Food security, water security or both? A socio-hydrological conceptualization of the Ng'iro basin, Kenya

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Abstract

Agriculture plays a major role in African economies and forms the livelihood of millions of small holder farmers. At the same time the continent is predicted to be severely impacted by climate change further raising concerns about food and water security. This study looks into the vulnerability of small-holder farmers living in river communities, taking the Ng'iro case study as example. The natural rainfall gradient along the river results in an uneven distribution in resources, with downstream communities potentially more vulnerable than upstream communities. Taking into consideration crop choice as an adaptive strategy of the individual farmer and water sharing rules as a community adaptation strategy, the different development paths of the communities are explored given climate variability. This is done through use of a general, stylized model framework consisting of a set of differential equations. We (expect) to find a threshold in the system in which simple water sharing rules based on the fulfilment of individual stakes and equity might no longer be sufficient to ensure food security. When this threshold is reached depends on the interplay between climate (rainfall) and population characteristics. Adaptation could be either front end (changing the water sharing rules) or back end (ensuring adequate internal food trade) or both.

1 Introduction

For most African countries, agriculture is a major contributor to its GDP ranging from 10 to 70 % (Mendelsohn et al., 2000). In Kenya, but also in countries like Tanzania, Ethiopia and Uganda agriculture is dominated by smallholder farmers (Salami et al., 2010). Even without potential effects from climate change, obtaining stable yields is a major challenge, as these countries are characterized by a low annual rainfall and high variability throughout the year and between years. Although the impacts of climate change in Africa are uncertain, it is expected that average temperatures might increase and the length of the growing seasons might decrease (Parry, 2007). Large regions of marginal agriculture could be forced out of production. The vulnerability of the communities depend on their possibilities to adapt within the face of the for-mentioned climate variability, but also in the face of population growth and to a more or lesser extent market forces.

The rationale behind this paper is based on the situation found in Mount Kenya's Upper Eawaso Ng'iro Basin, which is situated on the north western slope of Mount Kenya. During the period 1960 to 2000, the population in the basin increased by 450.000 people or with an average growth rate of 5 to 6 % per year (Ngigi et al., 2007). Mostly this is the result of immigration of people from nearby areas in search for available farmland (Gichuki et al., 2002). Water in the region is obtained either through rainfall directly on the land or through access to river water. With the incoming people, the number of extraction points have more than doubled over the last years and concerns over water scarcity have increased. Formal regulation exists in the catchment through the introduction of the Water Act in 2002. With its introduction, Water Resources Management Authorities (WRMAs) were established at the regional level and rights of local Water Resources User Associations (WRUAs) were recognised at the local level (Mumma, 2005; Dell'Angelo et al., 2014). Permits to abstract water can be issued by the WRMA's.

In practice, many people are part of community irrigation projects. This is also the case for one of the major rivers of the catchment, i.e. the Likii River, governed by the Likii Water Resource User Association (McCord et al., 2015) Water for a project is abstracted trough a single intake, after which it is subdivided among community members through a network of pipes. The water that flows towards the communities is thus proportionally to the river stage and seems fairly equal in the sense that if total water volume goes down, everyone gets less water. However, when rainfall is taken into account the situation becomes quite different. Rainfall in the area follows a gradient, with on average 850 mm of rainfall falling in the upper areas of the catchment and 700 mm of rainfall falling at the outlet. Effectively, this thus means that farming communities in the upstream area are better off compared to downstream communities, even if compliance was 100 % with respect to river water abstraction.

This paper aims to explore the situation of these communities through the adoption and adaptation of a stylized model framework developed by Kuil et al. (to be submitted). First of all, we are interested in the differences in vulnerability, related to food security, in these communities given the current situation. Secondly, we aim to provide insight in the communities development under a number of low rainfall conditions. Thirdly, by considering different adaptation strategies, i.e. different crop strategies or water allocation rules, we aim to provide insight in the adaptive capacity of agricultural, river communities in the face of climate change and population pressures. The paper is built up as follows, in the section 2 the model framework is introduced, in section 3 the case study is discussed in further detail to provide the information needed for the modelling. The results, discussion and conclusion are presented in sections 4, 5 and 6, respectively. NOTE: as this still is a draft paper and the I am in the middle of this research, the paper will focus on the model conceptualisation and the planned approach. The paper does not have actual results.

2 Model

In order to address the research question, we adopt and adapt a conceptual model formulated in Kuil et al. (to be submitted). In this model framework the dynamics of the hydrological system and the social system are explicitly linked in order to account for the continuous adaptation or co-evolution of both systems. This approach has first been proposed by Sivapalan et al. (2012) and forms also the starting point of the International Association of Hydrological Science (IAHS) Scientific Decade 2013-2022 "Panta Rhei" (Montanari et al., 2013). The stylized model framework has been constructed to conceptualize the interactions between an agriculture society with its waterscarce environment, thereby drawing from the hydrological, socio-economic and vulnerability literature.

The conceptualization of the model (as it is at the moment of writing) is presented in figure 1. We assume we can conceptualize the area in a upstream region and a downstream region, as can be seen in the left panel. The model dynamics are presented per unit area (right panel). While the original model framework in Kuil et al. (to be submitted) consists of the state variables Storage (S), Population Density (N), Vulnerability (V), Reservoir building (R) and Memory (M), the model framework used here has maintained the basic structure of the framework (S, N, V) but highlights a different adaptation mechanism, i.e. the change in crop fraction (C) representing the possibility of farmers to change their crop type as a response to variability in rainfall.

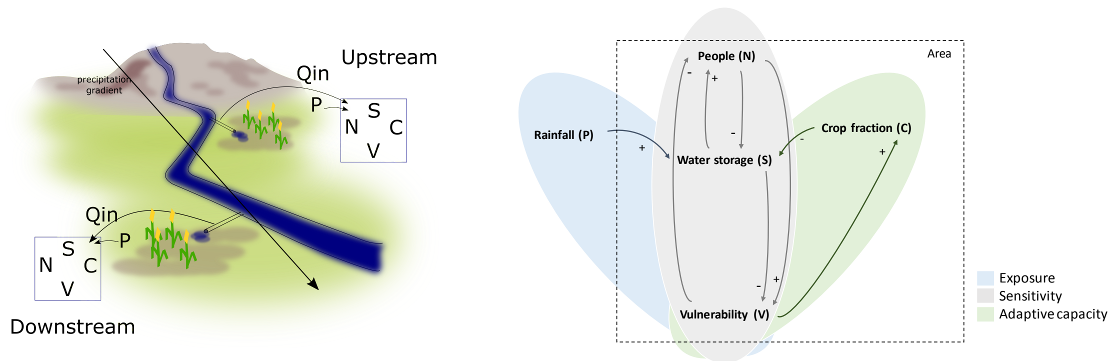

Figure 1: Model conceptualization. We divide the river in an upstream and a downstream area (left panel). Dynamics are represented per unit area for each system (right panel).

In the sections below, background to the model is provided. The exact formulation of the equations has been left out as they are still subject to change. We follow a two step approach, focusing on the crop dynamics feedback first, after which we incorporate the water sharing feedback. At the moment of writing, we are still at the first step.

2.1 Hydrology

With water storage (S), the hydrology is represented in the model. It consists of a simple water balance equation describing the in- and outflows for a unit area. The inflow consists of precipitation (P) and incoming streamflow (Qin), evapotranspiration (ET), evaporation (E) and outgoing streamflow (Qout) make up the outflows. A schematic of the processes is shown in figure 2.

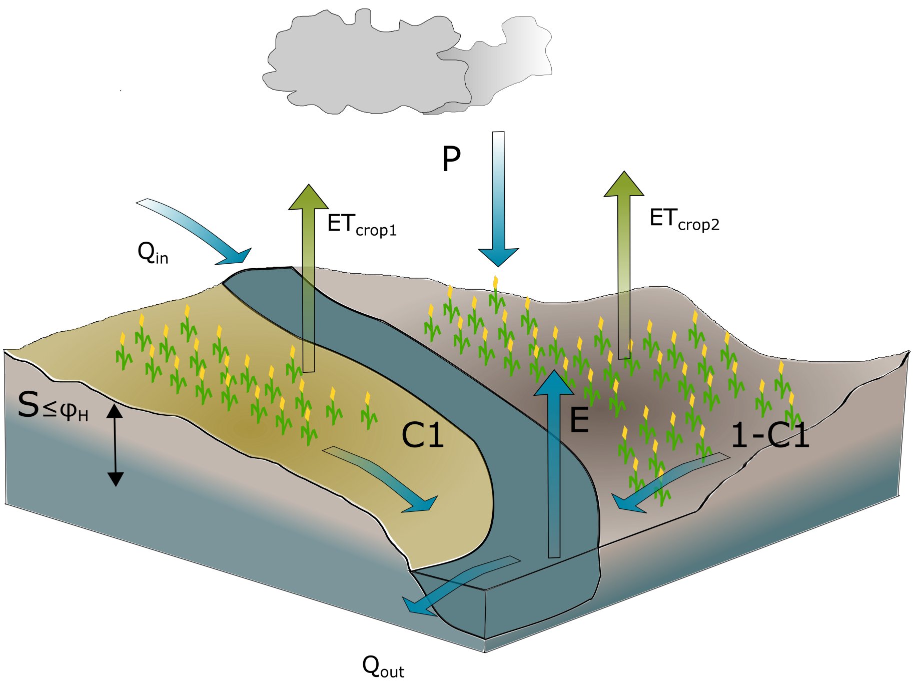

Figure 2: xx

Conceptually, the governing processes can be represented by equation 1.

$$\frac{dS}{dt} = P + Q_{in} - ET_{crop1} - ET_{crop2} - E - Q_{out} \tag{1}$$

In the equation, S is the soil moisture storage per unit area [L]. The maximum amount of water the soil can store is given by the field capacity ϕ_H [L]. It is defined here as the water content of the soil after drainage has stopped and is considered to be ideal for crop growth (FAO, 1991). In practice it is determined by soil properties and root depth. In this model, the community has two crop types to choose from and devote area C1 and C2 (= 1-C1) to their cultivation, respectively.

2.2 Population dynamics

Population density (N) represents the population dynamics within the unit area. The basic assumption is that the population is self-sufficient in terms of food supply, which implies that all resources need to come from the land and cannot be imported from outside the system. The modeled system represents therefore a subsistence, closed economy. Furthermore, the theory behind the equation is Malthusian (Malthus, 1798); the society is able to grow as long as it has enough resources and experiences a decline when the resources fall below a minimum subsistence level. In Malthus' original theory the resource base is fixed, it is important to realize that this is not the case in this framework. The principle resource, i.e. water, varies to the extent that precipitation varies. Secondly, adaptation strategies will also result in a more efficient population-resource relation, similar - but not limited to - the notion of technological change in a macroeconomic framework. The equation governing the population dynamics is the following (equation 2):

$$\frac{dN}{dt} = (b - d\,(1 + V))\,N \tag{2}$$

In equation 2, N is a population density, i.e. the number of people per unit area [persons]. b and d represent the birth and death rate, respectively. Both are a function of the food available for the community. The variable V is the measure of vulnerability [-] (see Gragnani et al. (1998) for a similar formulation to model the link between environmental pollution and population). To speak in terms of Malthus' theory, the population equation allows for both a preventing check and a positive check to occur. The preventive check occurs when society adjusts its net growth rate in response to food shortage. This is a gradual adaptation that may or may not occur timely. If the adjustment is too slow, and the population size remains above its carrying capacity too long, the society may become vulnerable (see equation **??**) leading to a positive check, which could be famine and/or emigration.

2.2.1 Food availability indicator

The food availability indicator (FA) is the ratio between the food that is produced and the food that is demanded by the society. The production or yield [L/T] is based on the FAO water production function and a function of water stress experienced by the crop (Steduto et al., 2012). The function accounts for the fact that yield response to water varies according to crop type and growth stage in which water stress occurred and is expressed as: $\left(1 - \frac{Y_a}{Y_x}\right) = K_y \left(1 - \frac{ET_a}{ET_x}\right)$, where Y_x and Y_a are the maximum and actual yields, ET_x and ET_a are the maximum and actual evapotranspiration, and K_y is a yield response factor.

2.3 Vulnerability of the community

The variable vulnerability (V) represents a measure of the state of vulnerability of the society. The IPCC definition applies, i.e. vulnerability is "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (drought). Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" page 306 of (Füssel and Klein, 2006).

The vulnerability of the community is represented by a logistic equation that depends on food availability (FA). The value of V varies between 0 and 1, where 0 represents a non vulnerable community (that can easily cope with a sudden change in precipitation) and 1 a vulnerable community (that experiences a shock, when experiencing the same drop in precipitation). At first instance, the vulnerability of the society depends on what is produced within the system, because of the assumption of self-sufficiency. However, food import through trade or aid could be accounted for by adding this to the food supply, after which vulnerability would be temporally or permanently reduced. Lastly, a society can be vulnerable to a multitude of things, including other biophysical threats or political instability. In principle, these factors could be added as additional drivers of the vulnerability equation.

2.4 Crop dynamics

Diversity in crops can be the result of the need for food diversity, as a response to market opportunists and as a consequence of local environmental conditions. For example, McCord et al. (2015) has found that for the Ng'ira basin the amount of precipitation and the size of the field are positively correlated with the observed diversification in crop types. Survey data showed that, in basis (ca. 60 %), farmers grow crops like maize, beans and potatoes as these are staple crops in their diets.

For this study, it is just as important to know in what way farmers change their crop strategy as a response to changing conditions and to rainfall variability in particular. Farmers could opt for a different crop or they could continue growing the same crop, but change variety. For example, a switch could be made to an early maturing crop (drought avoidance) or to a more drought tolerant crop (drought adaptation). Generally, trade-offs exist and genotypes adapted to one particular condition usually perform poorly when these conditions are absent (Sambatti and Caylor, 2007). Are farmers generally pro-active, experimenting with different crop types before the system is under stress or are they mainly reactive, i.e. a (big) drought is what motivates to adopt a different variety. Uncertainty is coming potentially from both changing rainfall patterns, as well as inexperience regarding the new crop. While research on mental models and farmers perceptions is ongoing within the study area (personal communication Tom Evans, Shahzeen Attari), part of this research is to test a number of plausible mechanisms or heuristics that farmers might employ to adopt a different variety. A simple example could be: droughts occur in the Ng'iro basin on average every 7 years, thus every 7 years the farmer changes to a drought tolerant variety, while the other six years he/she prefers to cultivate his/her traditional crop.

2.5 Water sharing rules

In first instance, water sharing rules will be exogenous to the model in order to explore how the system behaves under different low water conditions. As a second step, it would be interesting to explore the mechanism that leads to adaptation of the current rules.

3 The socio-hydrological system of the Ng'iro basin

3.1 Hydrology

To include information on:

- rainfall upstream and downstream
- river flows
- climate predictions

3.2 Demographics

To include info on:

- birth rate, death rate, migration rates, differences between up- and downstream areas?
- current population densities for upstream and downstream areas
- an estimate of maximum population numbers possible without food aid projects, so under normal conditions (a way to estimate this would be to look at the number of people that are allowed within a community irrigation project)
- estimation of amount of food aid

3.3 Agriculture

To include info on:

- average field size, up and down stream
- crop types
- yields
- average number of people supported by a unit area
- soil characteristics

4 Results

4.1 Model setup and approach

The idea is to gradually built up complexity. First, stylized rainfall inputs are used in order to get a sound understanding of potential model outcomes. Once we are comfortable with the model structure, the second step is to use actual rain and river data to generate results. Lastly, our aim is to perform a sensitivity analysis to check the robustness of these results.

4.2 Simulation

Several questions need to be answered by the simulations:

First, is the model able to produce plausible estimations in terms of population density, given the 'normal' rainfall years, with and without food aid? Or asked differently, given realistic parameter settings: what is the models equilibrium population density for both the upstream and downstream area given the difference in rainfall distributions for both regions?

Given a worst case drought scenario: how are population densities affected by a lower water availability? How does this relate to actual population densities? Is there enough 'surplus' in the system to ensure food security for the total population?

What is the effect of a changing crop strategy? Is it enough to overcome the loss in crops due to changing rainfall patterns? Is there a more optimal strategy of water allocation? If so, is this strategy of optimal water allocation realistic to achieve?

4.3 Expected results

Expected results are that the upstream area is able to maintain a higher population density than the lower area due to a higher amount of precipitation at the upstream areas, everything else (e.g. soil properties) being equal. A decrease in precipitation will therefore affect downstream communities more than upstream communities under its current water sharing rules. Adopting a different crop variety might mitigate yield loss due to lower rainfall, but this depends on the nature of the changing rainfall patterns, on crop characteristics, and lastly on the farmers decision making in terms of adoption rates, cultivation skills and ability to correctly estimate the onset and amount of rainfall. Whether internal food trade is able to overcome the reduction in yield is difficult to say without the actual simulations. Lastly, changing water allocation rules in favour of crop yield might give better overall results in terms of food production. If reduced rainfall results in individual water availability being too low to result in any yield (complete crop failure), maybe a (temporal) redistribution of water (and thus a change in the water rules) might be more efficient. However, whether this occurs depends on the amount of actors in the system and on the rainfall signal.

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