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Smallholder farmer resilience to water scarcity

Francisco X. Aguilar[1] · **Dienda Hendrawan**[2] · **Zhen Cai**[3] · **James M. Roshetko**[4] · **Judith Stallmann**[3]

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Abstract

Water scarcity poses one of the most prominent threats to the well-being of smallholder farmers around the world. We studied the association between rural livelihood capitals (natural, human, social, financial, and physical) and resilience to water scarcity. Resilience was denoted by farmers' self-reported capacity to have avoided, or adapted to, water scarcity. Proxies for livelihood capitals were collected from two-hundred farmers in South Sulawesi, Indonesia, and their associations with a typology denoting water scarcity impacts analyzed with a Taylor-linearized multinomial response model. Physical and natural assets in the form of irrigation infrastructure and direct access to water sources were saliently associated with overall resilience (avoidance and adaptation) to water scarcity. Years of farming experience as a form of human capital asset was also strongly associated with resilience to water scarcity. Factors solely associated with the capacity to adapt to water scarcity were more nuanced with social capital assets showing closer associations. A household with a larger number of farm laborers had a higher likelihood of being unable to withstand water scarcity, but this relationship was reversed among those who managed larger farming areas. We discuss possible mechanisms that could have contributed to resilience, and how public policy could support smallholder farmers cope with water scarcity.

Keywords Smallholder farming · Water scarcity · Weather resiliency · Livelihood capitals · Multinomial logistic

✉ Francisco X. Aguilar
Francisco.aguilar@slu.se

1 Swedish University of Agricultural Sciences, Umeå, Sweden

2 University of Goettingen, Goettingen, Germany

3 University of Missouri, Columbia, USA

4 Southeast Asia Program, World Agroforestry Center (ICRAF), Bogor, Indonesia

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1 Introduction

Smallholder farmers, households working on land plots smaller than two hectares, are the backbone of global agricultural production harvesting some 80% of the world's annual crops (FAO et al., 2018). By virtue of the size of their holdings, frequently on low-quality sites, and limited financial resources, they are more often vulnerable to market and weather fluctuations than farmers endowed with more farmland and financial resources. The livelihoods of 475 million small farm households in developing countries are at the forefront of the challenges posed by a rapidly changing climate (Rapsomanikis, 2015; Verchot et al., 2007). Climate change is already causing record temperatures and will very likely result in major deviations from historic rainfall patterns that will exacerbate the frequency and extent of drought (Collins & Knutti, 2013). Human–environment interactions occurring within agricultural systems highlight the importance of identifying characteristics associated with resilience to extreme climate disturbances (Turner, 2010).

Water scarcity, a condition where demand for water exceeds its availability, is expected to become a more prevalent event to which smallholder farmers will be particularly vulnerable (Damkjaer & Taylor, 2017; Röschel et al., 2018). Changes in the volume and distribution of rainfall directly affect rain-fed crops and hotter temperatures escalate irrigation requirements, thus, increasing water demands (Hanjra & Qureshi, 2010). Water scarcity affects the quality and quantity of agricultural yields with a direct effect on food security, the likelihood of social conflicts, and wider rural poverty (Kang et al., 2009; Rahmati et al. 2014, Maleksaeidi et al., 2016). In this context, resiliency captures the ability of farmers to avoid or adapt to the impacts caused by water scarcity while retaining the function, structure, and identity of their livelihoods (Carpenter, 2001; Folke et al., 2010).

Livelihood assets can help examine a household's capabilities to act and adapt to shocks (Bebbington, 1999), but the relationships between complementary capabilities to smallholder farmers' resilience to water scarcity are still rarely explored in the literature. This study aims to fill a knowledge gap in the current understanding of factors associated with rural households' resilience to water scarcity, particularly in smallholder farming contexts. Specific objectives included to quantify and determine the statistical significance of livelihood resources associated with smallholder farmers' self-reported capacity to avoid or adapt to water scarcity; and how such relationships change contingent on available farmland. Following a sustainable rural livelihoods capital framework (Bebbington, 1999; Ellis, 2000; Knutsson & Ostwald, 2006; Quandt, 2018; Quinlan et al., 2016), we gathered and analyzed information on smallholder farmers' natural, human, social, financial, and physical assets to determine their respective associations with self-reported resilience to water scarcity.

Our empirical data were collected in Indonesia—a country with over 12 million small farms, of 0.92 hectares in average size that account for over 90% of the annual value of national crop harvests (FAO, 2018). Compared to historical patterns, climate change projections suggest Indonesia will suffer from fluctuating temperature and rainfall patterns, and more frequent water scarcity and drought (World Bank Group, 2019). Data collected from small Indonesian farms in South Sulawesi were used to test our research questions. Next, we describe the five capitals framework that served as our theoretical framework, define the psycho-social construct that assessed household-level resilience to water scarcity, and outline the methods used to analyze our data. Following our findings, we discuss the likely mechanisms that could have contributed to resilience to water scarcity, and stress results that reflect on land and other resource interactions—particularly between labor and farmland as two of the least and most constraining assets among smallholder farmers.

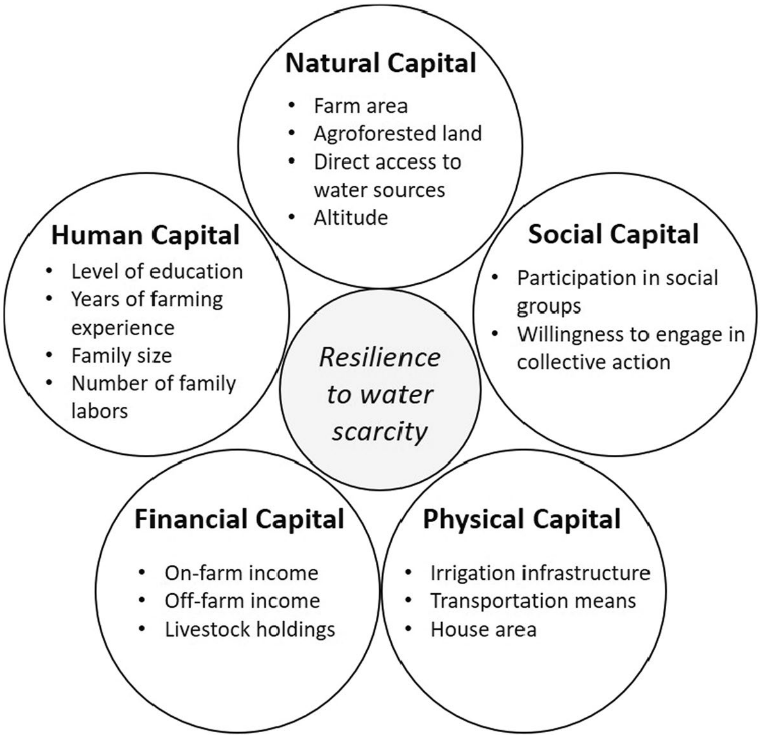

Fig. 1 Rural livelihood capital assets and examples relevant to rural tropical smallholder farmers. Adapted from: Bebbington (1999), Donovan & Stoian, 2012), Maleksaeidi (2016), Quandt (2018)

2 Theoretical framework: livelihood capitals and resilience to water scarcity impacts

The five capitals framework for sustainable livelihoods (Scoones, 1998; Shinbrot et al., 2019) served as the theoretical foundation to examine smallholder farmers' resilience to water scarcity. This asset-based framework identifies and recognizes the roles of natural, human, social, financial, and physical capitals, as resources to help measure capabilities to build and sustain rural livelihoods (Bebbington, 1999; Scoones 1999; Ellis, 2000; Donovan & Stoian, 2012). The sustainable livelihood capitals framework offers an inherent multidisciplinary approach to the assessment of how rural capital assets support and enhance the capacity to cope with external stressors (Emmanuel-Yusuf et al., 2017; Nelson et al., 2010; Williges et al., 2017).

Figure 1 depicts the five capitals framework including the proxies used in this study to assess each of them. Production, regulatory, and sustaining ecosystem services (e.g., water supply, water and micro-climate regulation, food production) emanate from natural capital to contribute to rural livelihoods (Altieri et al., 2012). Human capital encompasses skills, knowledge, dexterity, and good health, among other attributes available within individuals (Scoones, 1998; Adato 2002). Social capital builds on the development of human capital to support institutions or social infrastructure (e.g., schools, farmer groups, cooperatives) to achieve goals that could not be attained individually

(Adler & Kwon, 2002; Donovan & Stoian, 2012). Financial capital encompasses monetary assets that a household holds or has access to with cash being the simplest form of financial asset (Ellis, 2000). Physical capital, referred to as human-made capital or infrastructure, facilitates individuals and collective activities (Moser, 1998; Scoones, 2009).

Resilience emphasizes the capacity to avoid, or adapt to, unexpected changes to sustain one's well-being, whether or not such dependence is recognized (Biggs et al., 2015; Clark, 2007). Nelson et al. (2010) stress that agriculture is a dynamic system that constantly needs to adapt to magnitude, rapidity, and direction of unexpected extreme weather events, such as those triggering water scarcity. The five capitals framework for sustainable livelihoods links households' capabilities and adaptation capacities, hence resiliency, to external stresses and shocks with empirical evidence pointing to such associations only recently emerging. For instance, Liu et al. (2020) report that ownership of forestland (as a type of physical asset) and off-farm employment (as a form of complementary financial asset) directly contribute to Chinese smallholders' farming strategies with respect to poverty alleviation following resettlement. In a different context, Sina et al. (2019) report the complex role of all livelihood capitals in supporting resiliency to large displacement (as evidenced after the 2004 Indian Ocean tsunami), and highlight the fundamental role that human capital had in supporting post-disaster livelihoods.

Resilience to the impacts of water scarcity is a psycho-social construct that embodies how a household deems its exposure to, impacts of, and capacity to cope with water scarcity. Water scarcity has inherent biophysical and socio-economic dimensions that partly determine its impacts and a household's coping abilities. Bio-physical water scarcity refers to a condition where there is not enough water available to meet local demands due to climatic and geographic circumstances (Rijsberman 1994). Economic water scarcity can be described as a condition where there is limited access to water due to inadequate infrastructure, thus, it is largely an anthropocentric condition (Damkjaer & Taylor, 2017). Resources available to a household, as encapsulated in the livelihoods capitals framework, influence the ability to cope with water scarcity (Quandt, 2019). Water scarcity has often intangible and ambiguous aspects that can lead to different interpretations; it is the affected party through individual experience and perceptions that internalizes and constructs the degree of effects and detriment (Langridge et al., 2006; Stehr and von Stoch 1995). Water scarcity and its impacts are both real (i.e., water supplies are scarce) and constructed by individuals and institutions through socio-political discourse and experiences framed by bio-physical and socio-economic contexts (Mehta, 2003).

As a psycho-social construct the impact of, and capacity to cope with, water scarcity is unobservable but the degree of self-assessed reported impacts and ability to withstand it is. This motivates a latent function that underlies self-reported water scarcity impacts and consequent degree of resilience. The degree of a farmer's self-constructed resilience (R*) can be modeled as a function of five capital assets as:

$$R^{*} = f(\text{natural, human, social, financial, and physical}) \tag{1}$$

Following a review of the literature and local focus groups, farmers' self-reported degree of resilience to water scarcity was classified under one of three mutually exclusive categories: (i) avoidance of water scarcity, (ii) adaptation to water scarcity, and (iii) inability to withstand water scarcity. These categories are outlined in Table 1. The period over

Table 1 Typology describing farmers' self-reported assessment of water scarcity impacts on their livelihoods

Categories	Self-reported assessment & description*
Avoidance of water scarcity	I have not experienced water scarcity: Farmer reported her/his household's livelihood has not been affected by water scarcity
	I have experienced water scarcity, but it did not affect my livelihood at all: The farmer reported her/his household's livelihood experienced only negligible impact to its quality in the face of water scarcity
Adaptation to water scarcity	I have experienced water scarcity, it affected my livelihood only a little and was able to recover: The farmer reported her/his household's livelihood experienced non-negligible impact, but was able to restore the quality of the household's livelihood
	I have experienced water scarcity, it affected my livelihood quite a lot but I have recovered: The farmer reported his/her household's livelihood has been negatively affected by water scarcity, however, was able to cope with it without impact to the quality of the household's livelihood
Inability to withstand water scarcity	Water scarcity is always an issue for me and it has affected my livelihood: The farmer reported her/his household's livelihood has and might still be negatively affected by water scarcity. Farmer reported non-negligible impacts and the inability to restore the quality of the household's livelihood

*Self-reported assessment recorded by enumerator through face-to-face surveys in response to descriptors of water scarcity impacts. Impacts encompassed the preceding five years from the time of the survey inclusive of the current farming season

which farmers were asked to self-assess their resilience to water scarcity included the five years preceding the time of the survey, inclusive of the current farming season.

The probability of reporting into any of the three j categories is conditional on the values of livelihood capital assets as:

$$\mathrm{Prob}\,(R^{*} = j|X) \tag{2}$$

where j possible categories correspond to the avoidance of water scarcity, adaptation to water scarcity, and inability to withstand water scarcity; $\boldsymbol{X}$ is an information matrix capturing levels of capital assets plus an intercept; with the condition that response probabilities Prob ($R^{*}=j$) sum to unity. We were interested in testing the directional and statistical significance of associations of capital assets with increased likelihood of self-reporting into one of the typological categories denoting resilient (e.g., avoidance or adaptation) livelihoods, over the inability to withstand water scarcity which served as our baseline for comparison.

We expected to observe a direct relation between greater availability of capital assets and resilience to water scarcity. Due to the physical and anthropocentric nature of water scarcity we expected natural and human-built physical assets to dominate direct associations with greater probabilities of reported avoidance of, or adaptation to, water scarcity that corresponded to resiliency categories. Given the particular characteristics of smallholder farmers, we tested whether farmland had statistically discernible associations with livelihood resilience when interactions with other non-natural forms of capitals were included. Here, we aimed to identify more nuanced associations beyond main asset-specific effects. Particular to the foremost condition characterizing smallholder farmers

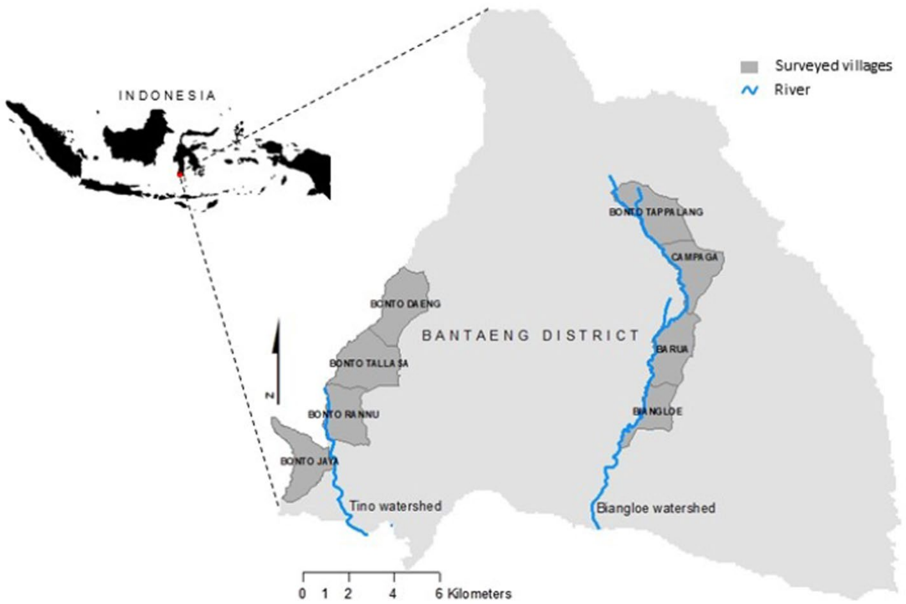

Fig. 2 Study area identifying watersheds and surveyed villages in South Sulawesi's Bantaeng District, Indonesia

(limited farmland acreage), we expected corresponding land-resilience associations to be contingent on human, social, financial, and physical factors. Findings on capital interactions highlight the importance of considering the various and assets that influence resilient smallholder farming (Mutenje et al., 2019; Walker et al., 2004).

3 Methods

3.1 Study area

We collected data from smallholder farmers in Bantaeng District of South Sulawesi, Indonesia (Fig. 2). This area and geographical scale were chosen to keep a degree of homogeneity across a socio-ecological landscape dominated by small farms. By keeping overarching climate and weather conditions homogeneous, differences in self-reported avoidance of, or adaptation to, water scarcity were associated with explanatory variables. Eight villages within two different watersheds, Tino and Biangloe, were included in our study. Our design included four paired villages along the altitudinal levels (0–300, 301–500, 501–800, and 801–1000 m above sea level) of the watersheds. This sampling aimed to keep a balanced design, yet allowed for differences in farming practices and capitals between altitudinal levels ranging from mountainous to coastal levels. Farms in both watersheds are characterized by mixtures of agroforestry-based system (cacao, cloves, and coffee) and degraded land with annual crops (maize and paddy).

The Bantaeng District is located at 5.5169°S, 120.0203°E, covers an area of 395.83 km^2, and has a population of 185,000 people. The landscape of the northern section of the District has steeper slopes and higher altitudes. The southern part of the District area is flatter and characterized by the coast that meets the Flores Sea. Historic rainfall pattern is bimodal with a rainy period between November and May and a dry period from June through October (Tsuchiya et al., 2009). It is during the dry period when water scarcity is most likely to occur which has been periodically reported in South Sulawesi since the turn of the century. When our research was conducted, the Bantaeng District received an average of 14 rain days/month with an average annual precipitation of 245 mm^3/month. A majority of farmers in Bantaeng are smallholders who rely on agriculture as main sustenance. Historically, smallholder farmers have planted maize, rice, and coffee. However, in the mid-1980s, planting hybrid maize became popular and subsequently led to conversions of more forested area into farmland. During that decade, there were also increases in plantings of coffee, cacao, and clove (Mulyoutami et al., 2012).

3.2 Survey instrument and data collection

We developed a survey for primary data collection. A first draft was prepared from September 2017 through April 2018 and pre-tested from May to June 2018 with individual farmers and focus groups. Pre-testing assessed the validity of the instrument, ensured clarity and tested interpretation of questions, and estimated the time needed for each interview (Dillman, 2011). Final survey sections and secondary data used in this study are outlined in Table 2**.**

Farmers were asked whether they have ever experienced water scarcity. Following their preliminary answer, they self-evaluated their household placement by selecting one of five statements that best described their experiences coping with drought over the preceding five years (including the current farming season). The statements and categories denoting resilience to water scarcity are outlined in Table 1. When necessary, we provided follow-up explanations of water scarcity and livelihood impacts during face-to-face interviews. We relied on a series of proxies to assess farmers' household-level capital assets. Proxies for each capital were based on previous studies focusing on smallholder farmers resilience, literature review, and previous studies on smallholder farmers in Bantaeng District. We differentiated between agroforestry and monoculture farming as the two main agricultural systems in the area. The combination of trees and crops in agroforestry can provide more robust ecosystem services such as carbon sequestration, biodiversity conservation, soil enrichment, and air and water quality, and diversify on-farm sources of income (Quandt et al., 2017, 2019). Direct on-farm water source denoted direct access to a stream or rainwater collected in natural ponds; altitudes of household location captured discernible differences in evapotranspiration and rainfall within watersheds (MacMillan & Liniger, 2005). Participation in group activities (farmer's group, cooperative, or village community association) and participants' willingness to engage in collective action captured preferences to solve water scarcity problems collectively—over tackling them individually—likely reflecting on local solidarity, reciprocity, and trust (Kumar Nath et al., 2010). We gathered information on total household income and livestock holdings as forms of financial capital. Information on housing area and means of transportation also reflected on access to physical resources in rural contexts (Donovan & Stoian, 2012; Scoones, 1998).

Considering the total number of households in the eight villages within the two watersheds, a sample size of 200 respondents was adequate to achieve a 95% confidence level with a 10% margin of error (Dillman, 2011). We followed a stratified random sampling approach where twenty-five households were randomly chosen from a registry available

Table 2 Description of variables used as proxies of livelihood capitals to examine associations with avoidance of and adaptation to water scarcity

	Variables	Response/ unit
Natural capital	Total farmland area[1]	Hectare
	Farmland share under agroforestry system management	%
	Direct natural access to water source[2]	0 = No, 1 = Yes
	Altitude > 300 m.a.s.l.[3]	0 = No, 1 = Yes
Financial capital	Total yearly household income[4]	US$/year, above subsistence
	Number of livestock holding[5]	Number of animal units
Human capital	Level of education (head of household)	0 = did not go to school, 1 = did not finish elementary school, 2 = elementary school graduate, 3 = junior high school graduate, 4 = high school graduate, 5 = bachelor's degree
	Farming experience	1 = 0–5 years; 2 = 6–10 years; 3 = 11–15 years; 4 = 16–20 years; 5 = 21–25 years; 6 = more than 25 years
	Number of household farm laborers	Number of persons
	Number of household members	Number of persons
Social capital	Participation in social groups[6]	0 = No, 1 = Yes
	Willingness to engage in collective action[7]	0 = No, 1 = Yes
Physical capital	Transportation modes	Number of transportation modes
	Irrigation infrastucture[8]	0 = No, 1 = Yes
	House area (m^2)	m^2

[1]Total hectares of farmland across all parcels managed including private and shared ownership or leased parcels. [2]At least one on-farm water source coming directly from a stream or rainwater collected in natural ponds. [3]Derived from geo-referenced geographic information system. [4]Summation of average yearly: on-farm income, off-farm income, and remittances. [5]Livestock animal units (AUs) converted using the following factors: 1 cattle = 0.65AU, 1 horse = 0.65 AU, 1 sheep = 0.1 AU, 1 chicken = 0.01 AU, (FAO, 2011). [6]Denotes involvement in any of the following: farmer groups, cooperatives, village community group. [7]Preference to solve water scarcity-related problems collectively over individually. [8]Includes on-farm equipment and materials used to distribute water to farm crops whether individually or collectively owned

in each village. Selection criteria were twofold: respondents needed to actively practice farming and be at least 25 years of age at the time of the survey. These sampling criteria ensured that the livelihoods of participants were agricultural and with the ability to make land management decisions. If these criterions were met, farmers were then asked for their willingness to participate in the study. We interviewed heads of the household, to consistently reach to the primary decision maker regarding a household's farming activities. There were several instances when the household head was not available (e.g., too old or frail), and farming decisions have been left to an offspring. In these cases, the latter was interviewed with the head of household present to validate answers.

Surveys were completed via face-to-face interviews by a local enumerator and included key-person in-depth interviews with chiefs of the village and senior farmers to collect more detailed information of village and farming history, water access, climate, and other contextual information. Local enumerators were trained for the unbiased delivery of the questionnaire and to ensure the consistent translation of questions as many of our respondents only spoke the local Makassarese language (Crawford, 1997). Data collection took place from May until July 2018. Across all villages we experienced a rejection rate of 10% until our sample size was met.

3.3 Econometric analysis

A multinomial logistic model was chosen as the correct econometric specification due to the complete and mutually exclusive nature of categorical responses. Moreover, this nonlinear model allows capturing complex interaction effects inclusive of explanatory variables' coefficients changing magnitude and direction contingent on other explanatory variables (Ai & Norton, 2003). We estimated the probability of a farmer self-assessing avoidance or adaptation to water scarcity, over the inability to withstand impacts of water scarcity. The normalized functional form of a multinomial logit model for three categories of the dependent variable was given by (Hausman 1981; Greene, 2011):

$$\mathrm{Prob}\left(R_i^* = j | x_i\right) = \frac{e^{\beta_j x_i'}}{1 + \sum_{k=1}^{J} e^{\beta_k x_i'}}, j = 0,\ 1,\ 2; \beta_0 = 0 \tag{3}$$

where the probability of the response by the ith farmer to be equal to the jth category (0 = incapacity to withstand water scarcity, 1 = avoidance of water scarcity, 2 = adaptation to water scarcity) is conditional on an information x_i' vector with first-element unity comprised of proxies for a household's five capitals and farmland interaction terms as per our research hypotheses. Moreover, β_j is a vector of coefficients for the $j = 1, 2$ categories relative to the $j = 0$ baseline. Log-odds were computed as:

$$\ln\left[\frac{\mathrm{Prob}_{ij}}{\mathrm{Prob}_{ik}}\right] = \left(\beta_j - \beta_k\right)x_i' = \beta_j x_i', \mathrm{if} k = 0 \tag{4}$$

and odds ratios calculated by exponentiating β_j coefficients. The percent change in odds was given by:

$$100 \times \left\{e^{(\beta_j x')} - 1\right\} \tag{5}$$

The multinomial regression was estimated for a stratified (village-level) dataset where each household represented our sample unit of equal weight. We used a Taylor linearization approach (also known as the delta method or the Huber/White/robust variance estimator) in the multinomial estimation of robust standard errors to reflect our sample design (Demnati & Rao, 2010). Before model estimation, we tested for the independence of irrelevant alternatives (IIA) assumption using Hausman and Small-Hsiao test-statistics (Cheng & Long, 2007; Small & Hsiao, 1985).

In the multinomial regression we used each proxy for livelihood capitals as an explanatory variable to capture capital-specific main associations. The variable 'total farm area' was log-transformed to deal with its non-normal distribution (Shapiro–Wilk test: p value < 0.05) and to better capture nonlinear effects. Main altitude effects capturing evapotranspiration and rainfall differences were discerned between farms at greater than 300 m.a.s.l., and those at lower altitudes. We interacted "total farm area" as one of the most limiting natural capitals with a proxy from each of the other capitals to capture more nuanced mixed effects—with particular attention paid to interactions between labor and farmland as two of the least available and most constraining assets among smallholder farmers. Else constant, we tested the association between having an additional farm laborer and a household's odds of either being in the avoidance and adaptation categories as:

$$\left\{100 \times e^{\left(\beta_{j,\text{Number of family laborers}}+\beta_{j,\text{Farm area (log)}\times\text{Number of family laborers}}\right)} - 1\right\},\ \text{for } j = 1, 2. \quad (6)$$

Inclusion of interaction effects between household's farmland and number of farm laborers further allowed assessing complex relationship including changes in the likelihood of being in a particular category. Specifically, we tested whether, there was a turning point that changed resiliency associations between the number of family laborers and farmland by setting odds ratios at '1':

$$e^{\frac{-\beta_{j,\text{no. family laborers}}}{\beta_{j,\text{no. family laborers}\times\ln(\text{farmland})}}}\ \text{for } j = 1,\ 2. \quad (7)$$

We identify outstanding capital factors making direct contributions to water scarcity resiliency as those positively and statistically ($p<0.05$) associated with greater odds of avoidance and adaptation to water scarcity, categories over incapacity to withstand it. All analyses were conducted in Stata Version 15.

3.4 Study limitations

This study has various inherent caveats. The first relates to our typology denoting impacts of water scarcity using a psycho-social construct. The categories depict heads of households' own subjective construction on the degree of how water scarcity has affected their livelihoods and whether they have avoided, coped, or could not withstand it. The nature of this response justifies our econometric specification, but observations themselves might be exposed to errors. We tried to reduce response bias in our data via face-to-face interviews to ensure the validity of answers, but we cannot completely rule it out. Another caveat relates to our inability to make causal inferences. Our results are limited to the association between capital factors and the likelihood of avoiding or adapting to water scarcity, over incapacity to withstand it. We are also limited in our ability to make inferences to populations other than those of similar bio-physical and socio-ecological contexts as found in our study area. For instance, our study area has two well-known dry and wet seasons, with annual rainfall of over 2900 mm^3, which, although common in many tropical regions, is not universal. Further, as compared to other areas in Indonesia and across the tropics, it is often common to find communally owned lands used for agriculture. Our context is one where farmed parcels are largely under private ownership with only a fraction under communal or leased management. Different land governance and tenure regimes can influence the capacity of smallholders to cope with exogenous stressors (Barbieri & Aguilar, 2011; Schlager & Ostrom, 1992), but our sample is not suited to test such effects. Moreover, our study area is deemed to be ethnically homogeneous; variability in perceptions of resiliency between ethnic groups could not be examined (Quandt, 2019). Lastly, our dataset corresponds to a single cross section and may not be applicable to future governance and climatic conditions that could be remarkably different from when our study was conducted.

4 Results

4.1 Descriptive statistics

Basic centrality and dispersion statistics for our sample are presented in Table 3. Respondents in the sample managed an average of 1.15 ha of farmland, which is slightly larger than the national average (0.92 ha), with a median of 0.85 ha. Other important characteristics worth noting within our data include that 76% respondents owned at least two parcels, 50% owned at least three parcels, 25% at least four parcels, and 13% at least five parcels. This distribution reflects the management landscape prevalent in our study area dominated by small farming plots. Regarding land tenure, most land was in private ownership, and 89% of all 530 parcels managed by farmers in our sample were under full private ownership. The remaining plots were leased or under shared communal ownership. Respondents' reported an average annual income of US$614.23/year, with median of US$266.67. Regarding self-reported typologies describing resilience to water scarcity, 32.5% of farmers had avoided, 30.0% had adapted, and 37.5% had not been able to adapt to its impacts.

4.2 Multinomial logistic regression

Results are presented in Table 4.[1] We found no definitive evidence to reject the null hypothesis for the IIA assumption. Results from the IIA Hausman test suggested the model may violate this assumption, although this is not an uncommon result in empirical applications even in well-specified models with large samples (Aguilar & Cai, 2010; Cheng & Long, 2007). Results from the IIA Small-Hsiao Test offered no consistent indication that the assumption was violated.

4.2.1 Avoidance of—over inability to withstand—water scarcity

Proxies for natural capital assets dominated the explanatory power between the odds of avoidance of, over inability to withstand, water scarcity (first set of columns in Table 4), in addition to irrigation infrastructure as a form of physical capital. Capital asset coefficients that exhibited the largest odds ratios and statistically significant ($p<0.05$) direct associations were in declining order: (i) access to irrigation infrastructure, (ii) altitude > 300 m.a.s.l., (iii) direct natural access to water source, (iv) 75th percentile income × livestock units, (v) total farm area (log) × family labor, (vi) years of farming experience, and (vii) percentage of farm under agroforestry system. For instance, farmers with access to irrigation infrastructure and at altitudes over 300 m.a.s.l. were, respectively, 1.64E + 07 and 8.55 times as likely to be able to avoid water scarcity over the inability to stand it.

In the opposite direction, the odds of avoiding water scarcity, over the inability to withstand it, were negatively associated with only two capital assets. Odds ratios of 0.004 and

[1] We also ran models that included watershed- and village-level effects. There were no significant watershed-level effects. In the case of fixed village-level effects, controlling for their inclusion yielded a few additional statistically significant coefficients but introduced a strong degree of collinearity. Results from these models are included in an Appendix.

Table 3 Descriptive statistics of variables denoting natural, financial, human, social, and physical capital assets

Capitals	Variables (assets)	Variable type	Response/unit	Total ($n=200$)				Avoidance ($n=65$)				Adaptation ($n=60$)				Inability to withstand ($n=75$)			
				Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max
Natural capital	Total farm area (ha)	Continuous	Hectare	1.2	1.4	0.002	7.0	0.82	0.7	0.002	4.5	1.3	1.2	1	5.5	1.3	1	0.002	7
	Log (natural) of total farm area*	Continuous	N/A	8.9	1.1	5.3	11.2	8.6	1.1	5.4	10.7	8.9	1.0	6.9	10.9	9.1	0.9	5.3	11.1
	Farmland share as agroforestry system	Continuous	%	55.7	40.4	0	100	58	42.3	0	100	61.9	35.2	0	100	48.5	42	0	100
	Direct natural access to water source	Binary	0 = no, 1 = yes	0.3	N/A	0	1	0.4	N/A	0	1	0.35	N/A	0	1	0.28	N/A	0	1
	Altitude > 300 m.a.s.l	Binary	0 = no, 1 = yes	0.8	0.4	0	1	0.9	0.3	0	1	0.9	0.3	0	1	0.5	0.5	0	1
Financial capital	Household income from all sources	Continuous	US$/year	614.2	769.4	0	4666.7	505.5	690	0	3333.3	745.6	842.1	40	4000	603	768	33.3	4666
	Household income 75th percentile (> $667/year)	Binary	0 3 = no, 1 = yes	0.3	N/A	0	1	0.3	N/A	0	1	0.45	N/A	0	1	0.34	N/A	0	1
	Livestock holding	Continuous	Animal unit	0.5	0.8	0	5.2	0.5	1	0	5.2	0.4	0.6	0	2.7	0.6	0.7	0	2.7

Table 3 (continued)

Capitals	Variables (assets)	Variable type	Response/unit	Total ($n=200$)				Avoidance ($n=65$)				Adaptation ($n=60$)				Inability to withstand ($n=75$)			
				Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max
Human capital	Level of education	Categorical	0 = did not go to school, 1 = did not finish elementary school, 2 = elementary school graduate, 3 = junior high school graduate, 4 = high school graduate, 5 = bachelor's degree	2.0	1.6	0	5	2.1	1.6	0	5	2.2	1.6	0	5	1.8	1.6	0	5
	> 20 years of farming experience	Binary	0 = no, 1 = yes	0.7	N/A	0	1	0.7	N/A	0	1	0.8	N/A	0	1	0.7	N/A	0	1
	Number of household farm laborers	Continuous	# of persons	2.1	1.1	0	6	1.9	0.9	1	4	2.2	1	0	6	2.3	1.3	1	6
	Number of household members	Continuous	# of persons	3.9	1.2	2	8	3.9	1	2	7	3.7	1.1	2	6	4.1	1.4	2	8

Table 3 (continued)

Capitals	Variables (assets)	Variable type	Response/unit	Total ($n=200$)				Avoidance ($n=65$)				Adaptation ($n=60$)				Inability to withstand ($n=75$)			
				Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max
Social capital	Participation in social groups	Binary	0 = no, 1 = yes	0.5	N/A	0	1	0.4	N/A	0	1	0.7	N/A	0	1	0.4	N/A	0	1
	Willingness for collective action	Binary	0 = no, 1 = yes	0.8	N/A	0	1	0.9	N/A	0	1	0.7	N/A	0	1	0.7	N/A	0	1
Physical capital	Transportation mode	Continuous	# of transportation modes	1.0	0.6	0	3	0.9	0.6	0	3	1.2	0.6	0	2	1.1	0.6	0	3
	Access to irrigation infrastructure	Binary	0 = no, 1 = yes	0.7	N/A	0	1	0.7	N/A	0	1	0.8	0.4	0	1	0.6	0.5	0	1
	House area (m^2)	Continuous	m^2	94.8	46.0	24.0	300.0	95.2	49.8	30.0	250.0	91.6	36.3	35	180	96.9	49.9	24	300

Associations with income and dependent categories were discerned after converting this explanatory variable to dichotomous values (75th percentile or higher = ‘1,’ otherwise = ‘0’). This transformation served two purposes, to capture effects of income within the highest quartile and to ameliorate potential outliers – and possibly errors in extreme self-reported amounts (Barret and Lewis 1994). Pede et al. (2012) adopted a similar quartile income-based approach to study rural livelihoods in a comparable Southeast Asian context

*Natural logs taken of squared-meters of farmland

Table 4 Beta coefficients, odds ratios, standard errors, and *p* values for multinomial logistic model with 'inability to withstand water scarcity' as baseline group ($n=200$), including Taylor-linearized robust estimates

	Avoided water scarcity impacts*					Adapted to water scarcity impacts*				
	Coef	Odds–ratio	Std. Err. [Taylor-linearized]	Z [Taylor-linearized]	*p* value [Taylor-linearized]	Coef	Odds ratio	Std. Err. [Taylor-linearized]	Z [Taylor-linearized]	*p* value [Taylor-linearized]
Natural capital assets										
Total farm area (log)	−0.499	0.607	0.432 [0.689]	−0.700 [−0.720]	0.483 [0.470]	−0.445	0.641	0.488 [0.679]	−0.580 [−0.650]	0.559 [0.513]
Farmland % agroforestry	0.011	1.011	0.006 [0.006]	1.930 [1.850]	0.054 [0.066]	0.009	1.009	0.006 [0.006]	1.500 [1.430]	0.132 [0.154]
Altitude > 300 m.a.s.l	2.146	8.548	5.791 [0.675]	3.170 [3.180]	0.002 [0.002]	1.631	5.107	3.185 [0.596]	2.610 [2.730]	0.009 [0.007]
Access to natural water source	1.669	5.308	2.803 [0.522]	3.160 [3.200]	0.002 [0.002]	0.914	2.495	1.277 [0.539]	1.790 [1.690]	0.074 [0.092]
Financial capital assets										
Income at 75th percentile	−0.913	0.401	0.271 [0.723]	−1.350 [−1.260]	0.177 [0.208]	−0.341	0.711	0.437 [0.630]	−0.550 [−0.540]	0.579 [0.589]
Livestock unit ownership	−4.608	0.010	0.036 [3.300]	−1.290 [−1.400]	0.197 [0.164]	−2.894	0.055	0.213 [3.232]	−0.750 [−0.900]	0.452 [0.372]
75th percentile income × livestock unit	1.352	3.864	2.609 [0.700]	2.000 [1.930]	0.045 [0.055]	1.397	4.043	3.145 [0.690]	1.800 [2.030]	0.072 [0.044]
Human capital assets										
Education level	0.225	1.252	0.208 [0.163]	1.350 [1.380]	0.175 [0.170]	0.118	1.125	0.183 [0.171]	0.730 [0.690]	0.468 [0.493]
Years of farming experience	0.431	1.538	0.247 [0.151]	2.680 [2.850]	0.007 [0.005]	0.292	1.339	0.213 [0.142]	1.840 [2.050]	0.066 [0.041]
Number of family laborers	−5.632	0.004	0.010 [2.231]	−2.120 [−2.520]	0.034 [0.012]	−5.215	0.005	0.015 [2.331]	−1.940 [−2.240]	0.053 [0.026]
Number of household members	−0.086	0.917	0.195 [0.196]	−0.400 [−0.440]	0.686 [0.661]	−0.426	0.653	0.14 [0.224]	−1.960 [−1.900]	0.050 [0.059]

Table 4 (continued)

	Avoided water scarcity impacts*					Adapted to water scarcity impacts*				
	Coef	Odds–ratio	Std. Err. [Taylor-linearized]	Z [Taylor-linearized]	*p* value [Taylor-linearized]	Coef	Odds ratio	Std. Err. [Taylor-linearized]	Z [Taylor-linearized]	*p* value [Taylor-linearized]
Social capital assets										
Participation in social groups	−0.157	0.854	0.426 [0.510]	−0.320 [−0.310]	0.752 [0.758]	1.340	3.817	1.910 [0.498]	2.680 [2.690]	0.007 [0.008]
Willingness to engage in collective action	5.507	246.529	1174.563 [4.423]	1.160 [1.250]	0.248 [0.215]	9.192	9.82E+03	4.46E+04 [4.248]	2.020 [2.160]	0.043 [0.032]
Physical capital assets										
Access to irrigation infrastructure	16.616	1.64E+07	7.65E+07 [4.517]	3.570 [3.680]	< 0.001 [< 0.001]	8.847	6.95E+03	3.21E+04 [4.772]	1.910 [1.850]	0.056 [0.065]
Transport ownership	−0.215	0.807	0.312 [0.385]	−0.550 [−0.560]	0.579 [0.578]	0.694	2.002	0.787 [0.364]	1.770 [1.910]	0.077 [0.058]
Area of house	0.008	1.008	0.006 [0.006]	1.430 [1.350]	0.152 [0.177]	−0.003	0.997	0.006 [0.006]	−0.450 [−0.460]	0.652 [0.642]
Farmland interactions										
Total farm area (log) × livestock unit ownership	0.416	1.516	0.596 [0.376]	1.060 [1.110]	0.290 [0.270]	0.165	1.180	0.508 [0.367]	0.380 [0.450]	0.701 [0.653]
Total farm area (log) × family labor	0.566	1.761	0.514 [0.243]	1.940 [2.320]	0.052 [0.021]	0.566	1.762	0.511 [0.254]	1.950 [2.230]	0.051 [0.027]
Total farm area (log) × willingness to engage in collective action	−0.451	0.637	0.341 [0.496]	−0.840 [−0.910]	0.400 [0.364]	−1.027	0.358	0.178 [0.467]	−2.070 [−2.200]	0.038 [0.029]

Table 4 (continued)

	Avoided water scarcity impacts*					Adapted to water scarcity impacts*				
	Coef	Odds–ratio	Std. Err. [Taylor-linearized]	Z [Taylor-linearized]	*p* value [Taylor-linearized]	Coef	Odds ratio	Std. Err. [Taylor-linearized]	Z [Taylor-linearized]	*p* value [Taylor-linearized]
Total farm area (log) × access to irrigation infrastructure	−1.865	0.155	0.081 [0.509]	−3.580 [−3.660]	< 0.001 [< 0.001]	−0.880	0.415	0.214 [0.540]	−1.710 [−1.630]	0.088 [0.105]
Constant										
	−0.599	0.549	3.530 [6.160]	−0.090 [−0.100]	0.926 [0.923]	0.756	2.131	14.907 [6.113]	0.110 [0.120]	0.914 [0.902]

Multinomial logit model fitness: log-likelihood ratio $Chi^2(40) = 120.85$, $Prob > Chi^2 < 0.0001$. Taylor-linearized model fitness: F-test $(40, 153) = 1.98$; $Prob > F = 0.0017$. * As compared with baseline category: inability to withstand water scarcity

0.155 were found for an additional family farm laborer and the interaction term 'total farm area (log) × water access infrastructure,' respectively.

4.2.2 Adaptation to—over inability to withstand—water scarcity

Different levels of associational strength and statistical significance emerged when examining variables that distinguished farmers who have adapted to water scarcity, from those unable to withstand it (second set of columns in Table 4). Results disclose significant associations with various capitals. Among them, social capital assets (e.g., willingness to engage in collective action, participation in social activities), human capital assets (e.g., number of family laborers and household members), and physical capital assets stand out. By declining order directly associated variables 'coefficients were: (i) willingness to engage in collective action, (ii) access to irrigation infrastructure, (iii) altitude > 300 m.a.s.l., (iv) 75th percentile income × livestock unit, (v) engagement in social activities, (vi) direct natural access to water source, (vii) number of transportation modes, (viii) total farm area (log) × family labor, and (ix) years of farming experience. For example, farmers willing to engage in collective action were 9.82E + 03 as likely to be able to adapt to water scarcity, over the inability to stand it.

Having an inverse association, in declining absolute value of coefficients was: (i) number of household farm laborers, (ii) total farm area (log) × willingness to engage in collective action, (iii) total farm area (log) × access to irrigation infrastructure, and (iv) number of household members. For instance, the odds of adapting to water scarcity over the inability to stand it were only 0.005 for an additional family farm laborer.

4.2.3 Assets with no statistical association with resilience to water scarcity

We found non-significant effect associated with years of education, although positive correlations have been reported in other contexts (e.g., Awazi & Quandt, 2021). This is possibly due to the fact that about 39% of farmers in our sample reported not attending school or finishing elementary education, and a third of them had only completed elementary education (Table 3). The prevalence of relatively low levels of schooling, which reflects the reality of the study area, might be linked to our findings of no related significant associations. Arguably, farming experience is the more important human capital asset in supporting resilience over traditional schooling. Lastly, the coefficient capturing house area was not statistically significant. Others such as Carney (1998) have reported that a farmer's house size can enhance livelihood resiliency as it provides a sense of security when stresses and shocks occur. In the case of Bantaeng, farmers commonly used their houses to store non-perishable yields (e.g., dried corn, nutmegs, dried cloves) and crop seeds. We initially expected a discernible association between larger house areas and resiliency, but it was not significant.

4.3 Capital assets contributing to overall resilience to water scarcity

Self-assessed resilience—i.e., greater odds of avoidance and adaptation of water scarcity, over inability to withstand it—was positively associated with most capital assets. Table 5 offers a summary of capital assets and their statistical significance on the greater likelihood of reporting avoidance and adaptation typologies. Variables proxying natural assets (e.g., natural access to water sources, higher altitude having greater rainfall

Table 5 Rural livelihood capital assets associated with greater resilience as denoted by significantly ($p < 0.05$) greater odds of avoidance and adaptation, over inability to withstand water scarcity

Capital assets	Asset (proxy)	Avoidance†	Adaptation†	Resilience*
Natural	Higher altitude (Altitude > 300 m.a.s.l.)	+	+	↑
	With natural water access	+	+	↑
	Farmland % agroforestry	+		
Financial	75th percentile income × livestock unit	+	+	↑
Human	Years of farming experience	+	+	↑
	Number of farm laborers	-	-	↓
	Number of household members		-	
Social	Participation in social groups		+	
	Willingness to engage in collective action		+	
Physical	Access to irrigation infrastructure	+	+	↑
	Transport mode ownership		+	
Natural × human	Farmland area (log) × number of family laborers	+	+	↑
Natural × physical	Farmland area (log) × irrigation infrastructure	-	-	
Natural × social	Farmland area (log) × willingness to engage in collective action		-	

† Association relative to base category: 'Inability to withstand water scarcity.' *Statistically positive associations with both avoidance and adaptation deemed as strong evidence of contribution to small-holder resilience to water scarcity

and less evapotranspiration), financial assets (e.g., 75th percentile household income in combination with number of animal units), human assets (e.g., years of farming experience), and physical assets (e.g., access to water irrigation) had strong positive associations with categories denoting resiliency. Noticeably, social capital assets only had significant effects ($p < 0.05$) with higher odds of adapting to water scarcity.

Our focus on smallholder farmers motivated the closer examination of capital asset associations with resiliency contingent to total available farmland. As shown by statistically significant interaction effects, total farmland influenced the degree of association with other capital assets such as number of household farm laborers and access to irrigation infrastructure. For instance, the sole effect of another household member working as farm labor was consistently detrimental to the ability to withstand water scarcity, but this relation was influenced by total farm area. Farmland and number of household farm laborers interactions, and their expected odd ratios of avoidance and adaptation are depicted in Figures 3 and 4. In these, odds ratios above '1' indicate a greater probability of household resilience to water scarcity impacts. A general trend in both cases shows that a larger number of farm laborers in a household reduced the odds of being resilient (either avoid or adapt to water scarcity), but that ratio was reversed if a household had more farmland. Regardless of number of family laborers, there was a turning point at 2.1 ha in the case of avoidance and 0.9 ha in the case of adaptation. An additional interpretation of this trend is that having a larger number of farm laborers in a household was associated with an increase in the odds of resilient farming systems—only if accompanied by more farmland. This trend is more pronounced in increasing the odds of adaptation among households with smaller farming areas.

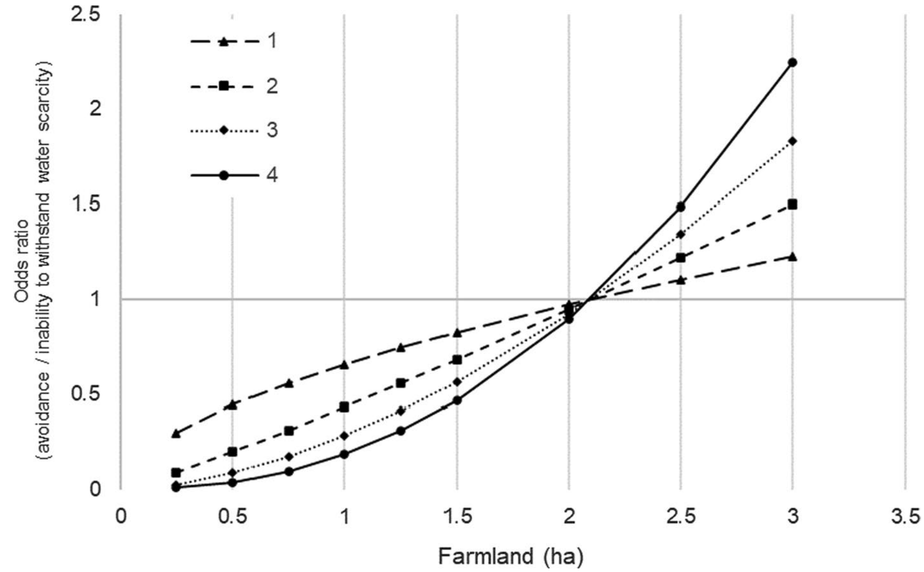

Fig. 3 Odds ratios for probabilities of self-reported avoidance of, over inability to withstand, water scarcity across selected farm size, and number of household farm laborers (1–4)

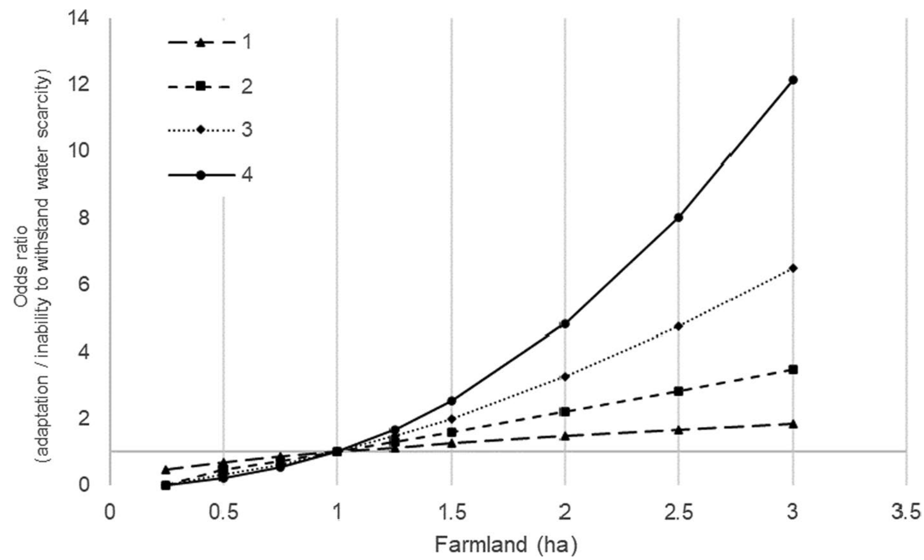

Fig. 4 Odds ratios for probabilities of self-reported adaptation, over inability, to withstand water scarcity across selected total farm size, and number of household farm laborers (1–4)

5 Discussion

Disturbance in the form of water scarcity is one of the biggest risks faced by smallholder farmers worldwide (Rockström, 2000). Water deserves special attention in resiliency studies since it is crucial in every aspect of farming and other forms of net primary productivity (Webb et al., 1978). However, water uneven distribution and accessibility contributes to some farming areas being more exposed to the expected increase in incidence and magnitude of drought (Mollinga, 2003). Particularly among smallholder farmers, it is critical to better understand the resources that can enhance their resilience to water scarcity (Donovan & Stoian, 2012).

5.1 Livelihood capitals associated with resilience to water scarcity: avoidance and adaptation

Natural capital assets dominated positive associations with resiliency as access to water is inherently important to prevent or alleviate the water scarcity impacts (Awazi & Quandt, 2021; Wutich et al., 2014). In our sample, farmers with direct access to water sources were consistently more likely to be in the avoidance or adaptation categories—over inability to withstand it. This relationship highlights the sheer importance of bio-physical assets when coping with water deficits. Consistent with what was reported by Namara et al. (2010) farmers with direct access to water resources, often at higher altitudes within a watershed, tend to be less prone to water scarcity. In our sample, access to financial resources showed that on-average farmers at or above the 75th percentile of income and owning an additional livestock unit were, respectively, 3.9 times and 4.0 times more likely to avoid or adapt to water scarcity. Individual coefficients denoting main effects of financial resources (e.g., 75th income percentile, number of animal units) were not statistically significant, which suggests that resilience is more closely linked with both income and other financial assets as is the case of animal units (Abdul-Razak & Kruse, 2017; Armah et al., 2010).

Farming experience had a strong association with resilience with an additional 5 years of experience associated with a 53.8% and 33.9% greater likelihood of being able to avoid or adapt to water scarcity, respectively. As suggested by Defiesta and Rapera (2014) the number of years of experience in farming is often highly correlated with the awareness, knowledge, and skills necessary to withstand climate stressors. Another possible explanation might be provided by anecdotal observations from key interviews—older farmers might simply be more accustomed to the perception of being water scarce. We posit that the more frequent exposure to this condition made them perceive that their livelihoods were not as threatened, while less experienced farmers were still not used to dealing with water scarcity.

The one asset that consistently showed a negative main association with resilience to water scarcity was the number of household farm laborers. This finding has not previously reported in similar studies using a livelihoods capital framework where a household size had either no significant associations (Awazi & Quandt, 2021) or suggest a positive association (Quandt, 2018). Else constant, an additional farm laborer in a household reduced the odds of it being in the avoidance and adaptation categories. Intuitively, the greater availability of farm labor can offer a wider set of capabilities and strategies that would be beneficial to resilient farm management (Eakin et al., 2011; Moser, 1998). With farmland being a largely fixed capital asset, a growing household translates into fewer farming resources per individual and often results in a less efficient use of labor and land (Scully, 1962). In our particular sample there was an average of 5.3 laborers ha^{-1} (SD = 10.6) which highlights the degree of limited farmland. As a household has more farm-dependent laborers, detrimental effects of stressors such as water scarcity more widely reduce the relative proportion of income and other farm-level resources that sustain their livelihoods.

5.2 Livelihood capitals associated with avoidance of, or adaptation to, water scarcity impacts

Here, we focus on livelihood assets that had only a significant association with avoidance or adaptation to water scarcity. Wider adoption of agroforestry was associated with an increase in the odds of avoiding water scarcity. This was the only statistically significant variable uniquely associated with avoidance of, but not adaptation to, water scarcity. In Bantaeng District, cacao, coffee, and cloves are the most popular agroforestry-based systems. Agroforestry adoption can support the avoidance of water scarcity because the wider presence of trees can reduce evapotranspiration and regulate water infiltration; thus, water demands and the likelihood of nutrient losses are reduced (Nigussie et al., 2018; Roshetko, 2013). Others also found that the adoption of agroforestry can contribute to diversified incomes, thus contributing to overall resiliency of farming livelihoods (Quandt et al., 2019; Seruni et al., 2021).

The number of statistically significant coefficients shows that modeling the odds of adapting to water scarcity over the inability to withstand it was more nuanced. Dominant associations were those with social capital assets. For instance, willingness to engage in collective action and participation in social groups increased the likelihood to be able to adapt to water scarcity. Openness to collective action and participation in social groups (e.g., farmer groups) can facilitate awareness of strategies to cope with stressors and enhance information quality, relevance, and timeliness (Ellis, 2000). Social ties strengthen reciprocity among community members and can directly contribute to farming resiliency (Martini et al., 2017; Portes, 1998), although such relationships might be context-specific (Abdul-Razak & Kruse, 2017; Awazi & Quandt, 2021; Seruni et al., 2021).

Having more transportation modes increased the odds of adaptation. A wider availability of transportation means can facilitate access to off-farm water sources. This was observed during data collection in the specific case of motorbikes, where farmers, motivated by a lower cost of ownership and use than of cars, were used to transport crop yields and water in containers. Another form of transportation was horses from and to locations of difficult terrain.

5.3 Livelihood capital asset interactions and resilience to water scarcity: farmland

Previous research in Indonesia has showed that small-scale farmers with greater access to farmland can diversity their farming activities, thus contributing to being more financially resilient (e.g., Seruni et al., 2021). In other contexts, farming areas have been positively associated with increased resiliency to extreme weather (e.g., Awazi & Quandt, 2021). Different contexts and model specifications prevent direct comparisons, but a particular finding in our study is the inverse association between higher odds of adaptation and family size. Likely, this points to how, other capital assets constant, larger families are less capable to cope with water scarcity (Legesse et al., 2018). However, that relationship is relaxed for households who have greater farmland access. Empirically, we report that larger farmland areas reversed the detrimental effects of having more household members working as household laborers. Instead having more family laborers can enhance household resiliency with adequate access to farmland resources. This is evident when at least 2.1 ha farmland was needed to outright avoid the effects of another farm laborer on the odds of inability to withstand water scarcity. Comparatively, only 0.9 ha was needed to improve the odds of adapting to water scarcity when having an additional family laborer.

It is also worth noting how the average association of willingness to engage in collective action and the odds of adaptation was weakened with a household's greater area of land farmed by 41.5%. We posit that collective action is strongly associated with adaptation to water scarcity as reported by many others (Awazi & Quandt, 2021; Maleksaeidi et al., 2016; Seruni et al., 2021). However, the strength of this relationship tends to fade over larger farming areas. Conversely, engagement in collective action had an even more important association with the likelihood of adaptation among smaller farms, i.e., farms with even less access to farmland had higher odds of adapting to water scarcity when also engaged in collective action.

5.4 Public policy implications

Enhancing the capacity of smallholder farmers to adapt to extreme weather is essential to attaining the United Nations' Sustainable Development Goals of 'No poverty,' and 'Zero hunger' (FAO, 2020). The first policy implication we draw from our results is the importance of building resiliency within available resources and established farming practices. Within our sample 62.5% of respondents reported to had either avoided or adapted their livelihoods to the impacts of water scarcity which highlights smallholders' capacity to cope with climate shocks with current resources (Cohn et al., 2017). Specifically, we point to the strong effects in access to irrigation infrastructure and agroforestry adoption to fully avoid the impacts of water scarcity. Expanded access to irrigation will likely require public investments in infrastructure, extension services, and research to maximize its resiliency contributions and simultaneously support reductions in farming-related greenhouse gas emissions (Campbell et al., 2011; FAO, 2020). Although our study did not test effects associated with any new technology designed to cope with water scarcity, many (e.g., FAO, 2020) recognize that the potential benefits to smallholder farmers from new technologies might be minimal, come at a high cost, and carry many uncertainties for which their adoption will be unlikely. Thus, investments within known irrigation techniques and other farming approaches (including established agroforestry practices) might be strongly suited to promptly help smallholder farmers avoid the impacts of water scarcity.

A second policy implication is the importance of supporting grassroot-level efforts that encourage stronger social ties. Others have stressed the importance of spontaneous or organized processes by which individuals and society adjust to a changing climate, yet, the linkage between social capital and climate adaptability might be even more pronounced among smallholder farmers. Among others, investments in social capital have been suggested by Awazi and Quandt (2021) when reporting the importance of participation in agricultural groups in supporting livelihood resilience of smallholder farmers in Kenya and Cameroon. In Indonesia farming information is frequently provided by the Indonesian government, but final land management decisions tend to be more directly influenced by fellow farmers, village leaders, and other peer groups (Seruni et al., 2021). Hence, policies that facilitate local learning and empowerment among different stakeholders and local institutions might directly contribute to more climate resilient households (Phuong et al., 2018). Interventions that enhance social capital will likely be most fundamental to the resiliency of smallholder farmers with the least access to land. To support access to land, across Indonesia and other countries, legal accessibility and the right to usufruct from publicly owned parcels might be a tool to address this challenge while complementing social investments (Seruni et al., 2021).

Our third policy implication is the importance of tailoring policy interventions to local contexts (Campbell et al., 2011; FAO, 2020; OECD 2020). The complexity of dealing with water resiliency stresses how public policy should invest in various livelihood capital assets. For instance, our results recognize that access to diverse forms of capital will be instrumental to support smallholder water scarcity resiliency. This is illustrated by how household income and owning livestock jointly increased the odds of avoiding or adapting to water scarcity, but there were no statistical associations of individual financial assets in our sample. Apparently inconsistent evidence in the literature to how different capital assets contribute to weather resiliency (e.g., Awazi & Quandt, 2021) might just be a reflection of local farming system intricacies. Policies addressing weather resiliency needs should simultaneously consider existing contents and contexts to advance mitigation potential and complex links to food security, trade, land use and sustainable forestry policies (Campbell et al., 2011; Cohn et al., 2017).

Lastly, public policy needs to recognize that some farmers will not be able to avoid nor adapt to water scarcity. About a third of smallholder farmers in our sample had not been able to withstand water scarcity even in recent weather conditions. OECD (2020) points to the necessity of transforming farming livelihoods when the risks of entrenched incapacity to cope with extreme weather are too high. A household's capacity to transform might be considered an extension of the capacity to adapt, but acknowledging the need for structural change may become increasingly necessary as climate change intensifies. The issue of when policy toward climate resilience should shift to a paradigm of structural transformation, inclusive of some households who might need to become non-farmers, is highly contested in long-term policy debates (Campbell et al., 2011; OECD 2020). The transformation of livelihoods is already evidenced around the world when smallholder farmers unable to cope with climate stressors migrate to urban areas (Bhatta & Aggarwal, 2016). When policy interventions, inclusive of those that fundamentally change livelihoods away from farming, should engage in structural change over enhancing current livelihood resiliency is a large and impending question for which longer-term data, analysis and public debate will be necessary to answer it.

6 Conclusions

We found that smallholder farmer resilience to water scarcity was most strongly associated with biophysical assets within natural and physical capitals. Access to diverse financial assets (e.g., households within the highest income quartile with cashable animal units) showed strong and consistent associations with greater odds of avoiding, and adapting to, water scarcity. Smallholder farmer resiliency showed nuanced associations with human capital assets; farming experience had a major positive effect, but larger number of family laborers showed a detrimental association among households with lesser access to farmland. Associations with social capital assets highlight the importance of smallholders' group interaction and engagement in collective action to adapt to water scarcity.

Greater availability of some assets did not necessarily enhance resilience to water scarcity. In particular, we note the inverse odds of either avoiding or adapting to water scarcity with a larger number of household farm laborers. This relationship was extended to the lower odds of adapting to water scarcity among larger households. But our results also point to how access to farmland can reduce such detrimental associations. Within our sample, having at least 2.1 ha enhanced the odds of avoiding the impacts of water scarcity associated with another family laborer. That threshold was a lower 0.9 ha to enhance the odds of adaptation. We also stress the importance of engaging in collective action among smallholder farmers with the least access to farmland in order to adapt to water scarcity.

Our results have various policy implications. Among them, development programs that facilitate access to farmland and irrigation, and adoption of agroforestry practices can immediately support smallholder farmer resilience to water scarcity. Grassroot-level efforts that encourage stronger social ties can help smallholder farmers adapt to water scarcity. Such type of enhanced social capital will be most instrumental to smallholder farmers with the least access to land. Although our findings are specific to the context of South Sulawesi, we stress the complexity of water resiliency for which public policy should invest in various livelihood capital assets to support smallholder farmers' capacity to cope with water scarcity. The complexity of the association between capital assets and resilience to water scarcity is further illustrated by how household income and owning livestock jointly increased the odds of avoiding or adapting to water scarcity, but there were no statistical associations of individual financial assets. However, policy will also need to recognize that some smallholder farmers will be very unlikely to withstand water scarcity in the future for which approaches designed to transform their current livelihoods will be needed.

Appendix 1

See Table 6.

Table 6 Beta coefficients, standard errors, and p values for multinomial logistic model with 'inability to withstand water scarcity' as baseline group ($n = 200$), including watershed-level effects

	Avoided impacts of water scarcity				Adapted to impacts of water scarcity			
	Coef	Std. Err	z	$p > z$	Coef	Std. Err	z	$p > z$
Natural capital								
Total farm area (log)	−0.506	0.715	−0.710	0.479	−0.494	0.763	−0.650	0.517
Agroforestry adoption (%)	0.012	0.006	1.980	0.048	0.008	0.006	1.310	0.191
Altitude > 300 m.a.s.l	2.066	0.682	3.030	0.002	1.675	0.630	2.660	0.008
Access to natural water source	1.751	0.549	3.190	0.001	0.845	0.527	1.600	0.109
Financial capital								
Income higher than average	−0.942	0.680	−1.390	0.166	−0.277	0.623	−0.440	0.657
Livestock unit ownership	−4.841	3.539	−1.370	0.171	−3.174	3.763	−0.840	0.399
Higher − than − average income × livestock unit	1.405	0.671	2.090	0.036	1.223	0.768	1.590	0.111
Human capital								
Education level	0.242	0.167	1.450	0.147	0.102	0.163	0.620	0.534
Years of farming experience	0.445	0.162	2.750	0.006	0.278	0.159	1.750	0.080
Number of family laborers	−5.614	2.680	−2.090	0.036	−5.228	2.713	−1.930	0.054
Number of household members	−0.077	0.214	−0.360	0.721	−0.430	0.219	−1.960	0.050
Social capital								
Engagement in social activities	−0.169	0.500	−0.340	0.736	1.317	0.500	2.630	0.008
Willingness to engage in collective action	5.443	4.800	1.130	0.257	8.636	4.609	1.870	0.061
Physical capital								
Access to irrigation infrastructure	16.889	4.676	3.610	0.000	8.599	4.660	1.850	0.065
Transport ownership	−0.181	0.389	−0.470	0.642	0.656	0.398	1.650	0.099
Area of house	0.008	0.006	1.410	0.157	−0.003	0.006	−0.450	0.651
Interaction terms								
Total farm area (log) × livestock unit ownership	0.433	0.389	1.110	0.266	0.215	0.421	0.510	0.610
Total farm area (log) × family labor	0.564	0.295	1.920	0.055	0.567	0.293	1.930	0.053
Total farm area (log) × willingness to engage in collective action	−0.431	0.540	−0.800	0.425	−0.970	0.502	−1.930	0.053

Table 6 (continued)

	Avoided impacts of water scarcity				Adapted to impacts of water scarcity			
	Coef	Std. Err	z	$p > z$	Coef	Std. Err	z	$p > z$
Total farm area (log) × access to irrigation infrastructure	−1.886	0.521	−3.620	0.000	−0.871	0.519	−1.680	0.093
Fixed effect								
Watershed (1 = Tino; 0 = Biangloe)	0.334	0.534	0.620	0.532	−0.356	0.533	−0.670	0.504
Constant	−1.338	6.548	−0.200	0.838	2.054	7.151	0.290	0.774

Log-likelihood = −157.44; LR $\chi^2(42) = 122.84$; Prob > χ^2 = < 0.001

Table 7 Beta coefficients, standard errors, and $p-$values for multinomial logistic model with 'inability to withstand water scarcity' as baseline group ($n=200$), including village – level effects

	Avoided impacts of water scarcity				Adapted to impacts of water scarcity			
	Coef	Std. Err	z	$p>z$	Coef	Std. Err	z	$p>z$
Natural capital								
Total farm area (log)	−0.366	0.867	−0.420	0.673	−0.782	0.883	−0.880	0.376
Agroforestry adoption (%)	0.004	0.007	0.590	0.555	0.001	0.007	0.210	0.835
Altitude > 300 m.a.s.l	4.631	1.450	3.190	0.001	1.356	1.329	1.020	0.307
Access to natural water source	1.428	0.701	2.040	0.042	1.325	0.699	1.900	0.058
Financial capital								
Income higher than average	−0.053	0.777	−0.070	0.946	0.059	0.692	0.080	0.932
Livestock unit ownership	−6.774	3.941	−1.720	0.086	−2.807	4.155	−0.680	0.499
Human capital								
Education level	0.221	0.181	1.220	0.223	0.062	0.178	0.350	0.727
Years of farming experience	0.352	0.179	1.970	0.049	0.152	0.182	0.840	0.403
Number of family laborers	−4.926	2.887	−1.710	0.088	−5.413	2.979	−1.820	0.069
Number of household members	0.031	0.241	0.130	0.898	−0.432	0.237	−1.820	0.069
Social capital								
Engagement in social activities	0.028	0.571	0.050	0.960	1.468	0.563	2.610	0.009
Willingness to engage in collective action	7.311	6.166	1.190	0.236	8.266	5.703	1.450	0.147
Physical capital								
Access to irrigation infrastructure	15.134	5.444	2.780	0.005	6.715	5.105	1.320	0.188
Transport ownership	−0.607	0.472	−1.290	0.199	0.210	0.477	0.440	0.660
Area of house	0.004	0.006	0.690	0.491	−0.007	0.007	−1.040	0.297
Interaction terms								
Total farm area (log) × livestock unit ownership	0.639	0.424	1.500	0.132	0.202	0.455	0.440	0.657
Total farm area (log) × family labor	0.487	0.318	1.530	0.126	0.591	0.323	1.830	0.067
Total farm area (log) × willingness to engage in collective action	−0.559	0.678	−0.820	0.410	−0.884	0.612	−1.440	0.149
Total farm area (log) × access to irrigation infrastructure	−1.748	0.603	−2.900	0.004	−0.680	0.561	−1.210	0.225

Table 7 (continued)

	Avoided impacts of water scarcity				Adapted to impacts of water scarcity			
	Coef	Std. Err	z	$p > z$	Coef	Std. Err	z	$p > z$
Higher – than – average income × livestock unit	1.383	0.689	2.010	0.045	0.836	0.771	1.090	0.278
*Village fixed effects**								
Campaga	−1.131	1.323	−0.860	0.392	0.353	1.320	0.270	0.789
Bonto Tappalang	−2.837	1.305	−2.170	0.030	−0.405	1.311	−0.310	0.758
Barua	−2.804	1.251	−2.240	0.025	−0.791	1.262	−0.630	0.531
Biangloe	−0.731	1.225	−0.600	0.550	−3.563	1.395	−2.550	0.011
Bonto Tallasa	−3.052	1.163	−2.630	0.009	−2.938	1.326	−2.220	0.027
Bonto Daeng	−4.766	1.316	−3.620	0.000	−2.182	1.307	−1.670	0.095
Constant	−1.187	8.026	−0.150	0.882	6.831	8.295	0.820	0.410

Log-likelihood = −138.54; LR $\chi^2(52) = 160.62$; Prob > $\chi^2 = < 0.001$. *Fixed effect for Bonto Jaya dropped to avoid perfect collinearity. Bonto Rannu served as base level

Appendix 2

See Table 7.

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Authors Contributions All authors contributed to the design of the study. DH collected primary data with support from local enumerators. FA, DH, and ZC analyzed the data. FA and DH led writing of the manuscript. JR and JS contributed to data interpretation and implications. All authors agree to submission of the manuscript.

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Declarations

Conflict of interest The authors declare that they do not have any conflict of interest.

Code and data availability Anonymized data archived in the open access Data MO Space repository. STATA program will be made available online too.

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