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Can Water Abundance Compensate for Weak Water Governance? Determining and Comparing Dimensions of Irrigation Water Security in Tajikistan

Frederike Klümper [1,*], Thomas Herzfeld [1,2] and Insa Theesfeld [2]

1 Agricultural Policy, Leibniz Institute of Agricultural Development in Transition Economies (IAMO), 06120 Halle (Saale), Germany; herzfeld@iamo.de

2 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; Tel.: +49-34-5292-8101

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Abstract: In this paper we consider both hydrology and governance as critical dimensions for irrigation water security. We scale down the overall water security concept to the agricultural sector, suggest an index of irrigation water security faced by farmers, and provide an empirical illustration in the case of Tajikistan. Irrigation water security is investigated by three different dimensions: (a) a hydrology dimension, expressing a lack of water availability; (b) a governance dimension, the perceived difficulty in accessing water; and (c) a hybrid dimension of governance and hydrology. We developed an irrigation water security index, which we empirically tested using farm household survey data (N = 399). This index provides evidence that different farm types, e.g., small versus large, perceive different water security threats. Further, we found that if one dimension is less distinctive, the complementary dimension occurs as a coping mechanism. Thus, we conclude that diversified support mechanisms for infrastructure and management are needed to reach a higher level of water security.

Keywords: irrigation water security; governance dimension; hydrology dimension; Tajikistan

1. Introduction

According to the World Bank [1], currently 1.2 billion people suffer from absolute water scarcity. Grey et al. [2] and Zeitoun [3] emphasize that particularly the world's poor face water insecurity. In this context, water insecurity can hamper adequate access to food and limits agricultural production potential [4].

Water security can be evaluated on different scales, from the global to the household level. One has to differentiate between different security threats such as to drinking water supply, to economic growth, to water related ecosystem services [5], as well as to agricultural production [6]. Globally, 20% of cropland is irrigated and in some countries, such as Tajikistan, the share amounts to even 65%. This makes agriculture the largest water user worldwide with 70% of water withdrawals [6]. "The development of irrigated agriculture has boosted agricultural yields and contributed to price stability, making it possible to feed the world's growing population" [6] (p. 205). Water for irrigation is strongly linked to food security, but farm households and consumers depend on it differently. Whereas commercial farms and rich consumers might have the capacities to deal with variability in water availability, poor consumers and subsistence farmers face direct and immediate consequences. Thus, it is relevant to look at the disaggregated level in terms of irrigation water security to specifically understand water security threats to different farm households. Especially in rural areas and where irrigated agriculture is the main income source, water security for all households within one community is of importance [1]. Furthermore, even water abundant countries can be hampered by water insecurity. In these countries, water distribution can differ greatly between regions e.g., between up- and lowlands. In addition, water availability can also vary a lot during the year, e.g., high run-off during the melting of glaciers in spring compared to dry summers. Thus, water might only be temporally abundant.

In Central Asia, the agricultural sector is to a large extent dependent on irrigation systems [7]. Both the agricultural and water sectors have changed tremendously since 1990. Some of the countries aimed to quickly dissolve the Soviet state and collective farms. The resulting farm structure is dominated by family farms which, consequently, challenge irrigation infrastructure as new individual consumers. As in most post-socialist countries, the large-scale irrigation systems established during the Soviet era do not meet the needs of the increasing number of small-scale family farms that emerged following the land distribution process [8–10]. Water negotiations and conflicts between and within the countries are limiting agricultural growth. Zakhirova [11] emphasizes that "disputes over water are largely the result of an allocation policy rather than scarcity of water supplies in the region" [11] (p. 1997).

Tajikistan is one of the poorest of the Central Asian countries and more than 70% of the population lives in rural areas. Although fresh water resources are abundant (annual water availability: 17,000 m^3/cap/year), the country ranks medium to low according to a national water security indicator across different sectors [12]. We assume that the commonly published single hydrological figure for the agricultural sector at a national scale provides little informative value on farmers' irrigation water security. As Cook and Bakker [13] highlight, relatively few studies address and measure water security at community and farm or household level, neither do these studies link water security to the agricultural sector [14–16].

The objective of this paper is to go beyond a single national-level indicator and develop an irrigation water security index at household level that considers a hydrology as well as a governance dimension. Our contribution to the literature is twofold. First, we suggest an index of irrigation water security focusing on the farm household level, mainly smallholders. Another important aspect of irrigation water security at farm household and community level is that in many developing countries, irrigation canals are also used for domestic (drinking etc.) purposes. To attain water security in this regard would imply costs of providing 'clean' water suitable for drinking, which is especially difficult in a developing country. Van der Hoek et al. [17] describe the use of irrigation water as domestic water supply as one of the "highest-value" uses (p. 50). Van der Hoek et al. [17] also discuss whether taking irrigation and drinking water from one canal is a health hazard or an opportunity. Irrigation water in our case does not imply the use of the water for domestic purposes such as drinking water. Irrigation water security in our study concerns three dimensions: (1) hydrology; (2) governance and (3) governance and hydrology, the so-called hybrid dimension of water security. Therewith, we are able to answer the question whether different dimensions of water security are always necessarily complementary. So far, few water security indexes focusing on smaller-scale farm households specifically include hydrology and governance as two different dimensions. Second, we apply this approach to Tajikistan, a seemingly water abundant country. As data availability on the farm household level in Tajikistan is limited, our data collection resulted in a unique dataset which provides valuable insights into the perception of water use and management at farm level. Based on a cluster analysis, we are able to differentiate farm typologies with varying irrigation water security dimensions. Subsequently, we test whether the impact from the hydrology and governance dimension on water security in the irrigation sector is equal and always appears complementarily across the farm types. For decision-makers, we indicate and identify specific system characteristics that might increase water security.

The paper is structured as follows: First, we define the concept of water security with a focus on irrigation water security, according to three dimensions. Subsequently, we describe our methodology introducing the study area and data. The main part presents our irrigation water security index, where we operationalize the three different dimensions of irrigation water security: (1) hydrology; (2) governance; and (3) hybrid between governance and hydrology. The presentation of the results in Section 4 consists of a brief description of the overall index and the results of the comparison across farm types. While concluding, we discuss the strengths and limitations of a household level water security index.

2. Water Security: From the National to the Local Scale

Besides many other definitions, one common concept of water security defines it as "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable level of water-related risks to people, environments and economies, for agriculture and rural livelihoods" [18] (pp. 547–548).

This definition is mainly applied by studies analyzing national and global water security (see e.g., [12]). It encompasses different sectors and addresses different disciplines (e.g., social, economic, or environmental). However, Cook and Bakker [13] or Grey and Sadoff [18] stress that the definition of water security is often too broad to be operationalized as such. Therefore, we suggest re-defining this concept to be better suitable to the irrigation water security of farmers. This is especially important in countries such as in Tajikistan where agriculture is the main income source in rural areas.

With the agricultural focus in mind, we propose a definition in which irrigation water security relates to the hydrological condition and the governance option required by each farm household to sustain their agricultural needs either for subsistence or commercial farming. If farmers face a lack of water availability, the dimension of irrigation water supply security affected depends on hydrology alone. Here, we refer to it as the "hydrology dimension". In contrast, if farmers perceive any difficulty in access, the dimension of irrigation water supply security affected depends on governance, thus referred to as the "governance dimension". Farmers are assumed to be water insecure if the outcomes of one or both dimensions are challenged. However, we think that water security is not a binary concern and both dimensions should be able to capture more than just the two extremes 'enough' or 'not enough water'.

It is important to look at the disaggregated local level as water scarcity can, for instance, affect farmers' individual decision-making regarding irrigation technologies or other water applications [19]. Jepson [16] stresses that a household is "the key unit of water delivery and the place where most water services are accessed. [. . .] Farm households shape behaviors and decisions relating water use" [16] (p. 109). For instance, if a household feels insecure in accessing water, they might respond in different ways, i.e., they might find a coping strategy or try to avoid certain practices. Furthermore, a farmer's perception of the security of access to irrigation water will determine his willingness to invest in water saving technologies and adopt water saving practices [20,21]. As Alam [22] states, it is expensive and time consuming to mitigate water scarcity. Thus, it is not possible for all farmers to invest in mitigating strategies and the status quo of water security levels might differ among farm households.

2.1. Linking the Hydrology, Governance and Hybrid Dimensions

Whereas Harris [23] and Biggs et al. [24] stress the distinction of water security between (1) governance and (2) hydrology, Norman et al. [25] underline the connective capacity between them and stress that a systematic translation is missing in the water security debate [25,26]. There are many variables that seem to be related to hydrology, but are also influenced by governance. Thus we add a so called "hybrid dimension". In principle each dimension can be either measured objectively or subjectively, however hydrological variables are usually expressed with objective data. With regard to the governance and hybrid dimensions, objective as well as subjective variables can be adduced, depending on the aim of the concept.

For the governance dimension, we considered only subjective measures based upon perceptions, as we particularly want to express the variance of the governance dimension between households. Such information would be too difficult and expensive to be gathered through objective data. In addition, if they exist, they can be misleading especially in terms of information on corruption or on black market activities. In line with Kaufmann et al. [27], we rely on perception-based indicators for the required governance information.

As Aguilera-Kling et al. [28] have shown for the case of Tenerife, water scarcity can also be a social construction. Here, the governance dimension describes the decision-making process of resource supply where various interests, responsibilities, policies, and means of supply and services are considered for a certain time [29]. Transparency, accountability and participation are the main principles of water governance assessments [30]. The three principles include socio-political dynamics and aspects such as power relations [26]. In some irrigation systems, daily negotiations take place which demand farmers' participation and a transparent process. Of course, participation can be time consuming and only affordable for large farmers with abundant labor. However, the level of participation and transparency, e.g., farmers engaged in local water networks, can vary considerably among the farmers. Therefore, local governance can differ considerably between households. Especially at the farm household level, the subjective investigation of local governance, measured by perceptions, is very common. Sinyolo et al. [14] and Besley [31] mention that perception assessments indicate the de facto actions and decisions being made by the farmers.

The hydrology dimension of water security is an important measurement in determining water security (see e.g., [12,18,32]). Hydrology can result in water abundance and provide significant security of supply for irrigators, even if water governance is weak. The total actual renewable water resource indicator is a key hydrological water resource measure [18], also at farm level. The hydrology dimension of irrigation water security can also vary according to the distance to water infrastructure, available water sources used such as ground water, surface water, or rainwater as well as the quality of the water. Using multiple sources can be more reliable when it comes to environmental disturbances such as drought.

The hybrid dimension is influenced by both the hydrological and governance factors affecting a farmer's environment. Indicators of the hybrid dimension are just as likely to be of hydrological nature as they are to be influenced by governance. For instance, water variability which depicts a hydrological risk cannot be solely attributed to a hydrological problem. Water variability in the canal depends on the water flow/input (hydrology) as well as on access, control, and management regulations (governance). Subjective assessments of hydrological variables can also be important and determine current and future water use [16].

Figure 1 summarizes the three dimensions and indicators to design the water security index. All of the indicators of the different dimensions are considered to vary over households. Considering a scenario where all farmers have their own well with continuous water flow during the year, the hydrology dimension of water security should be close to equal among all farmers. If this scenario is supported by a situation where all farmers enjoy the same bundle of clearly defined water rights, conflict resolution mechanisms, and stability of the institutions over time, the variance of the indicators of the governance dimension is expected to be minimal. Subsequently, overall water security will vary little across households. However, in many developing contexts the impact of governance is particularly different among households [33]. This variance might tend to be higher in a context with low rule of law, relatively in-transparent regulation, and power imbalances between decision-makers or regulations under transition. Thus, the household perspective offers more specified insights than a national perspective.

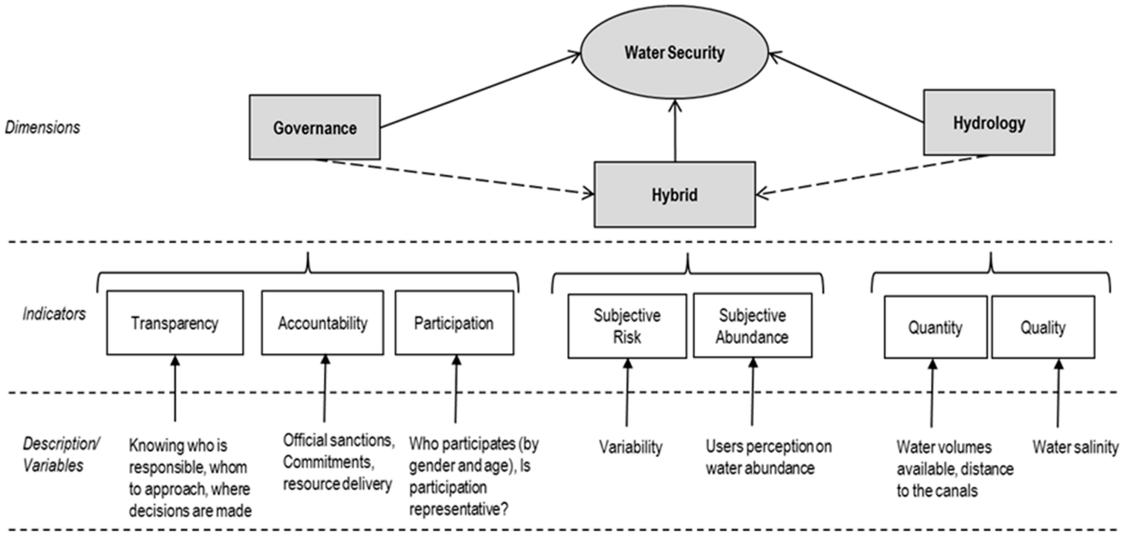

Figure 1. Three dimensions to design the irrigation water security index. Source: Own Figure.

2.2. Current Water Security Measurements

State of the art literature presents various water security measurements for the different sectors. For a detailed overview of water security indicators please see e.g., [16].

However, as far as we know, no major widely applied specific index exists that focuses on the agricultural sector only, specifically at farm household level. So far, agricultural water security is measured as sub-indices, and mostly at country level [12,34]. For instance, the index by Lautze and Manthrithilake [35] incorporates agricultural water security as one component for considering the hydrology dimension. Another national index by the ADB [12] incorporates agriculture into the economic water security component. To date, an integration of governance variables in such national indices is often missing, which was also stressed by Dunn and Bakker [36], who conducted an inventory of freshwater indices. Fischer et al. [32] have developed a national hydro-economic classification of water security that includes an institutional as well as a hydrological dimension. Although this index can be applied to the agricultural sector, it does not give detailed information about various governance schemes impacting on the rural households. Further, Norman et al. [25] emphasize that the current assessment tools are not meaningful in indicating water security at a local level. One exception is Norman et al. [25] who developed a water security assessment, the Water Security Status Indicator (WSSI). This addresses the local level and integrates multivariate indicators but is restricted to drinking/freshwater provision. Another local level water security index, for domestic water security, was developed by Jepson [16]. She considers three dimensions: (1) water access (capacity, physical access, and affordability); (2) water quality (biophysical characteristics affecting health); and (3) water affects (emotional and cultural experiences). Particularly concerning irrigation water security, the literature provides two measures. Sangkapitux and Neef [15] defined the concept of water security at a farm household level and developed an index based on: (1) diversity of water sources; (2) access to sources (using share of irrigated land); and (3) risk of water scarcity and conflict. Yet, each dimension is represented by only one single proxy. Sinyolo et al. [14] developed another farm household water security index based on perceptions of irrigators using 12 variables. In the latter, the focus lies on subjective assessments of reliability and consistency as well as water payment schemes. This is too narrow for our purpose.

3. Methodology

In this section, we briefly describe the study area of Tajikistan with a focus on the agricultural water sector. Then we present the data collection and the definition and calculation of our household water security index.

3.1. Study Area Description

Tajikistan is a mountainous and land-locked country in Central Asia. Agricultural production is restricted to only 7% of the total area. The high mountain ranges limit intensive agricultural production to the lowlands of Vakhsh and the Syr Darya river basin [37]. The mean precipitation level is 651 mm/year [38]. However, this level varies significantly between the lowlands and the uplands. Especially in the lowlands, precipitation is very minimal during the summer months. In contrast, during spring time many floods occur due to melting water from the mountains. The total renewable water resources are estimated at 21 m^3/year and 3140 m^3/year per inhabitant [38]. Despite increased water supply from melting glaciers in the short term, over time climate change is expected to reduce the water inflow to the rivers due to less snowfall in winter and overall increasing temperatures, which can be especially risky during the dry summer months. Within the lowlands, large-scale irrigation techniques were introduced during the time of the Soviet Union mainly to establish cotton production. Now, the main crops produced are cotton, rice, and vegetables. Wheat production dominates in the dry land areas with an acceptable elevation. Countrywide, irrigation and livestock account for 90% of the total water withdrawal. Surface water is the most important water source for irrigation, irrigating about 94% of the total irrigated area. Among others, the main surface water irrigation techniques use water pumped from rivers (35%) and water supplied as gravity fed (24%), or diverted from reservoirs (28%). Water losses between the source and the fields are reported at 50–65% [38]. About 38% of the main and inter-farm canals are concrete canals. When it comes to on-farm canals, about 65% are unlined earthen canals. In 2009 about 23,000 ha of the area was salinized and 25,000 ha declared as waterlogged by irrigation, which amounts to 7% of the irrigated land (647,000 ha). Both problems are seen as major challenges to sustaining the arable land [38].

After the collapse of the Soviet Union, water sector reforms were implemented with particular emphasis on the control and allocation of water. Water sector reforms in Tajikistan developed very slowly. The first reform was drafted in 1996 with the so called Water Code. The sectoral reform included the decentralization of responsibilities in irrigation management where district authorities became responsible for large-scale infrastructure and basic maintenance of primary canals and farmers became responsible for inter- and on-farm canal management and maintenance. In 2006, the Law of the Republic of Tajikistan on Water User Associations (WUA) transferred all irrigation related management tasks to Water User Associations [39]. Water, as well as land resources, remain state property. Farms have the possibility to obtain long-term use rights [8,9].

3.2. Data Collection and Empirical Methods

We selected two study areas in the main agricultural areas: Bobojon Gafurov in the Soghd province (northern region) and Bokhtar in Khatlon province (southern region) as indicated in Figure 2. Both regions are geographically separated by high mountain ranges.

Primary qualitative and quantitative data were collected by the main author from March to May 2013. Two focus-group discussions were conducted in each region, one upstream and one downstream of the watershed with 8–12 participants each. The main part of the focus-group discussions was a hands-on participatory mapping exercise, where farmers were asked to draw their irrigation system and to illustrate irrigation-related problems (see e.g., [7,40]). This problem-oriented research method provided insights into participants' attitudes, perceptions, and expectations concerning water related issues. The mapping allowed for more dynamic discussions where we aimed to identify major challenges within the administrative and hydrological water boundaries.All discussions were held in Tajik and Russian language and translated to English. Recordings during the discussions were partly prohibited. Therefore, the discussions were transcribed in a summarized way according to pre-determined criteria.

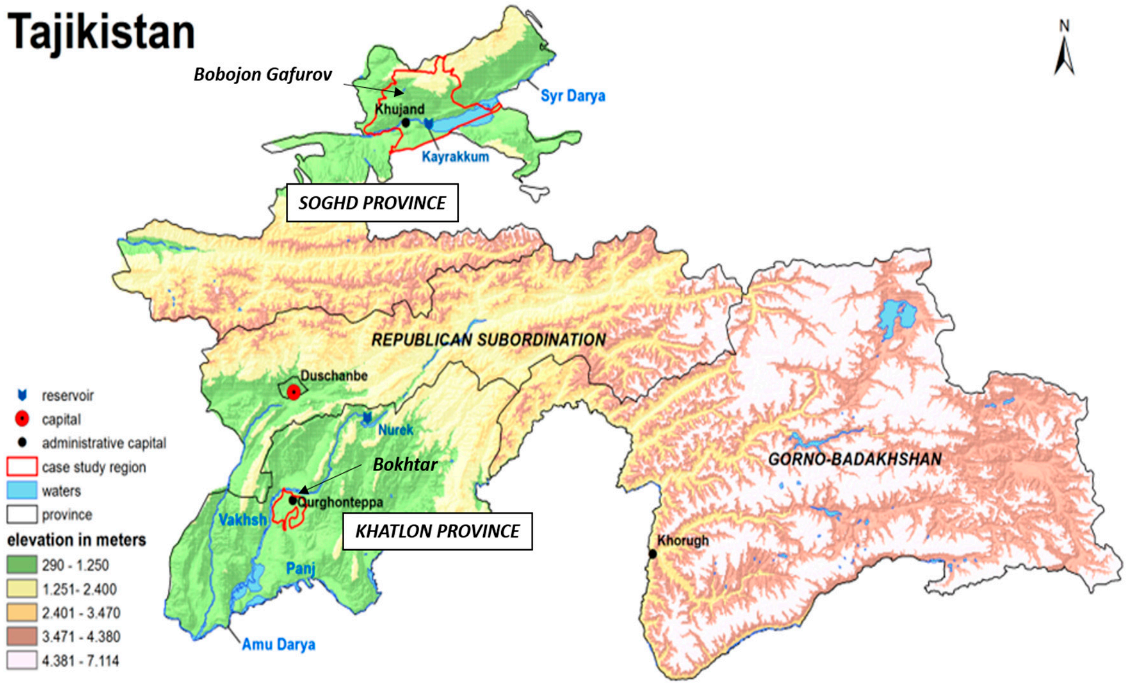

Figure 2. Topographic map of Tajikistan indicating the case study regions. Source: Figure prepared by Neumann and Klümper based on Global Administrative Areas (GADM), version 1 and Data from the Consultative Group in International Agricultural Research—Shuttle Radar Topography Mission (CGIAR SRTM); http://srtm.csi.cgiar.org/.

Further, the qualitative interviews contributed to adapt the survey, which was subsequently tested in each region before finalization.

The core analysis of this paper relies on a farm household survey. For the survey: first, two districts in each agricultural region were selected (purposefully), as they had to be comparable. Therefore both districts had a similar production pattern (cotton, vegetables, orchards, wheat), a high share of surface irrigated areas, a diverse structure of farm types, as well as a similar location to the next bigger city (economic hub, bigger agricultural market). Second, in each district all sub-regions were selected. Third, in each sub-region two villages were randomly selected and finally farm households within villages were chosen according to selection criteria by Bennett et al. [41]. Farm households were only selected if they had used irrigation water and farm land for at least two years. We have a total sample of 399 farms, of which $N = 222$ originate from the Northern Bobojon Gafurov area and $N = 177$ from the Southern Bokhtar area. The sample population includes small-scale households and individual family farms of different farm sizes. The survey included questions on (1) farm characteristics; (2) farmers' land and water management practices; (3) awareness of rights and responsibilities related to land and water; and (4) attitudes towards the potentials and risks of the farming situation. The survey was self-generated using the Bundle of Rights approach [42] to map farmers' property claims and the idea of the Social-Ecological System [43] to specify the irrigation system (as a common pool resource).

We used descriptive statistics presenting the distribution of the water security dimensions. We performed different steps to conduct a cluster analysis to derive a farm typology. First, we applied the single-linkage method to basically check for outliers. In the second step, we used the Ward method for the cluster analysis to determine how many clusters are actually valid for our study. Here, the Calinski stopping rule [44] was applied and we could determine three clusters. Calinski stopping rule suggests 3 clusters (=41.93), the pseudo f-index increased as more clusters were added, but was decreased after the three clusters (Duda/Hart Index 3 = 0.8537 [44]). In the third step, we applied a non-hierarchical cluster analysis using K-means. As we only used binary variables we applied the Matching measures in all three steps of the cluster analysis. In total, seven variables were used. This follows the rule of Formann [45] who mentions the sample size rule of 2 m, where m is the number of clustering variables. In addition, we checked for a low level of correlation between the variables and excluded redundant variables to avoid overrepresentation of some factors.

3.3. Developing an Irrigation Water Security Index for Tajikistan

Households play a significant role in terms of current and future water use practices. With the household perspective, we can show the appropriate variances across the chosen indicators, especially in a country where small-scale agriculture is the main income source for a large share of the rural population. This perspective details the socio-economic and environmental context, so that adaptation options are at hand.

Like the Asian Development Bank index [12], we first standardized and assigned scores from 1 to 5 for each variable of the dimensions. The variables of each dimension were added-up and divided by the number of variables. Each variable is considered to increase the risk of water insecurity if not fulfilled. We did not include any weights in our study, which could, however, be important for further exploration. Adding up the dimensions leads to the overall water security index (WSI). Table 1 lists all variables of each dimension and the assigned standardized values and their meanings.

$$\text{HWSI} = (\text{Quantity} + \text{Quality})/2 \tag{1}$$

$$\text{GWSI} = (0.5 \times \text{Transparency} + 0.5 \times \text{Accountability} + \text{Participation})/3 \tag{2}$$

$$\text{HyWSI} = (\text{Risk} + \text{Abundance})/2 \tag{3}$$

$$\text{WSI} = (\text{HWSI} + \text{GWSI} + \text{HyWSI})/3 \tag{4}$$

An objective statement of the hydrology dimension (HWSI) is difficult to capture for farmers, especially for smallholders in developing countries, where data availability is rare. Here, we used secondary data and the farm household survey data. The indicator quantity was measured by water availability per capita. As water availability per capita data was not available at the village level in Tajikistan, we weighted the regional variable (data) with the distance of the farm household to the next irrigation water source. The distance was measured in meters from the farm household to the next water source used for irrigation. The distance relates to the time and efforts individuals devote to make water available for irrigation [16]. The greater the distance, the lower the likelihood of water security due to reduced availability. This can be a result of higher water access costs (e.g., digging and maintaining canals) or the accumulation of losses from the head to the tail end of a canal. Precipitation figures were not considered as we focused only on surface irrigation areas in our sample.

As data on water quality were not available for the agricultural sector, we considered farmers' perceptions on water quality as an approximation (How do you evaluate your irrigation water quality on a scale from 1 to 5). Given the subjective nature of this measure, the results have to be handled carefully. It implies that farmers assess the water quality conditional upon their intended use of irrigation water resulting in different bases for comparison. However, as Jepson [16] points out, it is important to likewise consider subjective measures, because in the end farmers are the decision-makers. If they perceive a low water quality they might adjust their cropping choices and irrigation practices accordingly.

The governance dimension (GWSI) reveals the subjective access options of farmers. We applied the three governance principles transparency, accountability, and participation [46] to measure a subjective statement on local governance. Transparency and accountability are operationalized by two sub-indicators each. Therefore, both have to be divided by two. Transparency is represented by the farmer's awareness of responsibilities between the gate and on-farm, as well as by the farmer's perception on equal water distribution among farmers. Accountability is represented by the management and investment claims perceived by farmers. The accountability indicator exemplifies for instance means of control or supervisions [30]. In Tajikistan, farmers using irrigation systems are self-accountable as they have duties to manage and invest in the systems, especially inter-farm and farm level canals. If farmers for instance perceive investment or management as their duty, we assume they also have higher accountability and commitment towards good governance of the irrigation systems they use. Participation is the third indicator of governance water security. Enhanced participation of farmers in irrigation systems is likely to create more assurance and security over time, help to ensure the sustainability of the irrigation system, build social capital, and improve equity of water allocation in the long term [46,47]. We measured the level of participation with the variable "water negotiation claims", as farmers who negotiate about water related issues, directly participate in the decision-making process to stress their own water needs [46,47]. We did not include any water payment variables to indicate the ability of households to access water like Sinyolo et al. [14] or Jepson [16], because we did not consider this as a determinant for irrigation water security in Tajikistan, particularly not for the governance dimension. The focus-group discussions we conducted showed that paying for water does not guarantee water access.

The hybrid dimension (HyWSI) is captured by two indicators: water related risk of production and subjectively valued water availability. Risk is one key indicator which increases with higher water variability in the cropping season. If farmers face high water variability (measured in the main cropping months May–August), cropping becomes more difficult to schedule, especially for certain crops such as cotton where water availability needs to be stable. Subjectively valued water abundance forms the second indicator. If farmers perceive insufficient water supplies, this might lead to the adaptation of other cropping strategies or the reduction of certain crop productions [16].

Table 1. Operationalizing the three dimensions of irrigation water security.

Water Security Indicators	Variables	Standardized Values	
Hydrology Dimension (H_{WSI})			
Quantity	(Water availability/capita [a]) * distance to the next water source	1	<500 m^3/cap
		2	500–1000 m^3/cap
		3	1000–1500 m^3/cap
		4	1500–2000 m^3/cap
		5	>2000 m^3/cap
Quality	Evaluation of water quality by farmers (perception)	1	Very Poor
		2	Poor
		3	Acceptable
		4	Good
		5	Very Good
Governance Dimension (G_{WSI})			
Transparency	Awareness of responsibilities for water allocation (gate, primary canal, between canal and farm, on-farm)	1	Knowing none of the responsibilities
		2	Knowing one
		3	Knowing two
		4	Knowing three
		5	Knowing all
	Equal/transparent distribution of irrigation water (perception)	1	Very Poor
		2	Poor
		3	Acceptable
		4	Good
		5	Very Good

Table 1. *Cont.*

Water Security Indicators	Variables	Standardized Values	
Accountability	Perceived management claims	1 2 3 4 5	Never Rarely Occasionally Good Very frequently Always
	Perceived investment claims	1 2 3 4 5	Never Rarely Occasionally Good Very frequently Always
Participation	Perceived negotiation claims	1 2 3 4 5	Never Rarely Occasionally Good Very frequently Always
Hybrid Dimension (Hy_{WSI})			
Risk	High variability during cropping season (perception)	1 2 3 4 5	High variability: in all months (May-Aug) in 3 months in 2 months in 1 month Very low variability
Subjective Availability	Perception of water abundance	1 2 3 4 5	Not abundant Rarely Occasionally good Very frequently Always abundant

Notes: [a] = Data source: [48]; as threshold we used the Falkenmark [49] threshold: >1700 m^3/cap = no stress; 1000–1700 m^3/cap = stress; 500–1000 m^3/cap = scarcity; <500 m^3/cap absolute scarcity.

Stress factors not directly related to irrigation management, such as climate change or natural disasters, were not included in the farm household indicators as these variables affect all farmers to a more or less similar extent.

4. Results

We first display the results of the overall WSI and its three dimensions and then unpack each. Hence, we determine the different farm typologies and compare the governance and hydrology dimensions across these typologies. Finally, we discuss the results of the relationship between the governance and hydrology dimension of irrigation water security.

4.1. Overall Irrigation WSI and Its Three Dimensions

The irrigation WSI is compiled from the data gathered in both agricultural regions: Bokhtar and Bobojon Gafurov, that are similar with regard to their natural conditions (especially water availability, cropping patterns). However, we later tested for different WSI levels between farm types, as we expected regional variance among farms. The density plots (Figure 3) display the distribution of each dimension (dashed lines) from being water insecure to water secure (1 to 5) in contrast to the overall WSI (bold line).

Results between the hydrology and governance dimensions differ considerably (Table 2). The mean value of HWSI is larger (mean 3.19) than the mean value of GWSI (mean 2.45). This supports our assumption that, for a country such as Tajikistan which is naturally water abundant, another dimension besides hydrology is more crucial to irrigation water in-/security at the level of farm households. With respect to water availability (see Table 2 water quantity), we calculated that more than 50% of the respondents have more than 1000 m^3 per capita (i.e., category 3 and higher). The interviews showed that lower values (lower water security) are due to the disconnection to the main canals of some farmers or destroyed pumps for lifting water from the main canal to further downstream canals. Some of the farm household plots in Tajikistan for instance also rely on irrigation water from drainage canals, which is often very polluted (eutrophication, toxic etc.). In an open question we asked farmers to name some general disadvantages of the village. Many farmers answered that low water quality is a major barrier to increasing or maintaining agricultural production. In the long term, polluted water can even lead to a loss of arable land.

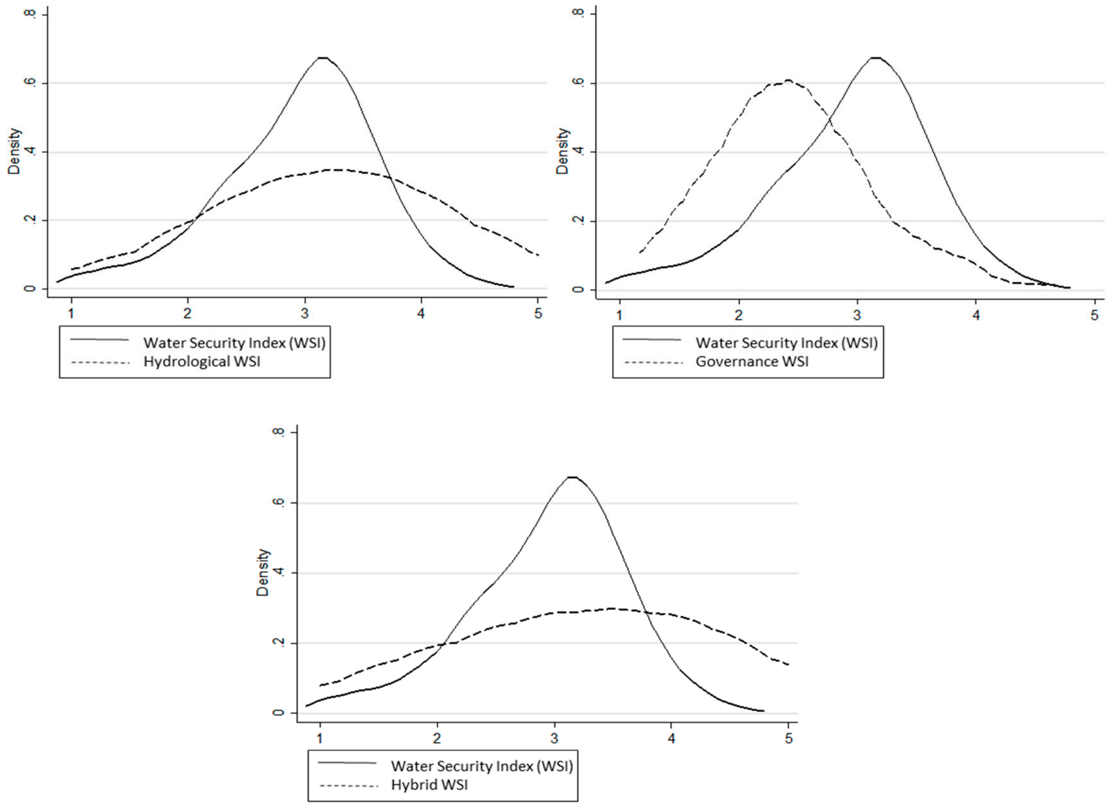

Figure 3. Distribution (k-density plots) of the three dimensions of irrigation water security. Source: Survey data 2013; Note: Scale from 1 = insecure to 5 = secure.

In contrast, the governance dimension received lower average ratings. About 50% of the surveyed farmers had an irrigation governance WSI lower than 2.2. The two principles of accountability and participation are not met with, because of very low values in negotiation and management claims. Also the interviews showed that participation of farmers in local collective action initiatives, e.g., in WUAs, remains low. In Bobojon Gafurov, most WUAs were established within administrative boundaries instead of watershed boundaries with very few active members. Another limiting factor for water governance security in Bobojon Gafurov is the issue of transboundary water problems. After the collapse of the Soviet Union, some of the remaining irrigation canals "now" cross the new borders. For some canals, Bobojon Gafurov holds the up- and downstream position, with Kyrgyzstan in-between. Especially on the Kyrgyz side, new agricultural land, demanding more irrigation water, has been taken into cultivation.

The third dimension, again, follows a platykurtic distribution around a mean of 3.23. The results of high water variability during the cropping season are not perceived as a major water insecurity stressor. In both districts, the mean value exceeds a level of 3 and about 50% of respondents report values of 3 and higher. The results of the perception of water abundance in a way reflect the hydrology dimension of water availability. In addition, there is a significant correlation between the hydrology and hybrid dimension of 0.44 (p-value 0.000). In the remaining part of the paper, we focus on comparing the hydrology and the governance dimension.

Table 2. Descriptive statistics of the three dimensions.

Water Security Dimensions and Indicators	Obs	Mean	Std. Dev.
Water Security Index (WSI)	391	2.95	0.66
Hydrology dimension of WSI (HWSI)	399	3.19	0.92
(Water availability/capita) * distance to the next source	399	2.87	1.09
Water quality	399	3.50	1.23
Governance dimension of WSI (GWSI)	399	2.45	0.66
Awareness of responsibilities	399	3.18	1.26
Equal distribution of water	399	3.02	1.20
Perceived water management claims	399	2.30	1.68
Perceived water investment claims	399	3.41	1.73
Perceived water negotiation claims	399	1.40	1.11
Hybrid dimension of WSI (HyWSI)	391	3.23	1.09
High variability during cropping season	399	3.16	1.22
Perception of water abundance	391	3.28	1.63

Source: Survey data 2013. Note: Mean values of answers to five-point Likert scale with 1 = insecure and 5 = secure.

4.2. Water Security for Different Farm Types

Once the different dimensions of irrigation water security are calculated, the question remains whether water security differs across farm types. This is answered based on three distinct farm types, a result of the initial cluster analysis (Table 3).

Table 3. Farm types based on cluster analysis.

Farm Household Characteristics	(1) Experienced, Small-Scale Subsistence Farms	(2) New Medium-Scale, Market Oriented Farms	(3) Larger-Scale, Market Oriented Cotton Farms
Number of cases (%)	189 (47.7)	144 (36.4)	63 (15.9%)
Mean agricultural area (ha)	0.5	3.4	18.5
in %			
Producing cotton	0.5	0.00	87.3
Producing wheat	15.3	15.3	44.4
Producing vegetables [a]	76.2	36.1	22.2
Production sold	18.5	52.1	96.8
Water fees are paid (1 = yes, 0 = no)	69.8	43.8	73.0
Farm is newly established (<3 years old, established after 2010)	11.1	83.3	68.3
Effective implementation of local land governance	47.6	25.7	58.7
Female farm head	44.4	19.4	17.5

Source: Survey Data 2013. [a] Only potatoes, tomatoes, and onions are included.

Table 3 describes the three distinct clusters identified. Within one community, all three clusters are always represented. The first cluster of farmers is characterized by very small-scale farms (including household farms). Here, only a small share sells their produced crops and subsistence vegetable farming dominates. Almost half of the production units are led by women. In addition, a large share of these farms had existed for a long time as only around 11% of these farms had been established during the past three years. Thus, this group of farmers is more experienced in farming on this specific plot and maybe better organized within the community. In addition, a considerable share evaluates the implementation of local land governance as effective. The respective survey question was: "How do you evaluate the implementation of local land regulations?" We transformed the initial

Likert-scaled variable into a dummy variable (1 = very good and good, 0 = acceptable, poor, very poor. In contrast to the larger-scale farmers, members of this first farm type group can be described as self-organized without the influence of external authorities.

The second cluster is characterized by medium-scale farms, producing diverse crops and marketing a considerable share of their production. Of these farms, 83% had been established during the past 3 years. However, local land governance was only perceived as effective by about 25%. This indicates that they have struggled with local authorities in getting access to farm land either in the past or at the time of the survey.

The third cluster is characterized by large-scale and market oriented farms, where 87% produce cotton. Wheat and vegetables are also produced. These farms are mainly male headed and about 68% were established only after 2010.

The results in Table 4 show that the WSI is similar across farm types. Considering the different dimensions, diverse farm groups do not represent one polarized position in irrigation water security, where both dimensions are either extremely high or low. Instead, different dimensions threaten the farm types differently in their production.

Table 4. Hydrology and governance dimensions of water security across farm types.

Farm Type	WSI	HWSI	GWSI	Correlation Coefficient of HWSI and GWSI [a]
(1) Experienced, small-scale subsistence farms	2.93	3.09	2.48	0.31 ***
(2) New medium-scale, market oriented farms	2.98	3.38	2.31	0.09
(3) Large-scale, market oriented cotton farms	2.94	3.02	2.66	0.32 **
Total	2.95	3.18	2.44	0.19 ***

Source: Survey Data 2013. [a] Pearson correlation coefficient with level of significance ($p < 0.01$) = ***, ($p < 0.05$) = **.

The group of small-scale farmers has the lowest WSI. The HWSI and GWSI values for this group are in the medium to low range. The small-scale subsistence farms are on average more experienced in farming. Compared to newly evolved farms, this experience in farming can be advantageous in terms of production practices and familiarity with the local supply market. Due to the still dominating traditional role of men in water management and negotiations, the fact that small-scale farms are typically run by female farmers might contribute to the lower GWSI value.

The lowest value of GWSI can be determined for the second cluster, the medium-scale farmers. Considering their characteristics, it can be noted that they belong to the group of the most recently established farms. New farmers who have previously worked on the state and collective farms might have less individual farm management knowledge, including water management experience. Remarkably, this group of farm types has the highest hydrology WSI value. In addition, only about 43% actually paid for water.

In contrast, the lowest HWSI value can be determined for the large-scale producers. In contrast, their GWSI values are highest. Some of the large-scale farmers are still organized as such and cultivate the same land as they did before 1990 when collective and state farms were very much subsidized by the state. After 1990, cotton remained an important export crop for Tajikistan. Therefore, the remaining cotton farms were (or still are) supported by local authorities, in terms of water allocation as well. For instance, during the cotton season they are in some cases prioritized in some of the surveyed communities. In contrast, they are also very much controlled by the same authorities, e.g., when it comes to often desired crop changes. This shows that de facto water abundance can be lower for some farmers. With a more pronounced water security level in terms of governance, the low level of the hydrology dimension can be seemingly compensated. As 97% of their production has been sold, they are still able to compete with sufficient agricultural production, which is apparently not limited by a lower level of the hydrology dimension.

Both, medium- as well as large-scale farmers produce irrigation intense crops for the market. Hydrological requirements, however, differ between the crops. Vegetables such as potatoes and tomatoes on average need 7500–9100 m^3/ha with 15–17 irrigation turns in one seasons in Tajikistan. In contrast, cotton requires a considerable but lower share of water with 6000 m^3/ha with eight irrigation turns in one season (irrigation figures were received specifically for Tajikistan (Soghd and Khatlon) from Soghd AgroServ in 2014). Though, to reach reasonable cotton yields, water flow between June and July has to be very exact and reliable. In this case, a higher level of water governance security is very valuable.

We can show that a statistically significant correlation between the two subcomponents, HWSI and GWSI, exists (see Table 4) for some farm types (small-scale and large-scale farms), which indicates complementarities in both measures. Overall, the correlation coefficients are rather low. Most interestingly, whereas such a relationship is supported by the data for large-scale and small-scale farms, for the group of medium-scale farmers the hypothesis of no correlation between the two measures cannot be rejected. For them, the governance dimensions have been valued the lowest on average, however, here HWSI is outstanding. As this is the group with the lowest GWSI value but still with a considerable share of marketed products, we would assume that where de-facto water is seemingly more abundant (high HWSI), GWSI can be substituted by sufficient water availability up to a certain level.

Figure 4 illustrates the relation between the two dimensions. HWSI especially in the lower ranges (between 1 and 3) correlates with an increase in GWSI (linear relationship). This interconnectedness can be identified for the first and third farm type. If an HWSI of about 3 is reached, almost no linear relationship can be determined. This indicates a threshold of the aligning capacity between HWSI and GWSI. In contrast, the close to zero correlation coefficient for the new medium-scale farm type can be explained by a strongly varying mean of GWSI across the levels of the HWSI.

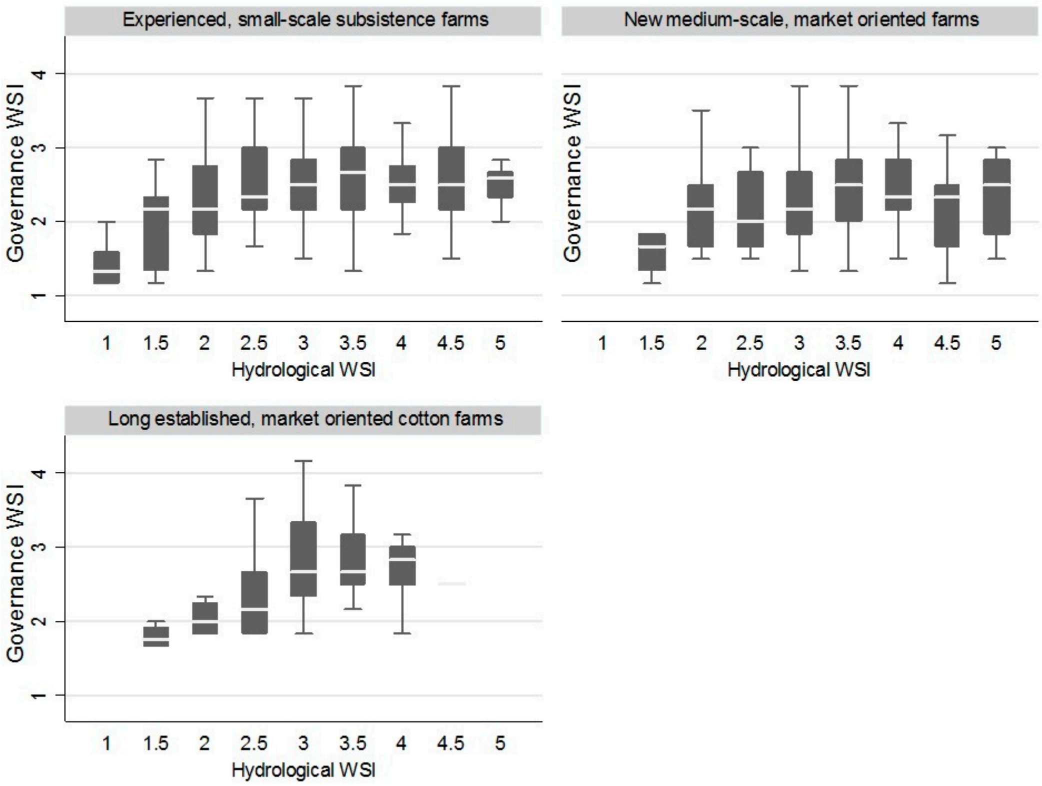

Figure 4. Boxplot of hydrology and governance dimensions across farm types. Source: Survey Data 2013.

5. Discussion

In this paper we analyzed three dimensions of perceived irrigation water security that were identified as central for farmers depending on irrigated agriculture in a semi-arid context. The study goes beyond previous studies on regional water security indicators [16] with a particular focus on the irrigation sector from the perspective of individual farms. We showed that perceived threats to irrigation water security can be of institutional/management or biophysical/infrastructural nature and result in different dimensions to be considered. Thus, (1) governance systems, governing farmers' decisions and actions; and (2) hydrological conditions, indicating the de-facto water availability are critical in enhancing irrigation water security. Jepson [16] points out that it is important to analyze subjective water security levels too, because in the end farmers are the ones deciding on water use and irrigation practices. If a farmer perceives his/her situation to be water insecure, he/she might develop a coping strategy or even try to avoid certain use practices [16], independent of the actual availability of water.

The dimensions and each variable pointed to the (potential) risks of water (in-) security. Similar to the water poverty index put forward by Sullivan et al. [50], our index aims at simplicity. Hence, it can be adapted to other contexts where regional data availability is low.

Obviously, the focus on the agricultural sector comes with the risk of neglecting potential conflicts of interest across sectors within one country [35]. For instance, a high level of water security in agriculture might affect water security for energy production or vice versa, the latter considered an increasing competitor for agriculture in Central Asia [51,52].

The limited availability of disaggregated hydrological data imposes constraints upon the analysis and the objective regional measurement of water security presented here, which also applies to other studies in similar developing countries. Despite these limitations, our index provides an initial idea of the hydrological situation of individual farms, here in two selected Tajik regions. Finally, the cross-sectional household data do not allow for testing long-term impacts, coping strategies regarding sudden disturbances, or external shocks. However, the suggested approach allows for repeat surveys and the construction of consistent panel data sets.

The following discussion follows upon our initial question, of whether the hydrology and governance dimensions are necessarily complementary. The paper does not aim at downplaying one or the other dimension, but rather to test the fit or unfit of both. As not all groups of farmers are threatened by both dimensions equally, our results do not support the assumption that both dimensions are equally important. Two possible trade-offs exist. First, the dimension governance could serve as a "coping" mechanism to deal with constraints in the dimension hydrology. Second, the constraints imposed by the governance dimension could in turn have less impact should the hydrology dimension be sufficiently high and reliable. However, there is no unique direction of causality.

Assuming that all farmers in Tajikistan have abundant access to water is misleading. Overall, farmers are expected to be more resilient when both dimensions exceed a certain threshold of water security, but different levels of the HWSI between farm households were determined. For farmers for whom water is comparably more abundant, HWSI is expected to have the ability to compensate for weaker water governance. As the results show it is also important to look at each dimension separately to interpret the overall aggregated index.

One would assume that higher levels of hydrological water security would be able to substitute weak governance. This goes in line with an argument by Meinzen-Dick and Nkonya [53] who state that when water is abundant farmers tend to be less concerned about governance issues. Our results support this argument. For example, governance measures are comparatively low for medium-scale farmers, but here, the hydrology dimension is more distinctive, and the farmers of this group still actively produce crops for the agricultural market. In addition, we could also show that the opposite coping mechanism can arise, where governance security can help in overcoming apparent hydrological insecurity. Our results show that the group of large-scale farmers have the capacity to cope with a seemingly lower hydrology dimension of water security by enforcing their governance situation.

For all three farm types we determined that if both HWSI and GWSI are lower (between 1 and 3), a linear relationship exists. But if the level of the hydrology dimension exceeds 3, a linear relationship with the governance dimension is no longer valid. Further, the water security dimensions of the different farm types are not disconnected (similar to [16]). If one farm type holds a more pronounced level of one water security dimension, it is weaker for another farm type. This is not unexpected as more influential farmers might have the power to exclude others (higher vs lower GWSI). In our case, this other farm type with a lower degree of GWSI, accordingly has stronger level of water security of the complementary dimension (e.g., HWSI). So there is not always a monotonic relationship.

A non-monotonic relationship could be also identified with the help of the qualitative interviews, where we determined further long-term feedback loops between the dimensions. Here, GWSI was reformed, but HWSI was more difficult to influence. Since 2010 many government initiatives with the help of international donors focus on the establishment of water user associations. However, the de-facto hydrological problems (such as increase in water salinity, drought, or flood management) are not addressed by these newly established associations. Hence, active participation in water user associations is low, as improvements in water access and availability are not realized and the hydrology dimension of water security remains low. Thus, the limiting factor, here GWSI, could switch to the other dimension (here HWSI) and hydrological limitations could become even more relevant in an improved governance situation.

Water security should also be regarded concerning the congruence between the prevailing water governance system and the bio-physical and social boundaries, as discussed under the concept of "fit" by Young [54]. For the case of Tajikistan, the GWSI has shown that the governance systems in place are differently perceived by representatives of the three farm types. These farm types are characterized by different socio-economic factors, produce different crops for different markets and are located at diverse irrigation canals (primary, secondary). Therefore, we assume that these farm types face diverse social boundaries, which points at the possibility of not all of them seeing themselves as well represented by the governance systems in place. Another aspect is a gender bias in governance, as the needs of female farmers who face different social boundaries are not well respected in the governance. Moreover, as we have discussed above, female farmers are not included in water management. Further aspects as to how far delineations of water use, fit the boundary of the social system have hardly been studied in Tajikistan and require further research.

Another question of fit arises between water security and land governance. We expect, similar to Hodgson [55] and Cotula [56], that the impact of land use rights on water security will become increasingly important as water becomes scarcer (i.e., HWSI declines). Irrigation governance boundaries do still widely follow the given boundaries of the technological irrigation infrastructure, which served the large production units of the socialist time. Thus, the current governance systems are not always in line with the newly emerging smaller farm and plot sizes. Therefore, we assume that effective water security in the future will require institutional water arrangements to take the dynamics of land use rights into account.

6. Conclusions

Water security is an issue, especially in regions where agricultural production depends on reliable irrigation water flow. In these countries, more extreme events such as floods and droughts are expected to increase hydrological water variability over the coming years. However, access to irrigation water is also subject to institutional constraints. Thus, governance mechanisms will have to act as coping mechanisms in linking water availability in rivers with water availability at the plot level. Therefore, water security is defined to consist of three different dimensions: (1) the hydrology dimension; (2) the governance dimension; and (3) the hybrid dimension.

The results, when analyzing the individual water security indexes of all three dimensions, emphasize the importance of going beyond the aggregated national-level. Particularly the hydrology and governance dimensions, with their clear conceptual boundaries, help to point to and prioritize critical aspects of Tajikistan's water security among farm households. Recently established medium-sized farms perceive the lowest level of governance water security index, measured by GWSI. Farmers in this group appear to be less connected to the irrigation administration, as indicated in their low knowledge of water pricing and land market functions. Once the hydrological conditions of water security become insufficient, water governance security becomes especially important. But even under "normal" conditions, the relationship between the governance and hydrology dimensions has to be balanced. A proper water governance security reduces risks and uncertainty for farmers. In the long term, this might have an effect on the decisions and actions taken by the farmers. Thus, a transparent and reliable access of households to water shapes the development of agricultural production in rural communities and the economic prosperity of agricultural households and farms.

The hydrology dimension is key in improving agricultural production, e.g., by investing in infrastructure or drainage canals. This could implicitly cause better subjective water governance security (willingness to invest more, participating more) as farmers directly appreciate improvements in hydrological conditions. But if HWSI exceeds a threshold of 3, implicitly governance security improvements are limited. Thus, a specific emphasis has to be directed towards improved governance independent of the hydrological dimension.

As indicated by Sullivan et al. [50], hydrological water security measurements help decision-makers to identify specific interventions targeted towards the needs of the beneficiaries. However, especially for "donors", their understanding and willingness to invest in both dimensions has to be improved. Likewise, for domestic policy makers, it might be easier to facilitate improvements in water governance as the hydrology dimension is more static and depends also on natural conditions. Yet political actors tend to invest in projects which allow for short-term impacts, and are easy to evaluate, such as large-scale infrastructure investments. Likewise, changes in water governance might face resistance from previously privileged water users. In turn, improvements of governance conditions could lead to better hydrological conditions as a side-effect.

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