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Local Perceptions of Water-Energy-Food Security: Livelihood Consequences of Dam Construction in Ethiopia

Million Gebreyes [1,*,†], Davide Bazzana [2,*,†], Anna Simonetto [2], Detlef Müller-Mahn [1], Benjamin Zaitchik [3], Gianni Gilioli [2] and Belay Simane [4]

1 Institute of Geography, University of Bonn, 53115 Bonn, Germany; mueller-mahn@uni-bonn.de
2 Department of Molecular and Translational Medicine, University of Brescia, 25123 Brescia BS, Italy; anna.simonetto@unibs.it (A.S.); gianni.gilioli@unibs.it (G.G.)
3 Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD 21218, USA; zaitchik@jhu.edu
4 College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia; simaneb@yahoo.com
* Correspondence: gebreyes@uni-bonn.de (M.G.); davide.bazzana@unibs.it (D.B.)
† Million Gebreyes and Davide Bazzana contributed equally to this manuscript.

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Abstract: The concept of the water-energy-food (W-E-F) nexus has quickly ascended to become a global framing for resource management policies. Critical studies, however, are questioning its value for assessing the sustainability of local livelihoods. These critiques flow in part from the perception that the majority of influential nexus analyses begin from a large-scale, implicitly top-down perspective on resource dynamics. This can lead to efficiency narratives that reinforce existing power dynamics without adequate consideration of local priorities. Here, we present a community-scale perspective on large W-E-F oriented infrastructure. In doing so, we link the current debate on the nexus with alternative approaches to embrace questions of water distribution, political scales, and resource management. The data for this paper come from a survey of 549 households conducted around two large-scale irrigation and hydropower dams in the Upper Blue Nile basin of Ethiopia. The data analysis involved descriptive statistics, logistic analysis, and multinomial logistic analysis. The two case studies presented show that the impact of dams and the perception thereof is socially diverse. Hydropower dams and irrigation schemes tend to enhance social differences and may therefore lead to social transformation and disintegration. This becomes critical when it leads to higher vulnerability of some groups. To take these social factors/conditions into consideration, one needs to acknowledge the science-policy interface and make the nexus approach more political. The paper concludes that if the nexus approach is to live up to its promise of addressing sustainable development goals by protecting the livelihoods of vulnerable populations, it has to be applied in a manner that addresses the underlying causes that produce winners and losers in large-scale water infrastructure developments.

Keywords: water-energy-food nexus; sustainability; well-being; Ethiopia

1. Introduction

The water-energy-food (W-E-F) nexus was originally conceived by the World Economic Forum as a policy framework to meet the challenges of growing water scarcity and distributional conflicts in many parts of the world. Water is the entry point to the nexus, as structural problems of availability and distribution have been recognized as a significant global security issue, requiring urgent action to prevent economic and geopolitical crisis [1]. The W-E-F nexus paradigm emerged from the recognition that the effects of population growth, economic development, and urbanization are mutually enforcing each other [2], leading to exponential growth in demand for water, food, and energy. These emerging resource pressures are complicated further by the impacts of climate change, such as reduced rainfall reliability, increased water requirements in the agricultural sector, and increased evaporation loss from reservoirs [3,4]. Given these trends, the report states that "if water is essential for all the core drivers of economic growth, we cannot afford to have our resources fail" [5]. Consequently, it is paramount to manage scarce resources at the nexus between water, energy, and food production more efficiently. This requires the engagement of multiple stakeholders, including governments, the private sector, civil society, and local communities [6]. In its pragmatic approach, the nexus concept takes a normative stance based on the rather optimistic view that feasible solutions are at hand to improve water use efficiency for a greater common good, despite some managerial obstacles that need to be overcome [2,5]. By addressing resource use efficiency for energy and food production, the nexus thinking aims at contributing to Sustainable Development Goal 17 [7].

In empirical research, the W-E-F nexus has the potential to play a vital role as a multi-level framework for managing water use for energy and food production [8]. Nexus studies often focus on hydrological potentials for energy and food production. Their aim is to understand synergies and trade-offs in competing water uses for energy and food production. While much attention has been focused on W-E-F nexus studies at the global [9], regional [10], or national [9] scale, the framework has also been applied to yield insights at the basin/sub-basins [11,12] scale, and even at the household level [13]. This kind of analysis often results in policy prescriptions for marketing, innovation, or trade-based solutions, with increasing attention being paid to integrated resource management, climate change adaptation, and livelihood protection [6]. A combination of hydrological, land-use, and economic models is often used to understand economy-wide trade-offs and synergies in water allocation for energy and/or food production [9,11,14].

Other critical issues include the contribution of the nexus approach to achieving sustainable development, and to what extent this goal becomes part of securitizing discourses [15]. From a technical point of view, Sarkodie and Owsusu [7] questions if nexus studies properly accounted for the sustainability dimensions of renewable energy sources, such as hydropower dams. Others alluded that with technical and economic fixes being the dominant approach, possible political barriers are relegated to the level of institutional barriers that need to be tackled to ensure that the technical and economic solutions work [2]. When explicitly addressing politics, nexus thinking adopts a macro level perspective, such as transboundary and geo-political considerations. Allouche et al. [16] argue that the nexus idea tends to prioritize technical aspects and solutions, which at the same time implies that the political aspects of contested interests, power asymmetries, and conflict are silenced. This is surprising, as the nexus approach aims at being pro-poor by "improving living conditions and livelihood opportunities for the 'bottom of the pyramid'" [1] and recognizing the need to give due attention to human rights issues in water interventions [1]. The critical argument here is that the focus on technical questions leads to an insufficient concern for political and social questions, and the priority given to top-down, macro-level studies leads to a relative neglect of bottom-up and household level perspectives [13,16]. Acknowledging these controversial issues, we aim to complement the nexus approach with grassroots level perspectives [17].

Previous W-E-F studies in Ethiopia have shown the interdependence and partial competition of energy and food production [12,18]. Karlberg et al. [12] have shown that while on-going agricultural intensification requires more use of energy, the energy required by the majority of smallholder farmers comes from biomass sources rather than centralized energy infrastructure. Guta et al. [18] have argued that land allocation for energy and food production may at times be competitive, favoring one over the other, with water acting as the critical constraint. Hailemariam et al. [19] have discussed possible ways to decrease the water and energy footprints of food production, taking sugarcane production as a case study. These studies tend to take an economy-wide or sector-wide approach, with limited attention paid to the ways that different sections of society see W-E-F security issues. However, Mueller-Mahn and Gebreyes [17] have indicated the importance of understanding differences in perceptions of the local W-E-F nexus by up-stream-downstream relations, and people living in dam and non-dam areas.

This paper builds on these previous studies and examines two recently constructed dams from the perspective of their local impacts, or more specifically, from the perspective of the people directly affected by the dams. The paper addresses local perception of dam construction in Ethiopia and the impact on local livelihoods. This perspective is particularly relevant for the W-E-F nexus debate as the successful implementation of hydropower and irrigation schemes depends on it, and it has significant implications for the science-policy interface [20]. We have done this in two stages. First, we link the nexus approach to existing debates on dams and their impacts. While most of the literature on dams does not explicitly address the water-energy-food nexus, the nexus is implicit in studies of the risks created by dams constructed for energy and/or food production. Explicitly tying dam-related risks to the nexus helps not only to link the current debate on the nexus with existing debates on the water sector, but also to reveal the distributional issues surrounding nexus management. Second, we take a household-level water-energy-food security approach to show the importance of scale for the nexus debate. To address perceptions of the effects of dam construction on local livelihoods, we investigate the perceived changes at household level using three main proxy variables that are informative in respect of well-being, i.e., housing conditions, quantity of livestock per household, and amount of disposable land [21,22]. This helps us to elucidate how different types of households are affected by the newly built dams, and how negative impacts on the poor and the vulnerable are obscured in national- and global-level nexus management strategies. Hence, the research questions that the paper addresses are: How do local communities perceive the effects on their well-being of large dams constructed for hydropower and irrigation purposes? What are some of the factors that can explain perception differences among local community members affected by hydropower and irrigation dams? What insights can be derived from these differences for the water-energy-food nexus debate? In focusing on the perspective of local communities affected by W-E-F infrastructure, this paper aims to complement and counterbalance large-scale W-E-F analyses that consider resource efficiencies at the national and the global scales. While the paper uses two case studies in the Blue Nile basin of Ethiopia, the insights gained could apply beyond this specific geographic context.

2. Materials and Methods

2.1. Brief Description of the Cases

Both case studies considered in this paper come from the western highlands of Ethiopia. Ethiopia is a particularly interesting country for W-E-F nexus studies for a number of reasons. First, it is a rapidly developing economy that nevertheless continues to suffer from significant chronic and acute food insecurity. This insecurity derives, in part, from Ethiopia's significant climate variability and susceptibility to drought, along with unevenly distributed and underdeveloped water resource infrastructure. Ethiopia is also, famously, a "water tower of Africa" that has leveraged its water resources and topography for a hydropower development strategy [23,24]. The vast majority of Ethiopia's electricity is sourced from hydropower, with ongoing dam development, including, most notably, the enormous Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile River, which promises to turn the country into the most important electricity exporter in the region [25]. The joint development of water resources for both electricity and irrigation is built into Ethiopia's institutions, in the form of the Ministry of Water, Irrigation, and Energy (MoWIE), which is a rare, if not unique, example of a State ministry that addresses all pillars of the W-E-F nexus. Our study sites are also located in the Blue Nile basin, which add a transnational component to the nexus. Consumption of water in this basin, or even non-consumptive control of water for hydropower generation, have direct impacts on Blue Nile flows into Sudan, and mainstream Nile River flows to Egypt, with potentially significant implications for water, food, and energy security in those downstream countries.

In this context, our first case study is Fincha dam, located in Oromia Regional State, Abay Chomen District. The district was projected to have a total population of 31,491 in 2017 [26]. The dam is located in the Blue Nile basin, on Fincha River and its tributaries, the Amerti and Neshe. The main dam on Fincha River was built in 1973, with an additional storage dam built on Amerti River in 1987. The recent dam on Neshe River was built in 2012. The height of Fincha dam is 25 m with an initial installed capacity of 128 MW. Neshe dam's height is 38 m and it has an installed capacity of 97 MW (Hydropower & Dams in Africa 2017, International Journal on Hydropower and Dams). Without Neshe dam, the Fincha dam reservoir has a capacity of 650 million m^3 with an area of 345 km^2. The dam is part of a multi-purpose project, with a sugar plantation on 19,000 ha of land downstream of the dam (Ethiopia Sugar Corporation, http://ethiopiansugar.com/index.php/en/factories/finchaa-sugar-factory). Although it is hard to find definitive data, the number of households displaced because of the dams in the area is estimated to be 3115 for Fincha dam [27] and 1200 for Neshe dam (Focus Group Discussion (FGD) with local communities, 3 September 2017).

The second case study, Koga dam, is located in Amhara Regional State, Mecha District. The district has a total population of 350,757 according to the CSA [26]. The dam was completed in 2010 and has a height of 20 m, with a reservoir capacity of 83.1 million m^3, and a reservoir area of 175 km^2. The dam is exclusively for irrigation, with a command area of 7200 ha. A total of 602 households had to be displaced due to the dam, and the total number of farmers who lost their land due to the dam and the irrigation infrastructure area is around 5000 [28]. The dam was funded by the Africa Development Bank.

2.2. Source and Survey Design

The data for this paper came from a survey conducted in two study areas within the Upper Blue Nile basin of Ethiopia. The first survey was conducted in February 2018 at the Koga irrigation site, Amhara Region, and the second in May 2018, at the Fincha hydropower site, in Oromia Region (Figure 1). The study looks at how the construction of large-scale water infrastructures, such as hydro-power and irrigation dams, impacts the livelihood resources of local communities, and how this translates into water, energy, and food insecurities (Figure 2) Note that while this study focused on impact chains, there is also a feedback chain (Figure 2, the dotted lines), with perceptions of livelihoods and water-energy-food securities that can have an impact all the way up to the construction and management of large-scale water infrastructures. The survey questions were designed in two parts to capture basic information on households, such as household demography and water, energy, and food consumption. The variables included in the survey were adapted from the Living Standard Measurement Study [29] and the Energy Policy Multi-topic Household Survey [30]. The first part began with making a record of household members' age, marital status, educational level, and whether a particular household member contributes economically to the household or not. Data were also collected on housing conditions and changes in these conditions over the past 10 years. To capture livelihoods, households were asked about their main sources of income. Since agriculture is the main livelihood strategy, data were collected on livestock and land holding. Land holdings were divided into plots, and respondents were asked about each plot, its property rights, and crops grown during the previous production season, whether rain fed or, where applicable, using irrigation. In the second section, water, food, and energy related questions were asked. The food questions included an estimate of the food consumption of a household for 7 days, and incidences of food shortage over the past 7 days, and the past year, at the time of the survey. The water questions included water sources for home and irrigation purposes, the daily quantity of water used and means of accessing water. The energy data included energy sources for various purposes, the estimated quantity of energy required, and the cost of accessing different energy sources. After this, the respondents were asked about perceived changes over time with regard to housing, land, food, water and energy access, and perceived reasons for any reported changes. Finally, questions were asked in both study areas about the perceived positive and negative impacts of the dams and associated irrigation and hydropower infrastructure. The data were collected using semi-structured interviews. While some of the questions were open-ended, others were multiple-choice questions. The questions were pretested with 20 respondents in the Koga irrigation scheme. The final data were collected with five trained enumerators using tablets and SurveyCTO, a digital data collection platform (see https://www.surveycto.com/).

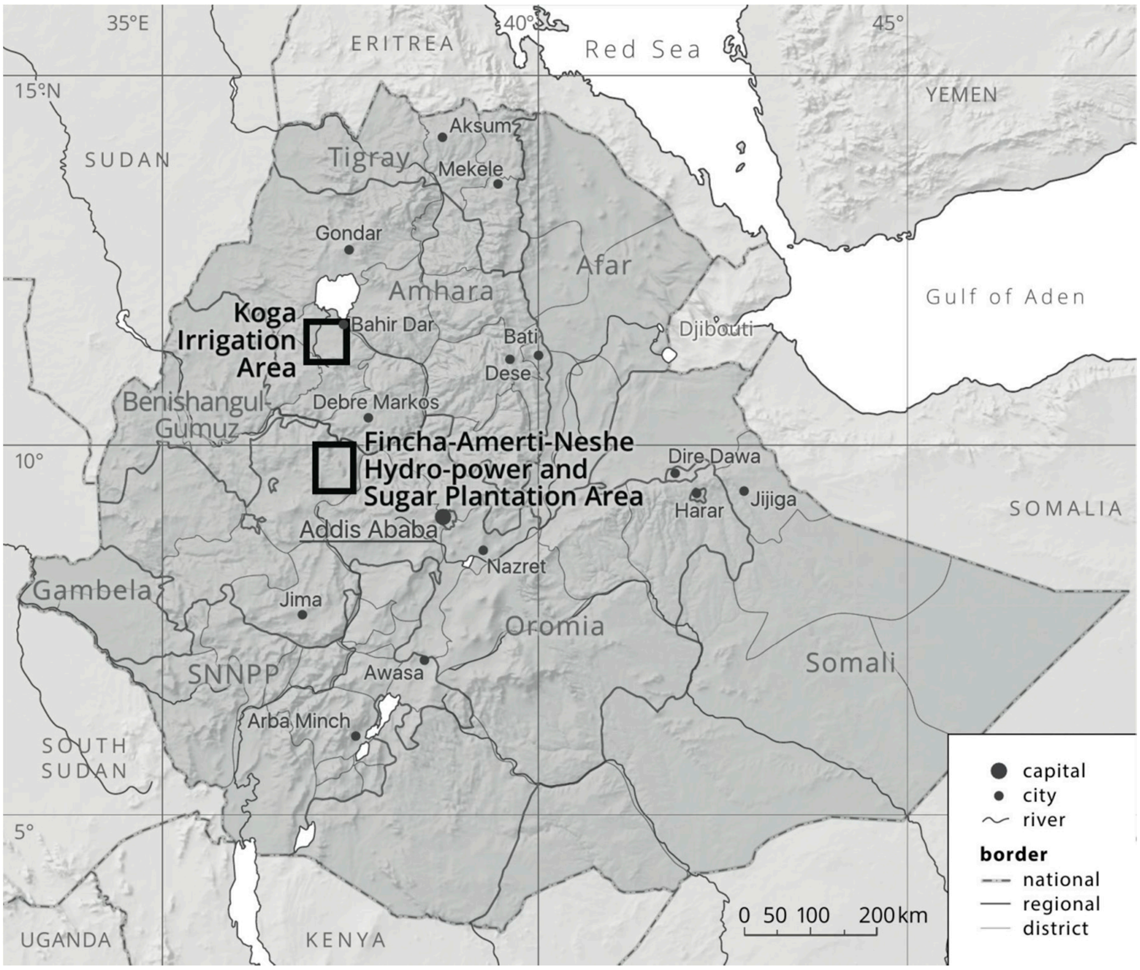

Figure 1. Location of sample sites.

The sampling strategy for the two sites involved two stages. In both cases, the purpose of conducting the study was to understand the perceived impact of the dam and the irrigation scheme on households' well-being. Hence, the samples were drawn from the dam and irrigation areas. In the case of the Koga irrigation scheme, the dam area is under one village administration. The village had a total population of 1654 households, residing in five sub-villages, and households impacted by the dam are predominantly in three of the sub-villages. One sub-village was selected randomly for further sampling. Within the selected sub-village, a sampling frame with a total of 550 households was taken from the village administration office and sample respondents were selected using a systematic random sampling technique, with a total of 101 sample households selected, distributed proportionally to the size of the population in the three sub-villages. For the irrigation site, the sampling population was taken from irrigation blocks established in the irrigation scheme. The irrigation scheme involves 12 irrigation blocks, with close to 10,000 irrigation users' households, each block getting water from secondary canals. To make sure that we captured variations in access to water, we randomly selected two blocks from the upper end of the primary canal, two in the middle, and two at the lower end. Out of a total of 682 households, sample respondents were then selected using a systematic random sampling technique, with 150 respondents selected proportionally to the size of the six irrigation blocks.

In the Fincha case, local livelihoods are affected by three combined dams and the associated sugar plantation. The three dams are spread over various districts in the Horo-Guduru Wollega Zone. We chose the Abay Chomen district for sampling, as this is a district affected by all three dams, the sugar plantation, the sugar factory, and the hydropower plant. This was to help us understand the impacts of various components of the hydro-development in the area, as most of the villages in this district have experienced one or more impacts related to the dams. In the second stage, we asked local experts in the districts to help us identify villages that they perceived as being highly impacted by the three dams, and villages that they perceived as being minimally impacted. Two villages, namely Homa Kulkula, with a total population of 1392 households, and Sendabo, with a total population of 2628 households, were identified as being highly impacted by Neshe dam. Jere, with a total population of 2416, Genji, with a total population of 3128 households, and Homi, with a total population of 864 households, were identified as being highly impacted by the Amerti and Fincha dams. Dino, with a total population of 1147 households, and Ashaya Egu, with a total population of 1078 households, were identified as being less affected. In each of the villages, the sampling frame used was the list of village residents found in village administration offices. Proportional to size, a systematic sampling technique was used to identify and select 229 sample respondents. In addition, a non-affected village was selected purposely, and a total of 70 respondents were selected using a systematic sampling technique.

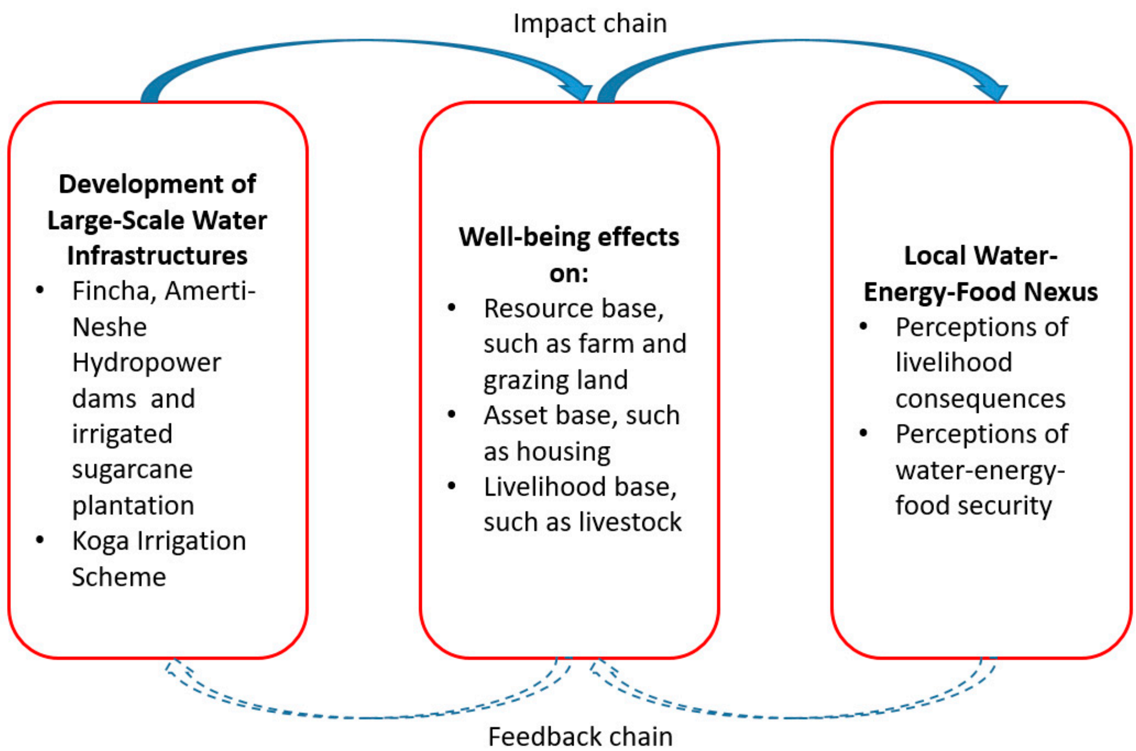

Figure 2. Simplified conceptual framework of the study.

2.3. Data Analysis

We investigated perception of the effects that dam construction has had on the well-being of the rural population through two discrete choice analyses: logistic and multinomial logistic models (Cameron and Trivedi, 2005; Cassy et al., 2016). Logistic regression is used to model the probability of the dichotomous dependent variable Y (distributed as Bernoulli random variable with probability p) to be equal to the reference modality (usually indicated as 1). Logistic regression is based on the logistic function to describe the relationship between k continuous or discrete explanatory variables X_i

(e.g., village) and Y (e.g., access to irrigation: yes/no). Therefore, in the logistic model, the probability to assume the reference modality of the dependent variable, conditioned to the explanatory variables is

$$Y \sim Be(p)$$

$$Pr(X_1, \ldots, X_k) = \frac{exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k)}{1 + exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k)} = p. \quad (1)$$

When the response variable is categorical but it can assume m $(m > 2)$ categories (e.g., current condition after construction of the dam compared to the condition prior to construction of the dam: better, same, worse), a multinomial logistic regression model (mlogit) is applied. Mlogit is a generalization of the logistic model. Let p be the vector of the probabilities of the multinomial response variable Y, i.e., $p = \left[p^1, \ldots, p^m\right]$, where $p^1 = Pr(Y = 1)$ so we have:

$$Y \sim Multinom(p)$$

$$p = \frac{\exp(\eta^l)}{\sum_{r=1}^{m} \exp(\eta^r)}, \quad l = 1, \ldots, m \quad (2)$$

$$\eta^l = \beta_0^l + \sum_{j=1}^{k} x_j \beta_j^l, \quad l = 1, \ldots, m \quad (3)$$

Logistic and multinomial logistic analyses were performed considering the two regions (Koga and Fincha) separately in order to make reasonable comparison within villages in the same area. In the case of Koga we compare the results from dam and irrigation sites, and in the case of Fincha we investigate the dissimilarities between dam and control sites.

3. Results and Discussion

3.1. Characteristics of Survey Respondents

The survey was conducted on a sample of 550 households, 45.64% of the respondents were in the Koga region and 54.36% in the Fincha region. The 36.7% of the respondents had access to irrigation. Details of respondents' distributions are reported in Table 1. The socio-demographic characteristics of the respondents are shown in Table 2, as well as their declared sources of income.

Table 1. Regional distribution and irrigation access of survey respondents.

Region	Village Site	Total Households Selected	Access to Irrigation	
			Absolute	% (on Total Households)
Koga	Dam	101	21	20.79%
	Irrigation	150	145	96.67%
Fincha	Control	70	13	18.57%
	Dam	229	23	10.04%
	Total	**550**	**202**	**36.73%**

Table 2. Socio-demographic characteristics and income sources of respondents.

Question	Answer	Koga Dam	Koga Irrigation	Fincha Control	Fincha Dam
Role in the household	Household head (hh)	98.02%	98.67%	88.57%	89.52%
	Spouse of the hh	0.00%	0.00%	11.43%	10.04%
	Child of the hh	1.98%	1.33%	0.00%	0.44%
Gender	Male	87.13%	90.00%	75.71%	76.86%
	Female	12.87%	10.00%	24.29%	23.14%
Education	Under age	0.00%	0.00%	1.43%	0.00%
	None	66.34%	59.33%	45.71%	32.31%
	Basic education	20.79%	25.33%	14.29%	20.96%
	First cycle school (1–4)	6.93%	6.67%	14.29%	16.16%
	Second cycle school (5–8)	4.95%	6.67%	15.71%	19.65%
	Secondary school (9–10)	0.99%	2.00%	5.71%	7.42%
	Preparatory school (11–12)	0.00%	0.00%	1.43%	1.75%
	College education	0.00%	0.00%	1.43%	1.75%
Income Source *	Agriculture	92.08%	100.00%	100.00%	89.08%
	Mining	0.00%	0.00%	0.00%	0.00%
	Charcoal making	11.88%	3.33%	0.00%	0.00%
	Transport service provision	6.93%	5.33%	0.00%	0.44%
	Agricultural laborer	19.80%	8.67%	0.00%	0.00%
	Selling traditional drinks	3.96%	3.33%	0.00%	1.31%
	Private trade	5.94%	6.67%	0.00%	0.44%
	Carpentry	3.96%	1.33%	0.00%	0.44%
	Wavering	0.99%	0.00%	0.00%	0.00%
	Other income sources	6.93%	4.00%	1.43%	3.49%

* Respondents could declare multiple sources of income.

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Assessments of the Consequences of the Dam for Local Livelihoods: Impact on Housing Conditions

Table 3 shows how housing conditions have changed compared to 10 years ago. The results show that housing conditions are at least equal to 10 years ago for 98.29% and 59.39% of the households in Koga and Fincha, respectively. Analyzing the survey data with a multinomial logit we observe that living in a village directly affected by the Fincha dam site is associated with a reduction of 1.43 in the log odds ratio for having a better housing condition now, compared to the control villages. Moreover, residents near Fincha dam register an increase in the log odds ratio for having a worse housing condition than 10 years ago (p value < 0.05). By contrast, from the multinomial analysis, we find that there is no significant difference in housing condition changes between people living in Koga dam and Koga irrigation sites.

Table 3. Pooled results distribution, multinomial logistic analysis of changes in housing conditions.

Region	Village Site	Better	Same	Worse
Koga	Dam	56	8	2
	Irrigation	89	19	1
Fincha	Control	55	7	5
	Dam	73	39	114
Mlogit Analysis				
Region	**Variable**	**Coefficient**		**p-Value**
Fincha dam	Better	−1.4345 ***		0.0013
	Worse	1.4091 **		0.0218

** Significant at 5 percent probability level. *** Significant at 1 percent probability level.

As shown in Figure 3, households mainly explain their improved housing conditions as a result of better access to irrigation (in Koga irrigation site), an increase in eucalyptus revenues (in Koga area), and improvement in agricultural technologies (in all four sites). However, applying a logit analysis to the data (see Table A1), we observe a higher probability that households in the Koga irrigation sites will explain their better housing conditions by access to irrigation than respondents living in the dam sites. On the contrary, households living in the Koga dam area explain their better housing condition as a consequence of additional income sources, more frequently than households living in the irrigation sites.

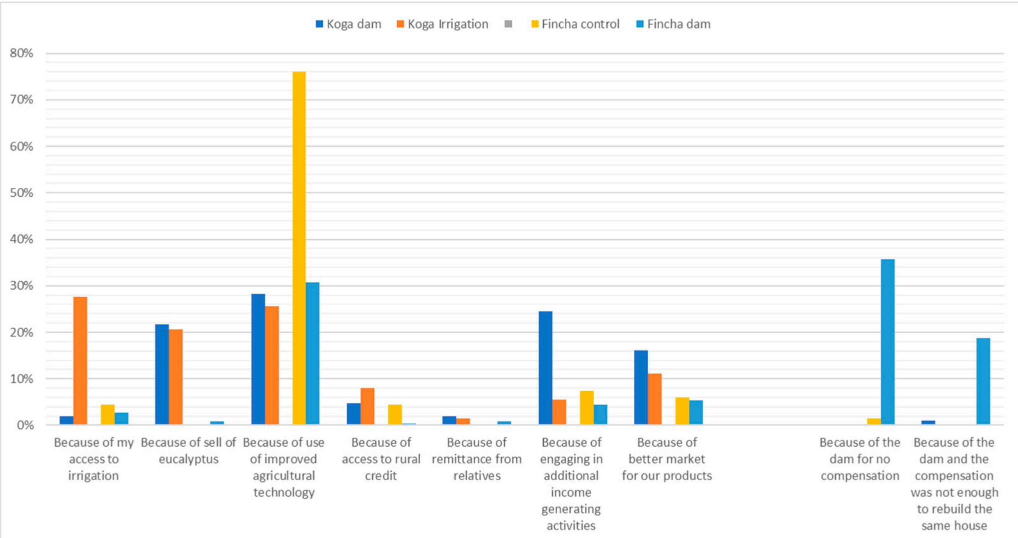

Figure 3. Distribution of answers to a question about "reasons for change in housing condition", positive change: first seven subplots, negative change: last two subplots.

Moreover, only households at Fincha dam attribute the deterioration of their housing condition to the loss of their original house because of the dam, without receiving any compensation, or not having enough resources to rebuild the same house.

The results suggest that while the Fincha hydropower dams have had serious negative consequences for the housing conditions of local communities, the Koga irrigation dam has been less detrimental for the local community. The latter can be explained by two factors. First, the irrigation scheme was built to be used by the local communities. Hence, while the scheme had a distributional justice issue in terms of creating inequality between those who lived in the dam area and those who lived in the irrigation channel area, overall it improved the well-being of the local people. Second, even in the dam area, improvements in housing conditions and household well-being in general can be explained by the increase in alternative on-farm income from eucalyptus plantations, which have been expanding at an alarming rate, replacing food crop production. Such alternative income sources were not available in the Fincha dam area.

3.2. Assessment of the Consequences of the Dam for Local Livelihoods: Livestock Dynamics

Looking at the quantity of livestock kept, most of the respondents at the four sites report a reduction in herd size compared to the situation ten years ago. In the Koga sites, the level of livestock ownership has fallen by 67.02% and 57.34% in the dam and irrigation sites, respectively. In the Fincha sites, these percentages are 55.22% (control villages) and 85.71% (dam areas). In the Koga irrigation scheme, households state less frequently than in the Koga dam sites that they hold less livestock due to a reduction of grazing land because of the dam. Instead, people affected by the Koga irrigation scheme attribute the loss of grazing land to infrastructure developments (e.g., irrigation canals) more often than people living in the dam site. These differences are strongly significant (p value < 0.001). The significant difference in these two possible answers also emerges when comparing the Fincha dam with its reference cohort. In this case, the logit model produces results opposite in sign: in the dam (control) area, households say less frequently that the reason for their livestock loss is the dam infrastructure development (Table 4).

Table 4. Reasons for reduction in herd size.

Logit Analysis			
Region	**Variable**	**Coefficient**	***p* Value**
Koga irrigation scheme	Grazing land loss because of the dam	−3.348 ***	<0.001
	Grazing land loss due to infrastructure development	1.4214 ***	<0.001
Fincha dam	Grazing land loss because of the dam	6.596 ***	<0.001
	Grazing land loss due to infrastructure development	−1.19 ***	<0.001

*** Significant at 1 percent probability level.

3.3. Assessment of the Consequences of the Dam for Local Livelihoods: Impact on Available Agricultural Land

We obtain comparable results if we analyze changes in the size of farmlands. Looking at Koga villages, the proportion of respondents reporting farmland losses is 63.95% and 62.24% in the dam and irrigation scheme sites respectively. In the Fincha dam site, 77.42% of respondents report a reduction in landholding against 23.81% in the control villages. Thus, in the Fincha area, being located close to the dam has a strongly negative impact on landholdings. Respondents living in dam sites have a higher probability of suffering a reduction in land than the control sample, with a significance level of 0.01.

The main causes of landholding reduction in the four sites are dispossession due to the dam (with and without replacement) and bequeathing land to children. However, as shown by Table 5, only the Fincha sites exhibit strong location-specific differences. Indeed, residents in dam sites explain the negative change in landholding as being due to a top-down decision (e.g., government decisions in respect of dam construction) with a much higher probability than comparable households in the control villages (p value < 0.001). On the contrary, the probability of connecting land reduction to voluntary decisions (i.e., giving land to one's children) is half (0.47) that for respondents living in the Fincha control site.

Table 5. Reasons for reduction in landholding.

Logit Analysis			
Region	**Variable**	**Coefficient**	***p* Value**
Fincha dam	Because of top-down decisions	4.934 ***	<0.001
	Because of voluntary decision	−0.7587 **	0.0395

** Significant at 5 percent probability level. *** Significant at 1 percent probability level.

These results explain the differential effects of the dam on local livelihoods. Although community members in both the dam and the irrigation areas of Koga reduced their herd size, for those in the irrigation area, the loss was offset by access to irrigation, while those in the dam area remain with a net loss. The effects in the Fincha dam area are even worse. The difference in herd size between the dam area and the control area is significant, suggesting that one of the most negatively felt side effects of dam construction is the loss of communal grazing land. These results add to the perception of land loss in general, with those in dam areas reporting a significant land loss without adequate compensation or replacement. These two aspects, reduction of livestock ownership and land size, have had grave consequences on food security in local communities. Finally, we investigate perceptions of the impact of the dam by analyzing the answers to a direct question. As expected, 97.14% of respondents living in Fincha control sites are not negatively affected by the dam. In the Fincha dam area, on the other hand, the percentage of households that do not suffer direct consequences from these infrastructures is very low (3.06% of the sample population). For households in Koga sites, even if the imbalance in negative impacts is not as extreme as in the Fincha sites, location also affects the way the impact of the dam is perceived. Indeed, 19.80% of respondents in the Koga dam site speak of negative impacts, whereas this share increases to 42.67% for households in the irrigation scheme area. The figure is higher for respondents living in the irrigation scheme area, since almost all of them had to give up 20% of their original land, for channel construction, and as compensation for those relocated from the dam area. However, as shown in Table 6, households in the Koga irrigation site have a much lower probability of reporting negative impacts due to: (1) decisions imposed by the authorities, i.e., relocation to less productive land; (2) deterioration of economic conditions; (3) reduction in access to common pool resources; and (4) losses in respect of social capital, i.e., health problems, home status, or social relations. The same negative impacts on living conditions emerge in the Fincha dam sites. Moreover, these sites exhibit a higher probability than the control villages of being negatively impacted because of land dispossession without replacement (p value < 0.001).

Table 6. Negative impact. Pooled results distribution (percentage), logistic analysis.

Region	Village Site	Direct Land Dispossession	Top-Down Decisions	Worse Economic Conditions	Less Common Pool Resources	Deterioration of Social Capital
Koga	Dam	49.51%	38.61%	63.37%	76.24%	33.66%
	Irrigation	44%	16.67%	22%	38.67%	4.67%
Fincha	Control	1.43%	1.43%	4.29%	2.86%	4.29%
	Dam	70.74%	9.61%	96.07%	93.89%	91.70%
Logit Analysis						
Region	**Variable**	**Coefficient**		**pValue**		
Koga Irrigation	Top-down decision	−1.1459 ***		<0.001		
	Worse economic conditions	−1.8136 ***		<0.001		
	Less common pool resources	−1.6271 ***		<0.001		
	Deterioration of social capital	−2.3386 ***		<0.001		
Fincha dam	Direct land dispossession	5.117 ***		<0.001		
	Top-down decision	1.992 ***		0.0534		
	Worse economic conditions	6.3025 ***		<0.001		
	Less common pool resources	6.2579 ***		<0.001		
	Deterioration of social capital	5.5087 ***		<0.001		

*** Significant at 1 percent probability level.

Thus, in the Fincha dam site, most households say that they do not receive any benefit from the dam (86.03%). Those respondents who mention some improvement in their living conditions mainly attribute this benefit to better road access (15.93%) and social capital enhancement (4.20%). Households from Fincha control villages seem to benefit from social capital improvement (36.36%) more than from road access (25%). This suggests that being located near the dam site has a negative effect on both improved road access and living conditions in general (see Table A2).

3.4. Water-Energy-Food Dimension

This section expands the study by presenting an analysis of data concerning the living conditions of the rural households, focusing on their access to water-energy-food resources.

Location does not have any statistically significant effect on the quality or stability of the drinking water supply, which is mainly from private and communal taps. The majority of respondents have not experienced interruptions or breakdowns in the drinking water supply in the last six months. However, when these interruptions happen, they differ in intensity depending on the particular site. For example, the average number of days of interruption in the Koga dam area is 1.9 (with standard deviation equal to 8.2), whereas in the irrigation scheme area, breakdowns last, on average, for 7.2 days (standard deviation, 20). This heterogeneity in the quality of the service can also be observed when comparing the two Fincha sites. In control villages, the drinking water supply is interrupted on average for less than one day (standard deviation, 3.6). By contrast, the dam sites exhibit interruptions in the water supply, which, on average, last more than four days (4.5, with standard deviation equal to 17).

This strong variance in the stability of the drinking water service is coupled with differences in access to irrigation (see Table 7). For this variable, living in the Koga irrigation site has a statistically significant positive effect (p value < 0.001) for households. However, almost 97% of respondents who are residents in this area have access to irrigation, whereas this percentage drops to 21% in the dam site. By contrast, the probability of having access to irrigation is statistically lower for households living near Fincha dam than for residents in the control villages, with the percentage figures for access being 10% and 19% respectively. While those in the Fincha dam area appear to have better access to irrigation compared to those in the control area, in absolute terms this is not much to celebrate, as those in the dam area could have a higher access rate if it was not for the restricted use of the dam water for private irrigation.

Table 7. Logit results in respect of access to irrigation.

Logit Analysis			
Region	**Variable**	**Coefficient**	***p* Value**
Koga irrigation	Access to irrigation	−4.7048 ***	<0.001
Fincha dam	Access to irrigation	0.7143 *	0.0587

* Significant at 10 percent probability level. *** Significant at 1 percent probability level.

Table 8 shows the impact that location has on both access to electricity and the sources of this electric power. In the Koga area, there is no difference in access to electric energy between the two sites. However, it is interesting that electricity from the central grid is used as an energy source much less in the Koga irrigation area than in the dam sites. On the contrary, the odds ratio for the other energy sources (electric generator, solar, and biogas) between irrigation and dam sites is 13.46. Looking at the other two sites, households living in the dam site report having a much higher probability of access to electric energy (p value < 0.001) than the control villages. However, the odds ratio between Fincha dam and control villages, that the source of energy will be hydropower, is 0.27, whereas living in the dam area has a positive effect on the probability of using other energy sources (four times greater). This result is more interesting for the Fincha dam area. Households have lost their land and their livelihoods due to a dam, which was to generate hydropower energy for the nation. However, the results show that those people affected by the hydropower dam do not have better access to the electricity generated.

Table 8. Logit results in respect of access to electricity and its different sources.

Logit Analysis			
Region	**Variable**	**Coefficient**	***p* Value**
Koga Irrigation	Dam-generated	−3.161 ***	0.002
	From other sources	2.6061 **	0.0149
Fincha dam	Access to electric energy	1.1982 ***	<0.001
	Dam-generated	−1.3159 ***	<0.001
	From other sources	1.3994 ***	<0.001

** Significant at 5 percent probability level. *** Significant at 1 percent probability level.

Analyzing the type of fuel used in the households, it seems that there is no great difference between the comparable samples (see Figure 4). For example, households living in the Koga dam and irrigation sites report that crop residues represent 37.45% and 35.66% of their fuel sources, respectively. Firewood has equivalent frequencies, 37.07% for the sample living near the dam, and 36.41% for residents in the irrigation site. In Fincha area, the main types of fuel used are firewood (64.22% in control villages and 75.08% in dam sites) and charcoal (31.19% in control villages and 20.98% in dam sites).

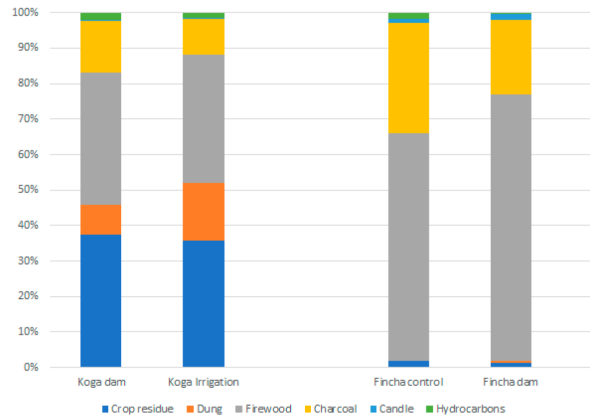

Figure 4. Main types of fuel used in the last 30 days.

Finally, we analyze food security aspects by addressing two dimensions: factors limiting access to an adequate supply of food, and the variety of foodstuff consumed. According to the survey data, only a minority of households living in the Koga area and in the Fincha control villages did not have enough food in the last year. In Koga, the share of respondents who had enough food to feed their family during the last year is 76% and 85% in the dam site and the irrigation site respectively, and this figure is 61% in the control villages located in the Fincha area. Households located in the Fincha dam site exhibit a higher level of food insecurity, with more than 78% of the survey population facing a shortage of food in the last 12 months. In more than 45% of the cases, this problem lasted for at least three months (see Table A3), but there are households that endure food insecurity throughout the entire year (8%). Applying the Student test, we can say that (1) there is no statistical difference in the average between households living in the Koga sites, but (2) we can strongly reject the null hypothesis of equality between the averages in the duration of food insecurity in the two Fincha sites (p value < 0.001).

Moreover, interestingly, it seems that there are significant differences in diet variety between residents in the two Fincha sites (see Figure 5). Respondents living near the Fincha dam consume less animal products (−7%) than their reference cohort, compensating their diet with higher shares of cereals and vegetables (+3% for both food commodities). There was no significant difference in diet variety between the irrigation and dam sites at Koga (Figure 5). The results show that the effects of the dams on food insecurity are higher in the Fincha area as compared to the Koga area.

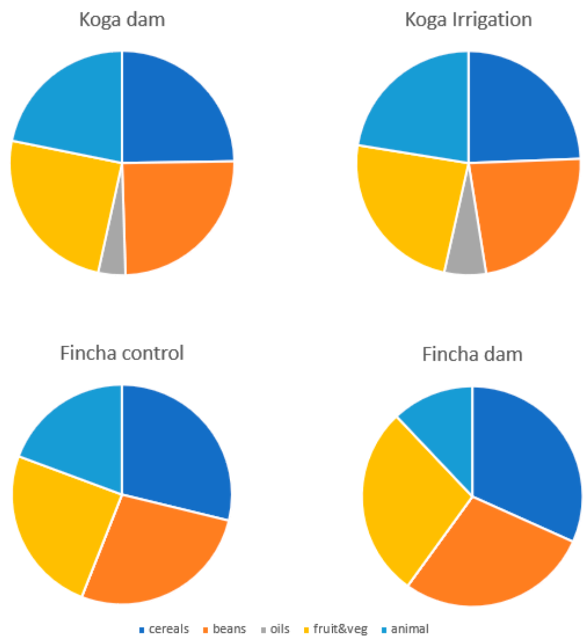

Figure 5. Diet variety in the last two months.

4. Conclusions

This study was designed to offer a local nexus perspective on infrastructure projects that are more commonly framed from a top-down nexus development perspective. We have done this in two ways. First, we have linked the nexus with existing debates on the impacts of large-scale water infrastructures on local livelihoods. This reveals the importance of considering issues beyond the trio water-energy-food. Where top-down nexus framing can lead to an exclusive focus on W-E-F resources, and, indeed, these may be the resources that are most relevant from a national development perspective, the local nexus analysis shows that there are other issues, such as housing conditions, land, and alternative livelihood options. Our survey results show that while people in the Fincha hydropower dam area perceive serious negative consequences for their housing conditions, those in the Koga irrigation dam area perceive lesser impacts. The fact that the irrigation scheme at Koga was designed to be used by smallholder farmers, and the availability of alternative on-farm income for those who have lost their land because of the irrigation infrastructure, appear to influence perceptions of the effects of the dams in the two study areas. Similar observations can be made in respect of people's perception of the effects of the dams on their assets, especially their livestock. In both case studies, livestock ownership dwindled because of the water infrastructures. In the case of the Koga irrigation scheme, those living in the dam areas experienced a net loss, while those in the irrigation area were able to offset their income loss due to loss of livestock by the benefits arising from access to irrigation. In the case of the Fincha hydropower site, the difference in herd sizes between the dam site and the control site was significant. The perception of loss of land, both communal grazing land and farm land, reveals a similar trend. The Koga irrigation scheme still appears to be a case of distributional injustice between those local communities who benefit from the irrigation scheme and those who lost their land due to the dam construction. While people in the dam construction site and people in the irrigation site lost both communal grazing lands and private farmlands, the latter were able to offset the negative effects through their access to irrigation water. The former lost significant amounts of land. However, alternative on-farm activities, such as eucalyptus production, saved them from the worst consequences. In the case of Fincha dam, the loss of both communal grazing land and private farm land left local communities near the dams in a worse economic condition compared to their counterparts in the control site. These perceptions of the effects of the water infrastructures on the well-being of the local communities can also be translated into household-level water-energy-food dynamics. The most striking observation is that, despite the generation of electricity by the Fincha hydropower plant, and the availability of dam water for irrigation, the local people perceive minimal access to both electric power and irrigation. The food insecurity situation is also more pronounced in the Fincha hydropower area than in the Koga irrigation scheme area.

Second, our focus on assessing the nexus at household level revealed the concerns of local communities whose views and concerns are obscured in national- and global-level debates. Large-scale water infrastructures are characterized by uneven distribution of costs and benefits. This can be local (as between those living in the irrigation area, and those living in the dam area, in the case of the Koga irrigation scheme) or multi-scalar (as in the case of energy production for the national economy versus energy access at local level, in the case of the Fincha dam).

The two case studies presented indicate that the impact of dams and the perception of this impact is socially diverse. Hydropower dams and irrigation schemes tend to enhance social differences and may therefore lead to social transformation and disintegration. This becomes critical when it leads to higher vulnerability of some groups. To take these social factors/conditions into consideration, one needs to acknowledge the science-policy interface and make the nexus approach more political [20]. Hence, future nexus studies need to go beyond optimization models to better understand whose water-energy-food security is enhanced and whose is undermined by water infrastructure developments. If the nexus approach has to live up to its commitment of addressing sustainable development goals through protection of livelihoods for those at the bottom, it has to commit itself to addressing the underlying causes that produce winners and losers in large-scale water infrastructure developments.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Reasons for better housing conditions.

Logit Analysis			
Region	**Variable**	**Coefficient**	***p*-Value**
Koga irrigation	Access to irrigation	3.777 ***	<0.001
	Sale of eucalyptus	0.203	0.555
	Improved agricultural technologies	0.1511	0.660
	Access to rural credit	0.8045	0.139
	Remittance from relatives	−0.0599	0.949
	Additional income activities	−1.8157 ***	<0.001
	External support (NGO, Government)	NA	NA
	Better market conditions	−0.2833	0.457

Table A1. *Cont.*

Logit Analysis			
Region	**Variable**	**Coefficient**	***p*-Value**
Fincha dam	Access to irrigation	0.4397	0.547
	Sale of eucalyptus	18	0.996
	Improved agricultural technologies	0.3023	0.679
	Access to rural credit	−1.4240	0.223
	Remittance from relatives	18	0.996
	Additional income activities	0.4620	0.425
	External support (NGO, Government)	NA	NA
	Better market conditions	0.9196	0.13

*** Significant at 1 percent probability level. NA means "not available".

Table A2. Positive impact. Pooled results distribution (percentage), logistic analysis. The social capital variable considers improvements in education and health facilities, housing, access to energy and sugar, and general living conditions.

MLogit Analysis			
Region	**Variable**	**Coefficient**	***p*-Value**
Fincha dam	Social capital	−3.3742 ***	<0.001
	Better road access	−0.2929	0.402
	Access to alternative income	NA	NA
	Improvement in livestock feed	NA	NA
	No positive impact	2.1637 *	0.0534

* Significant at 10 percent probability level. *** Significant at 1 percent probability level. NA means "not available".

Table A3. Number of months in the last year in which households experienced food insecurity.

Region	**Village Site**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Koga	Dam	5	9	5	2	1	1	0	0	0	0	0	1
	Irrigation	6	10	4	1	1	0	0	0	0	0	0	0
Fincha	Control	4	3	18	2	0	0	0	0	0	0	0	0
	Dam	7	35	81	25	6	5	1	2	2	0	1	14

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