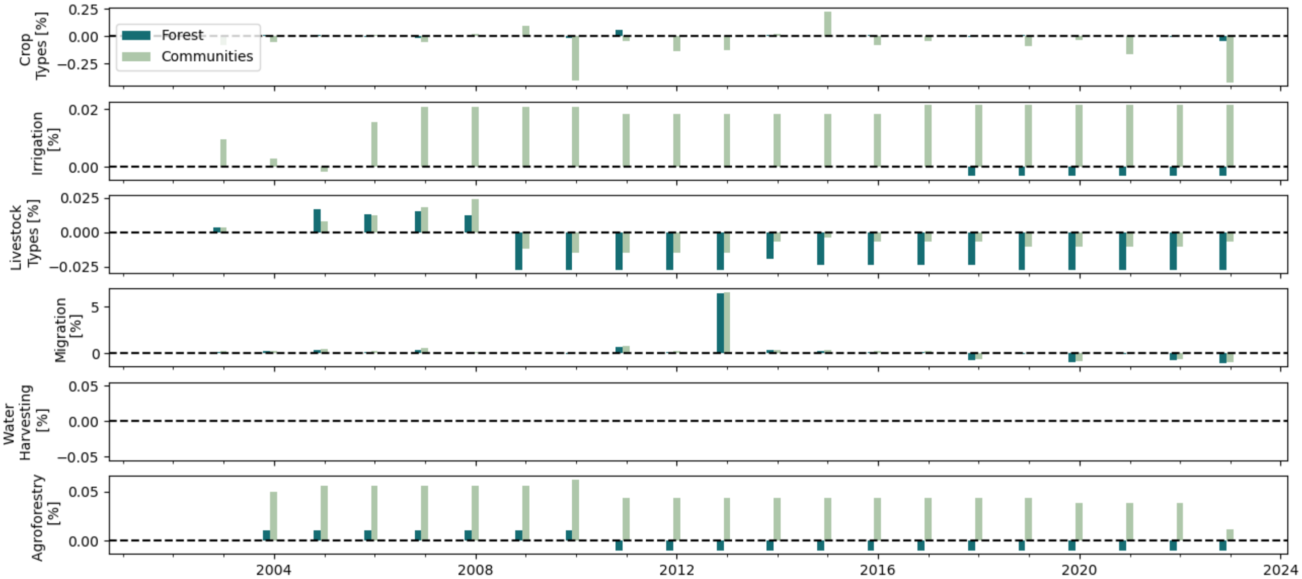
	Rainwater harvesting	Agroforestry
(Intercept)	1.47 ***	1.39 ***
	(0.23)	(0.21)
Education level	0.10 ***	-0.02
	(0.04)	(0.04)
No knowledge	0.19	-0.42 ***
	(0.15)	(0.14)

Access gov support or aid	0.16 **	0.09
	(0.08)	(0.07)
Access forecast info	0.32 ***	0.55 ***
	(0.07)	(0.07)
Crop farmer	0.63 ***	0.91 ***
	(0.16)	(0.15)
Livestock keeper	0.31 **	0.13
	(0.14)	(0.13)
N	484.00	480.00
AIC	1680.09	1600.03

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

S4. Adoption of adaptation measures over time

Figure S5: Timeseries of adoption of adaptation measure (% of people) for forest and communities scenarios, compared to the commercial farms scenario.



S5. Hydrological variables over time

Figure S6: Timeseries of hydrological variables over the entire catchment for the three scenarios