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The Land–Water–Food Nexus: Expanding the Social–Ecological System Framework to Link Land and Water Governance

Frederike Klümper * and Insa Theesfeld

Institute of Agricultural and Food Sciences, Martin-Luther-University Halle-Wittenberg, 06120 Halle (Saale), Germany; insa.theesfeld@landw.uni-halle.de

* Correspondence: frederike.kluemper@gmail.com

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Abstract: To date, the land–water–food nexus has been primarily addressed from an ecological, hydrological or agronomic angle, with limited response to the governance interface between the input resources. Likewise, in widely used heuristic frameworks, such as the social–ecological system (SES) framework, governance interactions between resources are not sufficiently addressed. We address this gap empirically, using the case of Tajikistan, based on a farm household survey analysis of 306 farmers. The results indicate that land system variables contribute to the willingness to cooperate in irrigation management. Specifically, formal land tenure has a positive effect on farmers paying for water as well as on the likelihood of their investing time and effort in irrigation infrastructure, which is decisive for Tajikistan's food and fiber production. Irrigation system variables show that, e.g., being an upstream user increases the likelihood to contribute to labor maintenance efforts. We further discuss how decisions with respect to the land sector could be designed in the future to facilitate cooperation in other resource sectors. Further, we conclude from a conceptual perspective that the SES framework integrating a nexus perspective can be adapted: either (1) by adding a second-tier "governance nexus" variable inside the governance variable of an irrigation system; or (2) by adding a land resource unit and system outside the irrigation system.

Keywords: land–water–food nexus; social–ecological system; governance linkages; land tenure; irrigation; Tajikistan

1. Introduction

Two trends are often discussed in the debate about the dynamics of resource use and development: (1) increased water scarcity; and (2) land rush for the best soils. In contrast to many studies that explore coupled human and natural systems focusing on effects of one human system on a natural system and vice versa [1], feedbacks involving two natural systems are not sufficiently discussed under a joint framework. To increase resource efficiency, an integrated approach between two natural systems is needed. One example for a recently developing approach is the water–energy–land–food (WELF) nexus [2]. The Stockholm Environment Institute [3] defines the nexus approach as a "systemic thinking and a quest for integrated solutions to guide decision-making about resource use and development".

Some exceptions, where two natural resource systems are interlinked, are provided by the forest and land sectors, where, for example, the impact of land tenure on forest conservation is explored [4]. However, between the two resources required for food production, a specific land–water nexus, where feedback loops between the governance systems of each resource are also considered, has hardly been investigated. Regarding food and fiber production, the water domain can be limited to the irrigation sector. Thus, the missing interface between land and water governance is even more pronounced. Irrigation water access is often considered to be part of land tenure as a "subsidiary component" [5] (p. 2). In particular, the impact of secure land tenure on local irrigation governance has not been addressed in detail. Some recent exceptions come from the water grabbing debate [6–9], which indicate a link between land and water governance. The global rush for land has shown that those interested in land also opt for long-term and secure water access [7,9]. This is particularly the case for semi-arid regions or where crops with intensive water needs are grown. Land deals can lead to a change of land use rights, which in turn can impact on the availability of irrigation water and water governance [6,8,10,11] or on water quality in terms of e.g., water pollution [12]. Land rush is not unique to large-scale, international land acquisition, it can also result from a sudden and quick change in land property structures, as has happened in many transition countries.

Empirically we relate the discussion to the case of Tajikistan, where irrigated agriculture represents a highly relevant economic activity. Since 1990, a domestic rush for land has emerged resulting from the change from large-scale, state farming units to comparatively small-scale farming arising from the enforced privatization of the former collective and state farms [13]. Agricultural transition is also taking place in the water sector. At the local scale, this implies a change from state-managed to farmer-managed irrigation systems that require collective participation from farm households. This participation consists basically of water payments from farmers and labor contributions to canal maintenance [14]. As Theesfeld [15] expresses for the case of Bulgaria, land reform with its changes in farm size and organizational structures challenges the remaining socialist irrigation systems.

Irrigation systems are often studied as an example of community-based management (see e.g., [16]). Although cooperation within irrigation systems and the social dilemmas faced by groups, e.g., by water user associations, have frequently been studied, we think that recent studies and frameworks do not provide enough opportunities to analyze the nexus effect of sector-specific governance systems of one resource on other resources. Specifically, we address the link between collective action in irrigation systems and land tenure, empirically investigated for the case of Tajikistan. We aim to identify specific attributes of the land resource system that affect new modes of irrigation governance at the local scale. This often requires cooperation between farmers. For the case of Tajikistan, we discuss how the land governance systems in place and land decision-making in the future could be designed in order to enable sustainable water governance, and how to facilitate the willingness to cooperate. In doing so, we further want to provide some food for thought in our discussion of how to address a resource nexus using the social–ecological system framework. This should help to also analyze other existing case studies and to make comparisons.

In the first part of the paper, we introduce the land–water nexus and give a brief overview of the social–ecological system (SES) framework in the light of a nexus perspective. Then we introduce the transition process of the land and water sector in Tajikistan. Based on the theoretical and case study background we formulate four hypotheses. These hypotheses are tested with farm household data from two lowland regions in Tajikistan using two logit models. Finally, we discuss the results regarding specific linkages between land and water governance.

2. The Land–Water Nexus

Land and water are inextricably linked [17,18], although they differ considerably in their physical nature [5]. In the land and water domain, the feedback loops between use practices, and soil and water management have been widely investigated from a hydrological perspective. For instance, land use and cover change can affect water quality [19] or land degradation can reduce water-use efficiency [20]. Increasing desertification also impacts groundwater level recharges and run-off, which leads to an increasing threat of floods. Lower water and soil quality consequently lowers the value of land property and possible food and fiber production. In addition, the concept of green and blue water has also added to the discussion of particularly linking irrigation and agricultural land [21].

Whereas land resources are increasingly being privatized, irrigation water often faces a change in management from the state to a common property regime. These regimes can face cooperation dilemmas, where a group of irrigators jointly access, manage and withdraw irrigation water from a common-pool resource for their individual benefit [16,22,23]. Well-investigated pitfalls of cooperation include the problem of access asymmetries or fee-riding by non-contributors, especially among head- and tail-end users [22]. Still, many irrigation systems have proven to function as a long-lasting and sustainably managed social–ecological system [24].

Irrigation systems and farmer cooperation dilemmas are a frequently addressed topic in the SES literature [25,26]. In this respect, the SES framework—a heuristic framework to study interactions in complex human–ecological systems—was developed, allowing us to use a common language, and systematically analyze empirical settings [27,28]. Initially, the SES framework was designed specifically to study common-pool resources, the benefits of cooperation or similar cooperation dilemmas [28]. Compared to previous frameworks in this field, it is also suitable for integrating the ecological and social context, and thus for integrating more complex interactions.

The SES framework, first developed by Ostrom and colleagues [27] and further developed over the years [28], consists of eight first-tier variables: resource system (RS), resource unit (RU), governance systems (GS) and the actors (A), which together influence the action Situation which is determined by the interaction (I) and the outcome (O) (see Figure 1). The social, economic, and political settings (S) and the related ecosystems (ECO) are two other important variables, considered as the contextual factors. In this nested framework, we can unpack each first tier of one system into multiple second- and third-tier variables. Of course, not all variables have to be analyzed for all cases; the selection depends upon the aims of the research.

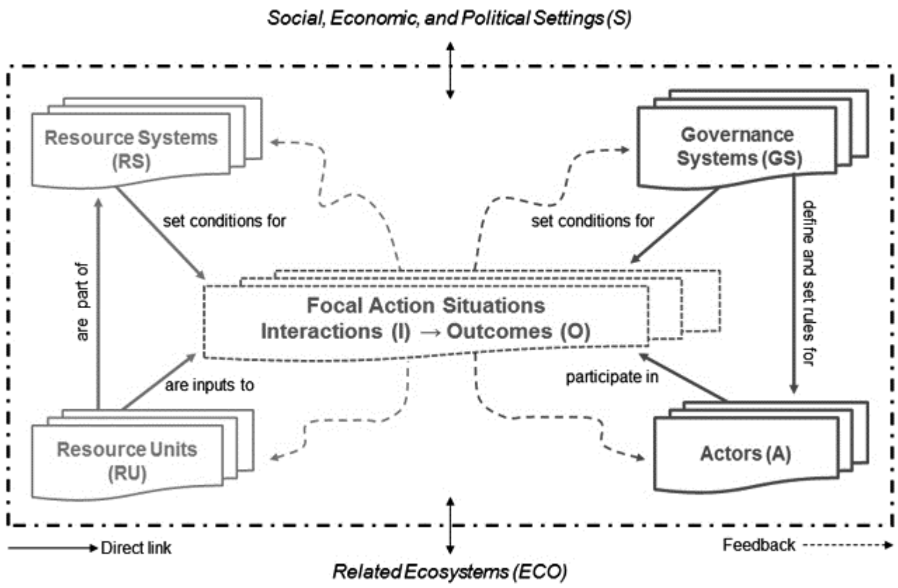

Figure 1. Social-ecological system (SES) framework with multiple first-tier components. Source: [28].

Most studies applying the SES framework refer to the robustness and disturbances of only one distinct resource system. We discovered in the current SES framework a second-tier variable of the resource unit (RU) that is named "interaction among resource units", which could imply a nexus of two resources. This variable has rarely been considered in SES framework applications so far. According to Delgado-Serrano and Ramos (2015) [29], it describes the identification of the relationship between resources such as competition and collaboration. Based on this definition this variable would not be sufficient to consider the entire nexus, because it only focuses on the resource unit and neglects e.g., governance linkages.

Other outside system effects derive mainly from the two variables "ecosystem (ECO)" and "social, economic and political system (S)". Both represent so-called global variables and include e.g., climatic or economic development conditions, without explicitly referring to the integration of another resource system. We suggest that for one resource a complementary resource can create disturbances.

These disturbances are considered an uncommon shift of inflow into a resource system [23] and may generate new outcomes that can also evolve from another resource unit or system.

We challenge the SES framework and ask whether the current form of the SES framework is suitable to discuss linkages between two resources systems and whether it is possible to adapt the SES framework, integrating a stronger nexus perspective. Up to now, the SES framework only allows for a limited analysis of the resource nexus.

3. Land and Water in Transition in Tajikistan

Tajikistan is a landlocked country in Central Asia with a semi-arid climate. High water variability between the seasons with floods in springtime and droughts in summer are an increasing threat for Tajik agriculture. Tajikistan has two important agricultural areas, which were greatly developed during Soviet times. With only about 7% of arable land, the area suitable for agricultural production is very limited in Tajikistan. In the lowlands, crop production fully depends on irrigation. Here, where irrigated land is scarce, food production competes with the well-established (and sometimes compulsory) fiber production. For instance, in the lowlands, cotton production was introduced during the Soviet period and is still produced on 20% of the agricultural land, although, officially, such planned production schemes have been abolished. Only over the last five years has food production, especially diversified vegetable production, increased [30,31]. Many of the rural households are subsistence farmers depending on the so-called kitchen gardens attached to their houses. These kitchen gardens are very important for Tajikistan's food security [32].

A change of resource governance has taken place during recent decades. Both land and water are state property and there are use rights for farmers. The use rights for Tajiks are long-term and mostly not limited to a certain period [13]. Use rights can be formalized in land certificates and can be obtained at the (regional) Land Committee. Land reform started with the goal of reorganizing former (Soviet) state and collective farms (both typically more than 1000 ha) into private farms. Now, different farm types exist, generally defined as household gardens, private peasant farms, and collective farms. The number of the latter has dropped drastically over the past years, especially since 2009, as private farms developed [13,30]. Farm sizes are now very small with about 40% of registered private farms cultivating less than 2 ha [13]. Thus, there is increasing competition for water among large-scale, medium-scale and household farmers. The increase in number of medium-scale and household farmers has thus resulted in an increase in the number of canal users.

Water reforms started in the water management rule-making process, and its organization has slowly changed from a centralized to a de-centralized system [14]. The most drastic changes happened at the inter-farm and farm levels, where irrigation systems are now collectively managed by farmers. Collective management can be either formalized, e.g., in water user associations (WUA), or informally organized within one community. Between the gate and the on-farm canals, forms of collective action initiatives are generally responsible for water supply [31]. Each farmer is now accountable to himself/herself for the maintenance and management of the secondary and on-farm irrigation canals. This includes investing time, effort and financial means. Before 1990, irrigation system management and investment were mainly subsidized and organized by the state and self-governance was not needed.

One major change in water governance occurred with the introduction of water fees as a new policy instrument to cover operation and maintenance costs. Officially, since 2006, water payments (irrigation service fees) are calculated by the Ministry of Melioration and Water Resources by farm size and crop (0.78 Diram/m^3 in gravity irrigated areas, 1.25 Diram/m^3 in lift irrigated areas (2.25 US$ for 1000 m^3 and 3.63 US$ for 1000 m^3, respectively) [14] (Interview with Ministry for Water Melioration and Water Resources 2013). However, thus far, the implementation of collecting water fees is weak and huge capital losses for the maintenance of the irrigation infrastructure are frequently reported. Social monitoring mainly exists among the larger-scale farmers. Household plot users are often not monitored regarding water use and an official monitoring and sanctioning system is not in place.

4. Hypotheses

Following a literature review, we put forward the following hypotheses for possible governance linkages between land and irrigation water systems. The hypotheses serve to empirically explore the land–water nexus in Tajikistan.

4.1. Hypothesis 1 (H1): A Land–Water Governance Nexus is More Likely where Farmers Hold Land Title

The first hypothesis investigates whether land titles can contribute to more cooperation in local irrigation management in Tajikistan. It is an already accepted fact that land tenure for instance increases the willingness to invest in land [33,34]. The same holds true for the water sector. For instance, as Meinzen-Dick (2014) [35] emphasizes, the strength of incentives and confidence regarding rights is especially important to sustaining an irrigation system. However, these studies do not consider cross-sector effects between two resource sectors. Although Meinzen Dick (2014) [35] refers to water tenure, we assume that land tenure security can have spillover effects on farmers' likelihood to participate in local water governance.

As a proxy for secure land tenure we use two variables, which focus on different aspects of tenure: (1) holding of formal land titles; and (2) access to the use of more land. Formal land titles can provide certainty and security to farmers. Land certificates guarantee long-term rights of use and the farmer is more motivated to invest in land resources [33,34]. We assume that these investment incentives are likewise transferred to the water sector. A so-called "assurance effect" [33] can evolve, and returns are expected to be more stable. In addition, the literature mentions a "collateralization effect", where land can be used as collateral and, with it, access to credit is improved [33], which can be also used for irrigation management. Sjöstedt [18] (p. 134) mentions that "for such investments [in irrigation infrastructure] to take place, citizens need some certainty that they will reap the rewards from their investments. This certainty is suggested to result from property rights to land, i.e., land tenure". We assume that this relationship especially holds true in Tajikistan, where land tenure became an important collateral, for smaller- and large-scale farmers. Second, if farmers were provided with access to more land, we would expect that they would cooperate more in water governance since they would not only increasingly depend on irrigation water, but also have the financial means to contribute. Also in Tajikistan, being able to afford more land likewise means to have certain negotiation power, e.g., with local administration when applying for more land.

4.2. Hypothesis 2 (H2): Perceived (Non-Formalized) Land Tenure Enhances the Likelihood to Cooperate in Local Irrigation Management

The second hypothesis refers to the perceived land tenure and represents a governance aspect. To contrast the effect of formal land institutions, the perceived land tenure could represent another third-tier variable in the SES framework. These perceptions do not necessarily have to be in line with the rights defined by land reform. Farmers also act, invest and justify their actions according to their perceptions, reflecting their de facto situation [36,37]. As knowledge of the formal land reform process and land certificates in Tajikistan is still considered as rather low [13], we assume that perceived land tenure can play an important role in our empirical case. We considered two different aspects of perceived land institutions, alienation and management rights, both representing collective-choice rights that are not necessarily formalized [38]. Perceived land alienation rights can create a "realizability effect" [33,34], where land is treated as an asset and investments in land are improved. To sustain the value of land, a similar contribution to improve collective water management is expected. Perceived land management rights reveal farmers' ability to make individual decisions regarding management practices, to invest and to transform the land by increasing the value of it [38], which is a new attribute for farmers in the Central Asian context.

4.3. Hypothesis 3 (H3): The Larger the Farm the Greater the Likelihood of Cooperation in Local Irrigation Management

Hypothesis 3 refers to the impact of farm size on the willingness to cooperate in irrigation management. Further, as regards the SES framework, it exemplifies a particular link between resource unit characteristics and irrigation governance, so far not clearly spelled out in the framework. Considering the leadership and cooperation literature, Baland and Platteau (1999), Vedeld (2000) and Olson (1965) [39–41] conclude that those enjoying more endowments than others in the same community are seemingly more willing to contribute to common-pool resource management. More endowments, e.g., in terms of larger land plots can, to a certain extent, provide more resources to contribute to irrigation management. Common-pool resource studies (e.g., [42,43]) suggest an inverted U-shaped relationship, which means that after a certain size of endowments is reached, contributions to common-pool resource management might decrease again. In our empirical analysis, larger land plots in the hands of private farmers are still comparatively rare, so we expect a future increase in cooperation with a rise in average farm size. Also looking at irrigation management, shortly after the transition in Tajikistan, mainly the large-scale farms (former collective farms) were the ones responsible for irrigation management and they are often still considered as being responsible by the community. In addition, smaller farms are regarded as having limited coping strategies [44,45] and thus would benefit relatively more from improved cooperation in the irrigation system.

4.4. Hypothesis 4 (H4): Cotton Cultivation Correlates with the Likelihood to Contribute to Local Irrigation Management

We include one crop variable to describe the land use system (RS). This should emphasize a land-use specific water governance mechanism. Of course, causality in this respect can be questioned. Thus, we include only cotton as a crop variable, since cotton production in Tajikistan is still assumed to be “semi-voluntary” and many obligations to grow cotton exist [46]. Cotton in particular is sensitive to volatile water supply and calls for a very reliable and on-time water supply during the cropping season, otherwise, production losses are likely [31]. Farmers involved in cotton growing are expected to be more willing to contribute to irrigation management and cooperation in water allocation. We assume that the motivation to invest time and labor in collective irrigation management is somewhat higher for farmers who grow cotton, due to better revenues but also due to the historical development of cotton production (see for instance [47]).

5. Data and Methodology

For our empirical analysis, we used a quantitative farm household survey (N = 306 farm households) from two regions in Tajikistan, namely Bokhtar (Southern Tajikistan) and Bobojon Gafurov (Northern Tajikistan). The data collection took place from March–May The farm household survey was divided into five parts: (a) general information (e.g., farm type, farm size); (b) land and water use and attributes; (c) land and water tenure and regulations; (d) bundle of land and water rights (farmers’ perceptions of land and water rights); (e) outlook of land and water access (open questions); (f) farm household details (gender, age etc.). The selection of the farm households took place based on a stratified random selection process. After non-randomly selecting the districts, all communes were selected. Within the communes 1-2 villages were randomly selected. Due to missing farm household lists, a quasi-random selection process was chosen, where the enumerators started in the center, chose a random direction and selected the first farm household in this direction. The following houses were randomly selected along that route by the enumerator. In each district, we further organized two focus group discussions (mostly with WUAs). This helped to understand and grasp the regional differences and the organization of irrigation management. Further expert interviews were conducted with the Land Committee, Water Ministry, Agricultural Ministry, statistical offices and local NGOs.

Both lowland regions were selected as they share similarities in their agricultural production patterns and are highly dependent on surface irrigation. Both regions are geographically completely separated from each other through the mountain ranges of Zarafshan. Table 1 gives further descriptive statistics of the socio-economic situation of the surveyed farm households. Most farm households in our survey have a male farm household head. However, the number of female farm households is increasing. But still, on average, women are the main working force within a farm household with about 60%, who were already the main working force during the Soviet period (e.g., for cotton picking at the collective farms). In addition, many men in the rural areas migrate to and work in Russia. Apart from agricultural income, remittances contribute substantially to farm household income; a total of 39% of the sampled population received remittances in previous years. Of all female-headed farm households, 47% received remittances in the previous year. The average age of the respondents in the sample was 48 years. Only a small proportion of the surveyed farmers were born around the transition period and thus a substantial share of the surveyed population could have been farmers before the Soviet Union collapsed. The results of the survey show that about 62% of surveyed farms were established within the past five years (up to 2013). The surveyed farm households only sold, on average, about 36% of their production, which shows that most of the farms use their production for their own consumption. About 13% of the irrigated land is used for cotton, which is a considerable share of total irrigated land and has a considerably higher water demand (6000 m^3/ha/year and eight irrigation turns per season) than winter wheat (3000 m^3/ha/year and five irrigation turns per season). Vegetables, here only depicted by tomatoes and potatoes, constitute a considerable share of the agricultural area (22%), but also need considerable amounts of irrigation water (e.g., tomatoes 9100 m^3/ha/year and 14 irrigation turns).

Table 1. Descriptive statistics of farm household characteristics.

Descriptive Variables	Mean (Standard Deviation) or Percentage
Gender of farm household head (% of women)	32.35%
Share of female farm workers on one farm	59.81 (26.60)
Age of farm household head	49.57 (13.21)
Number of $\leq$25 years old	19
Number of $\leq 45 \geq 25$ years old	106
Number of $\geq$46 years old	181
Receiving remittances (%)	39%
Farm established within the past 5 years (%)	61.64%
Share of production sold	36.15 (42.52)
Share of cotton area of irrigated area	13.19 (30.85)
Share of wheat area of irrigated area	12.72 (30.10)
Share of tomato and potato area of irrigated area	21.62 (29.75)
Share of irrigated land	88.01 (21.15)

Source: own calculation based on farm household survey 2013.

To investigate the land–water nexus for Tajikistan, we ran two logit regression models and estimated the marginal effects on two dependent variables: (1) paying water fees; and (2) labor maintenance efforts. Especially regarding the categorical variables used in the two models, the marginal effects can provide more information on the effects of discrete changes when the independent variables increase by one unit, holding all other independent variables equal. For the continuous variables, the marginal effects represent the instantaneous change. The pseudo R2 as well as the WaldChi2 were computed to address the accuracy of the model. In total, all models included 306 observations, observations with missing values were not considered.

Both dependent variables represent the change from top-down water governance to participatory, collective water governance, but emphasize different aspects of individual contribution. Descriptive statistics for both variables are displayed in Tables 2 and 3. “Paying for water” describes an invisible form of participation, whereas the variable “labor maintenance efforts” in irrigation infrastructure indicates a visible form of participation. For both contributions, no legally defined sanctions exist and free-riding is possible in both cases, thus we conceptualize both as voluntary contributions not required in order to obtain water.

Table 2. Frequency of paying for water or of contributing to maintenance work. Source: own calculation based on farm household survey 2013.

	(1) Paying for Water (N = 306)		(2) Labor Maintenance Efforts (N = 306)	
	Frequency	Percent	Frequency	Percent
No	110	35.95	140	45.75
Yes	196	64.05	166	54.25

Table 3. Frequency of intersections between labor maintenance efforts and paying for water. Source: own calculation based on farm household survey 2013.

	Labor Maintenance Efforts		
	No	Yes	Total
Paying for Water			
No	75	35	110
Yes	65	131	196
Total	140	166	306

The independent variables are derived in line with water-related cooperation theory [48]. Overall, they consist of three groups: (1) land-related variables to test the four hypotheses; (2) farm household characteristics (e.g., farm household experience); and (3) control variables of the irrigation system variables. Experience with farming implicitly includes experience with irrigation, thus it is considered here to be a variable describing the land sector. In Tajikistan, as in many other countries, it can be sensitive to talk about land rights. Therefore, we carefully chose ways of measuring tenure security and operationalizing perceptions of land and water rights. Through additional qualitative interviews, we can support the main argument resulting from the logistic regressions. Table 4 shows the descriptive statistics of all three groups of independent variables.

Table 4. Descriptive statistics of independent variables. Source: own calculation based on farm household survey 2013.

Explanatory Variable	Scale and Measure	Mean or Percentage	Standard Deviation	Hypo-Thesis
Land unit and system variables				
Holding a certificate	Binary, 1 = yes, 0 = no	58.82%		1
Access to use more land	Binary, 1 = yes, 0 = no	43.14%		1
Perceived land management rights	Binary, 1 = yes, 0 = no	85.95%		2
Perceived land selling rights	Binary, 1 = yes, 0 = no	38.89%		2
Farm size	Interval, in ha	3.22	9.83	3
Producing cotton	Binary, 1 = yes, 0 = no	17.32%		4
Farm household characteristics				
Farming experience	Interval, in years (since farming)	33.86	30.66	
Irrigation system characteristics (control variables)				
No water in cropping months (2012)	Binary, 1 = yes, 0 = no	11.44%		
Upstream user	Binary, 1 = yes, 0 = no	27.12%		
District	Binary, 1 = Bobojon Gafurov, 0 = Bokhtar	44.02%		

6. Results

Table 5 presents the results of the two logit models and the marginal effects explaining a farm household's financial contribution (for water use) and labor contribution to irrigation infrastructure maintenance.

Table 5. Logit model estimates. Source: own calculation based on farm household survey 2013.

	(1) Paying for Water	**(1) Paying for Water**	**(2) Labor Maintenance Efforts**	**(2) Labor Maintenance Efforts**
	Coefficient	Marginal effect	Coefficient	Marginal effect
Land unit and system variables				
Holding a certificate	0.902 **	0.173 **	0.913 **	0.198 **
	(0.384)	(0.0714)	(0.394)	(0.0826)
Holding a certificate * District BG †	−0.590		−0.745	
	(0.558)		(0.556)	
Access to use more land	0.0708	0.0136	0.533 **	0.116 **
	(0.271)	(0.0521)	(0.255)	(0.0535)
Perceived land management rights	1.083 **	0.208 **	0.380	0.0825
	(0.442)	(0.0821)	(0.387)	(0.0836)
Perceived land selling rights	0.424	0.0813	0.0708	0.0154
	(0.285)	(0.0541)	(0.270)	(0.0585)
Farm size	0.0501 *	0.00962 *	0.0509 ***	0.0111 ***
	(0.0271)	(0.00500)	(0.0168)	(0.00360)
Producing cotton	0.285	0.0547	−0.562	−0.122
	(0.529)	(0.102)	(0.482)	(0.105)
Producing cotton * District BGa	0.0853		1.625 **	
	(0.741)		(0.792)	
Farm household characteristics				
Farming experience	−0.00257	−0.000494	−0.00964 **	−0.00209 **
	(0.00427)	(0.000817)	(0.00422)	(0.000886)
Irrigation system characteristics (control variables)				
Upstream user	−1.378 ***	−0.264 ***	−0.110	−0.0240
	(0.441)	(0.0790)	(0.381)	(0.0828)
No water in cropping season (2012)	−0.209	−0.0402	0.518 *	0.113 *
	(0.294)	(0.0562)	(0.282)	(0.0600)
District BG (Bobojon Gafurov)	−0.778 *	−0.149 *	0.978 **	0.213 **
	(0.419)	(0.0787)	(0.444)	(0.0929)
Constant	−0.407		−1.181 **	
	(0.551)		(0.545)	
Pseudo R2	0.13 ***		0.11 ***	
Wald chi2	40.82		39.50	
Observations	306	306	306	306

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, BG = Bobojon Gafurov, the results of the variance inflation factor (VIF) shows multicollinearity is not an issue in either model (maximum VIF value 4.1). † = Value of interaction terms cannot change independently of the values of the component terms, thus, no separate effects of the interaction can be estimated [49]

The pseudo R2, pointing to the accuracy of the model, is significant for both logit models, explaining 13% (model 1: paying water fees) and 11% (model 2: labor maintenance efforts) of the variance of the dependent variables. Based on the model results, we suggest that it is of importance to consider specific land-related variables when studying the probability of contributing to cooperation in water management. Therefore, a cross-sectoral consideration is worthwhile when aiming at improved collective irrigation management. In particular, a formal land certificate increases the probability of cooperation in irrigation systems. In addition, perceived land management rights increase the probability of paying for water. Although the coefficients have the same signs between the two models, different magnitudes between the two modes of cooperation were determined.

6.1. Formal Land Tenure

Our results identify that formalized land tenure in the form of certificates is likely to increase the willingness to cooperate in irrigation systems. These results are even robust between visible and invisible contributions to cooperation. Although the coefficient of the interaction term is not significant (significance level of $p < 0.1$), the interaction term between holding a certificate and the district variable shows regional differences. This means, for example, that the implementation of land reforms through land certificates and the expected security for farmers profoundly relies on the trust towards the managing authority that oversees the distribution of and advocating for land certificates. If farmers hold a land certificate, but if they see the risk that it gets withdrawn any time by the authority, the willingness to invest in irrigation management is much lower. This was also supported by some of the interviews. The probability to contribute to canal maintenance is further strengthened when farmers can formally access more land. Our results support H1 that formal land tenure increases the likelihood to cooperate in irrigation management. This means for instance, that when supporting a land cadaster system with improved land tenure arrangements in irrigated areas, one can likewise intend and expect further improvements in collective irrigation management.

6.2. Perception of Land Rights

The two variables indicating farmers' perceived rights to land—(a) management claims and (b) alienation (land selling) claims—show positive effects on cooperation in irrigation management. Therefore, what farmers believe to be their rights can lead to improved overall perception of tenure security. However, only perceived management rights showed a statistically significant influence for our sample on contributing to payments. Individual control over and improvements in land use patterns, which for a long time were not the case in Tajikistan, similarly increase the likelihood that farmers will pay for water. This suggests that long-term investments in land resources motivates farmers to contribute to water payments, which is also considered a long-term investment where outcomes are not directly visible. Our results support H2 and specify the assumption that linkages are more pronounced between long-term land rights and long-term investments in water systems. For instance, farmers that feel free to manage their lands, e.g., by applying land conservation techniques for improving the soil properties or building hedges to reduce water runoff, likewise see the need and importance of long-term investment in irrigation infrastructure to overall increase resource efficiency.

6.3. Farm Size

The probability of cooperation is also influenced by farm size, however coefficients are rather low, which means that the farm size is not a decisive factor. The marginal effect in the labor contribution model is slightly higher, which indicates that larger farms require ad hoc improvement of canals, which can be better assured by labor contribution. The larger farms, which retained most of their assets (machinery) and workers from the Soviet period, have better means to invest time and effort into the maintenance of canals and are thus more likely to participate by contributing labor. Overall, the results support H3.

6.4. Land Use: Cotton Production

Since the breakdown of the Soviet Union, according to qualitative interviews in some communities, farmers still have to fulfil informal cotton quotas. In these communities, local authorities still control the regulation of cotton production. Although in our sample we did not identify a statistically significant effect of cotton production on the willingness to contribute to a functioning irrigation management, the results are interesting. Considering the interaction term of cotton, producing cotton in Bobojon Gafurov increases the probability of participation in canal maintenance, whereas the opposite is the case in Bokhtar. For Bokhtar, this can mean that cotton farmers might still be reluctant to contribute to canal maintenance in a collective manner and that they are supported more by local authorities. In contrast, the payment model reveals that cotton farmers, who are anyway more controlled by authorities, are more likely to contribute to the fees and that free-riding is less possible. Thus, our fourth hypothesis (H4) can only be partly supported by our results.

6.5. Farm Household Characteristics

Farming experiences show overall robust results between the two models. Some studies indicate "bad experiences" as a driver of uncooperative behavior [50–52]. In transition countries in particular, farming experience should incorporate whether farmers were already farming during the former Soviet structures or early post-Soviet times, i.e. whether they experienced the transition period, including the important changes in governance and responsibility. In our case, we were able to show that the less farming experience farmers had, the more they were willing to contribute to collective irrigation management. Older farmers, or more experienced ones, might be more influenced by the

Soviet style water management system, where the large collective farms, which indeed represented pseudo-collective action, were mainly responsible for water provision and individual participation was not needed.

6.6. Irrigation System Characteristics

We were able to determine differences in our model according to the location of the farm in relation to the canal and water availability during the cropping months (2012 season). Interestingly, being an upstream user has a strong positive and significant effect in our sample on the likelihood to contribute to labor maintenance efforts. Being located upstream seemingly provides more incentives and shows the need to cooperate visibly. Additionally, not having water in the previous cropping seasons seems to have a significant effect on the willingness to contribute financially for the next season.

7. Discussion and Conclusions

We explored the nexus between the land and irrigation system for both the core inputs for food and fiber production in Tajikistan. Specifically, the links between land system variables and cooperation in irrigation management stand out. In light of the anticipated future higher variability of precipitation, the expansion of agricultural production to non-suitable areas, and the increase in competition between food and fiber production, water rights and water security gain importance, but are often still isolated from land governance debates [53].

Our empirical analysis provides evidence that cooperation in irrigation management is likely to be influenced by specific land system variables. We show that it is not only in large-scale land and water grabbing cases [6,54] that the link between land and irrigation water can be determined. Locally, where changes in land governance are occurring, irrigation water governance can be influenced.

The empirical part of the paper dealt with the case of Tajikistan, which is a very good example for the study of the land–water nexus, since food and fiber production is highly dependent on irrigation and the transition period led to abrupt changes in land and water governance. Individual contributions to cooperation in irrigation management have newly been introduced. In particular, water payments and labor contribution to irrigation management are both instruments to cover operation and maintenance costs and to reduce the financial contribution of the state [55]. Both instruments were selected as dependent variables revealing new collective-action modes of irrigation water governance. The two different cooperation variables indicated robustness between the estimated linkages, which supports our request to look beyond one resource system. Formal land tenure (H1) and perceived land management rights (H2) provide evidence that cooperation in the agricultural water sector can also be stimulated by land governance. Formal land tenure is often considered to boost agricultural production, rural development and food security [56–58]. Our results further identify that formalized land tenure is also linked to cooperation in irrigation systems. Further, we show the importance of recognizing the informal rights of farmers in the land sector and of considering their importance in local water governance. In addition, positive effects of farm size on irrigation cooperation (H3) are characteristic for the land–water link. For larger farms, irrigated agriculture is an important economic activity, which has made them dependent on long-term improvements in irrigation governance.

Integrating a crop variable into the model is only possible to a certain extent due to the possible endogeneity. Therefore, we included only cotton because producing cotton in Tajikistan (or generally in Central Asia) has a very specific connotation. Cropping decisions have for a long time been influenced by administrative bodies. Furthermore, our results show differences between the regions in terms of production decisions and contributions to irrigation systems (H4). The interaction terms underlined regional differences regarding cotton farming and holding land certificates. Both variables are highly influenced by local authorities interfering in the overall land decision-making process, especially when it comes to large-scale farming. This shows that in those regions where there is a strong influence of administrative bodies on local land governance, building on this influence can be a starting point for encouraging collective action in natural resource use.

As indicated above, we also questioned whether the SES framework is suitable to better specify a land–water nexus. Based on our results, we outline first conceptual thoughts about how a heuristic framework, such as the SES framework, could be extended to catch the interface. We see two ways to study the interface between two different resources. We propose the further development of the SES framework, either by expanding the governance link between land and irrigation water, or by detailing a link between irrigation governance and land resource unit or system.

In our first suggestion, resulting from the findings in H1 and H2, we further unpack the first-tier variable "governance system (GS)" within the SES of an irrigation system. Here, we suggest adding a new second-tier variable "governance nexus" (see Figure 2, grey box) with related third-tier variables that can consist of land-specific variables, e.g., informal and formal land property rights as tested in H1 and H2. Similarly to other second-tier variables, this new variable is linked to the action situation as part of the irrigation system.

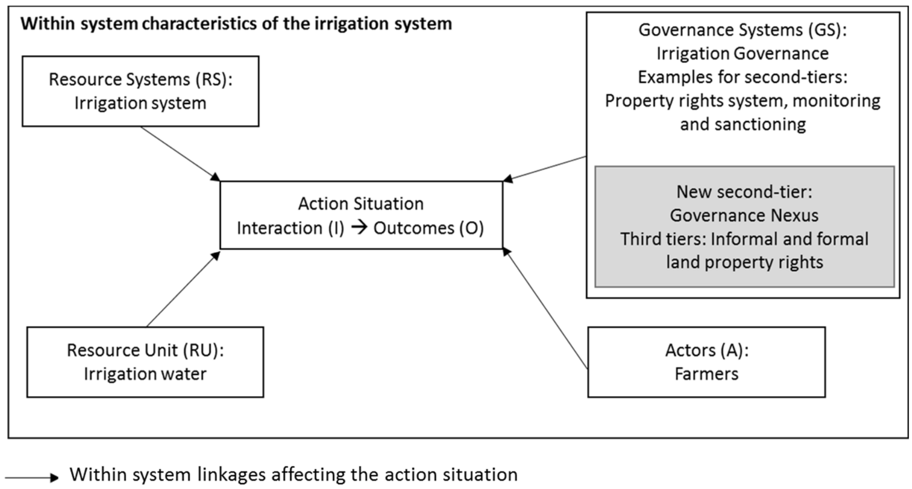

Figure 2. Adapted and simplified SES framework integrating land governance. Source: Adapted SES Framework from [28].

Our second suggestion for adapting the SES framework, supported by results of H3 and H4 includes considering two resource systems, each with a particular resource unit (RU) and system (RS) characteristics, and selected further system-specific tiers (see Figure 3). Compared to the first suggestion, the GS Box within the irrigation system does not change. The actors become more central in this regard, as they are the linking unit between the land and irrigation system. In an irrigation system, the main actor (conceptualized as the "user" in previous versions of the framework) is the farmer. Since the farmer depends on both, land and irrigation water, the farmer becomes the linking unit. Each system can be very dynamic and can respond to other systems, which would imply that a change of cropping patterns or farm structures can affect certain water governance instruments.

As shown in our application, either the farmer becomes the linking unit between two resource systems, or a second-tier variable "land governance" needs to be added to the first-tier of the irrigation governance box. The two options are meant to further emphasize the need for a more interlinked consideration of resources, also at the conceptual level. By including a new resource system, the SES framework is of course challenged in its simplicity. In this respect, the SES framework would become more encompassing and thus more fitting for more circumstances. However, we are also aware that with this it would also become less diagnostic. In addition, analysis becomes more complex when the resource system boundary is fuzzier than expected [59,60]. Actors cannot be simply attached to one system. In our example, the actors represent the linking unit between two resource systems. Changing one first-tier variable in the SES framework can imply that other second- or third-tier variables need to be adapted, too. This is also discussed by McGinnis and Ostrom (2014) [28]; when they changed the first-tier variable "users" to "actors", new "interactions" had to be considered. Aside from these difficulties, it shows the strength of the SES framework, offering academics the opportunity to continuously develop it further. We think that further research needs to be done for conceptualizing the land and water governance interface, especially using the SES framework. Here, it would be likewise interesting to investigate in how far the adaptations we made, also account for linkages between other resource systems. For the case of Tajikistan, water used for energy production becomes more and more important. Therefore, adding the energy sector to the land–water–food nexus would be important to investigate.

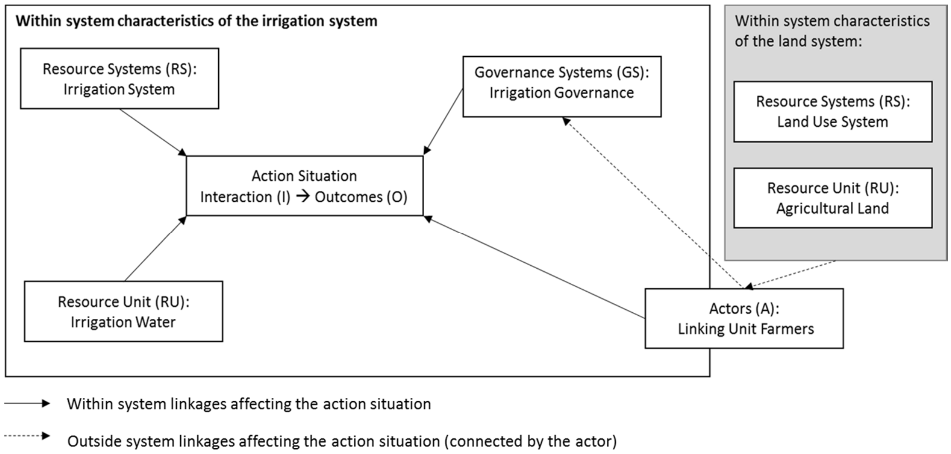

Figure 3. Adapted and simplified SES framework with two interlinked resource systems. Source: Adapted SES framework from [28].

To conclude, land governance and specifically formal and informal land tenure should be recognized in order to enable sustainable water governance in Tajikistan, in the same way as water-sector-related characteristics. Since worldwide irrigation governance systems are increasingly based upon cooperation and participation principles, specific land tenure governance and farming structures can support farmer cooperation in water governance. A more sustainable and better functioning irrigation system, supported by good land governance, would in turn allow more intensive production on the limited agricultural land resources of the country. The possible production increase may support an increase in the share of food production compared to the current large share of cotton production.

Scaling up these findings to other transition countries, and also to other areas of intense irrigation is generally possible, yet requires context-specific adaptation. For instance, as our district variables have shown, even between the two regions within Tajikistan, differences exist between trust in local authorities, and thus also in land governance. We have conducted the study in Tajikistan, which is dominated by small-scale farming. Therefore, transferring the results to e.g., very large-scale irrigated agricultural production in South Kazakhstan has to be done carefully, as the need for collective irrigation management is different Further, irrigation systems that are differently organized, e.g., private or state-managed, may show different results. In addition, we would like to stress that our analysis only investigates surface irrigation management. In regions where mainly groundwater or mixed water sources are used, we would also expect a certain land–water governance nexus. However, governance nexus variables in particular might change.

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