Climate Change Beliefs And Vulnerability Among Farmers In The Upper Corn Belt

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Abstract

Anticipatory water management must reflect not only future climatic conditions, but also the *social* and *psychological dimensions* of vulnerability that drive adaptation. Compared to the western U.S., farmers in the upper Corn Belt have had less exposure to extreme drought and have lower rates of irrigation adoption. If climate change threatens to increase drought frequency or severity in the Corn Belt, transitioning from rain-fed agriculture to irrigated agriculture would require systemic changes and significant financial investments. Knowing what drives perceptions and feelings of drought vulnerability will improve understanding and anticipation of farmer adaptation behaviors such as irrigation. We surveyed central Minnesota agricultural producers about their perceptions of water scarcity in two groundwater management areas where climate models show heightened variability in water supply during the growing season. We examined the influence of farmer beliefs about climate change, drought risk, farm sensitivity to drought, and adaptation capacity. We presented farmers with scenarios of drought severity derived from downscaled climate projections and asked farmers about their likelihood of adopting irrigation technologies or expanding irrigation extent. Findings indicate that many farmers feel vulnerable to climate and drought-related impacts, in part because they believe water scarcity is an imminent problem. Farmers believe humans are at least partially responsible for climate change, near-term droughts are likely, and their farms are particularly sensitive to drought stress.

Introduction

The impacts of climate change on water scarcity are well documented in the western U.S. where chronic droughts have led to historic lows in reservoirs that supply critical drinking water for growing populations and depleted aquifers are forcing farmers to switch crops or invest in deeper wells (Diffenbaugh et al. 2015, Tortajada et al. 2017). In contrast, water scarcity in the predominantly rain-fed Midwest has received less attention. Unlike the western U.S., the upper Corn Belt has little experience in irrigated agriculture. Transitioning the row crop production of the Midwest from rain-fed agriculture to irrigated agriculture would require systemic changes in water budgeting and water use management, as well as massive financial investments in new infrastructure for irrigation. Under scenarios of climate change-induced drought and increasing water consumption from irrigation, groundwater scarcity may threaten not only agricultural water supply, but also access to clean drinking water, surface water aquatic habitats, and other ecosystem services.

Irrigation is a climate change adaptation strategy. The majority of Midwest farmers are concerned about the impacts of climate change, regardless of their stated belief in climate change, and they support actions to protect farmland from increased weather variability, including water scarcity (Arbuckle et al. 2013a, b). Despite farmers' readiness to address weather variability in the Upper Corn Belt, there is uncertainty around the willingness of farmers to change practices and invest in adaptation behaviors that mitigate against potential impacts of climate change. Farmer perceptions of vulnerability to water scarcity prompt or constrain individual adaptations such as manipulating water use supply, demand, and efficiencies (i.e., water storage, alternative cropping, conservation irrigation) (Wheeler, Zou and Bjornlund 2013). When communities of water users adapt (or maladapt) collectively, "large-scale social restructuring" takes place, further amplifying responses and effects (Ohlsson and Turton 1999).

Our work is motivated by the need to anticipate how climate change may affect irrigation adoption in the Corn Belt and to understand farmers' beliefs and capacities driving adaptation. Documenting these dynamics in a region that is not yet experiencing severe water scarcity, but where widespread shifts in irrigation behaviors could have significant social, economic, and environmental impacts is valuable. Water supply planning and management must be anticipatory (Quay 2010) and reflect an understanding not only of future climatic forces, but also of the social and psychological dimensions of vulnerability that drive adaptation (Bassett and Fogelman 2013; Wheeler, Zou and Bjornlund 2013).

We focus on farmers and producers in Minnesota where groundwater supplies 75% of the state's drinking water and 90% of agricultural irrigation demand (Minnesota Department of Natural Resources 2021). Although the proportion of farmland using irrigation remains low, it is increasing. An estimated 200,000 acres of irrigation, from 4–6% of farmland, have been added in the past two decades (USDA NASS).

We hypothesize that farmers' perceptions of water scarcity, their farms' sensitivity to drought impacts, and their capacity to adapt to water scarcity shape their perceived vulnerability to climate change, and ultimately drive their adaptation actions (Fig. 1). This study's social vulnerability framework (Fig. 1) for investigating perceived vulnerability parallels the Intergovernmental Panel on Climate Change (IPCC 2007) model of climate change vulnerability: vulnerability is a function of a system's sensitivity to climate change (i.e., potential for negative consequences), its exposure to climate-related impacts, and its capacity to adapt to those changes. We test the social vulnerability framework through statistical modeling of survey data collected from farmers operating in two state-designated high-risk areas of central Minnesota. Specifically, we asked farmers about their climate change and drought likelihood beliefs, concerns about drought-related impacts to their own farms, and capacities to adapt to water scarcity. We believe these questions are critical to more inclusive, anticipatory, and sustainable narratives of water scarcity, risk, vulnerability, and management in the Upper Corn Belt. Our study findings elucidate the social and psychological dimensions of vulnerability and support anticipatory governance under a changing climate.

Background

2.1 Water Scarcity Risk Narratives

Technical risk assessment dominates water management and supply discourse among water scientists and professionals (Dobbie and Brown 2014). However, personal assessments of water scarcity risk, which directly influence human and social system adaptation, is increasingly recognized as perceptive, shaped by socio-political, cognitive and affective forces (Bassett and Fogelman 2013). Social science research has demonstrated that the human experience and perception of risk, whether that human is a scientist, policy maker, or resource user, is a complicated mash-up of beliefs, social influences, political and institutional forces, and behaviors (Kahlor et al. 2006, Ohlsson and Turton 1999).

Scientific definitions of water scarcity have changed over time, reflecting an evolving understanding of risk from a singular emphasis on absolute water scarcity, or the number of people using a given water supply (Falkenmark 1989), to an emphasis on relative water scarcity. Relative water scarcity takes into account social and institutional responses to water supply problems, actual and perceived (Padowski et al. 2015). Relative scarcity narratives have considered market adaptations (Allan 2011), social conflict (Starr 1991), cooperation between jurisdictions (Wolf 1998), and capacity for infrastructural and institutional change (Ohlsson and Turton 1999). Ohlsson and Turton's (1999) early work underscores the need for understanding the distinction between physical and social concepts of water scarcity. They argue for a multidimensional framing that includes both perceived scarcity of water (first-order scarcity) and a perceived scarcity of the means required to overcome it (second-order scarcity).

Prevailing water scarcity models are useful for simulating multiple scenarios across many combinations of technical and physical risk likelihood probabilities and magnitudes of impacts. What they lack, however, is the sensitivity, complexity, plurality, and relativity of human experience and perception. When scientific or managerial narratives of water scarcity risk dominate water discourse and ignore or exclude the human, social, and cultural experiences of, vulnerabilities to, and perceptions of risk, they are unlikely to be locally relevant and even less likely to compel transformative social action.

2.2 Water Scarcity Risk Perceptions and Adaptation Behaviors

At a micro-scale, risk perceptions have been shown to influence conservation decision making and adaptation actions (Olson and Davenport 2017). A survey administered in Texas before and after an exceptional drought in 2011 revealed that water scarcity risk perception among residents was significantly higher following the drought than prior to it. The study also showed that the conservation practices residents adopted during the drought were likely to become permanent even after water levels returned to normal (Gholson et al. 2019). Recent experience with extreme drought may significantly influence farmer perception of current and future water scarcity. However, Minnesota farmers have had few drought events relative to counterparts in states such as Texas and California where irrigated agriculture dominates (Gholson et al. 2019; English, Solomon and Hoffman 2002). Research on farmer irrigation decisions suggests several factors influence irrigation (an agricultural adaptation strategy), in particular including perceived likelihood of water availability (Guillaume et al. 2016), perceptions of soil and crop stress (Andriyas and McKee 2015), crop prices and production costs (Ng et al. 2011, Foster et al. 2014), technology and knowledge advancements (Levidow et al. 2015), attachment to and investment in the land (Kuehne and Bjornlund 2008), and engagement in farmer organizations and clubs (Ramirez 2013).

2.3 Water Supply Management Context in Minnesota

Projections for the Upper Midwest show, on average, warmer temperatures, increased precipitation, and stronger storms. However, these conditions are projected to be coupled with increasing variability in weather patterns, including longer dry spells and the potential for drought. Thus, despite overall projections of warmer and wetter spring and summer seasons, reduced water supply for row crops remains a possibility (https://www.dnr.state.mn.us/waters/groundwater_section/index.html). Increasingly variable conditions, in conjunction with the uncertainties inherent in climate modeling, portray a complicated scientific narrative of water scarcity and physical risk to agricultural communities in central Minnesota.

In 2012, this water scarcity narrative reached the Minnesota legislature, which prompted the Minnesota Department of Natural Resources (DNR) commissioner to designate groundwater management areas (GWMAs) and to potentially "limit total annual water appropriations and uses... to ensure sustainable use of groundwater that protects ecosystems, water quality, and the ability of future generations to meet their own needs" (Minnesota Statute 103G.287, subd.4). Three GWMAs were created: Twin Cities metropolitan GWMA to address the needs of a growing urban population and two central Minnesota GWMAs, the Straight River GWMA and the Bonanza Valley GWMA (Fig. 2). Both of these rural GWMAs were designated to address increases in irrigated agriculture (Minnesota Department of Natural Resources 2017). As part of the GWMA planning process, the MN DNR convened "project advisory teams" representing different water stakeholders such as "private businesses (e.g., farmers, food processors, well drillers), state agencies, county and city/township governments, a watershed district, industry and the federal government" (Minnesota Department of Natural Resources 2017, pg. 1–3) to identify objectives and actions toward sustainable groundwater use. The role of the advisory teams was to review and provide feedback on the plan. In a preliminary interview for our study, a local farmer, who was active in the planning process, described to us the importance of groundwater management to local agriculture:

At those [public] meetings, it would be a full house. So, it is a big deal, you know what I mean? We don't want this resource taken away from us, and there will be a real fight if somebody tries to do it, you know? And by the same token, I think most people understand that if there are really, in fact, issues with groundwater, we're going to do everything we can to manage it, to make it sustainable.

Both rural GWMA plans identify sustainable use of groundwater as their underlying goal, with actions including increased monitoring and modeling, development of sustainability thresholds, more stringent permitting and regulation enforcement, and better communication and transparency in decision making. Almost five years after the plans were released, questions and conflicting narratives persist about the risk of water scarcity, the vulnerability of farms, and how and when farmers will adapt to drought and reduced groundwater availability. An assessment of vulnerability including the psychological and social dimensions of water scarcity risk perceptions provides the foundation for an anticipatory approach to water governance.

Methods

3.1 Procedures

In the first phase of a larger project funded by USDA National Institute of Food and Agriculture, we convened one-on-one and group discussions with state-level agency representatives and agricultural producers to gather narratives of water scarcity and risk among key stakeholders. We also conducted water supply planning and policy document analysis to establish the current framing of water governance in Minnesota. We then identified key stakeholders with groundwater management interests (e.g., agricultural producers, irrigators association representatives, conservation professionals) and conducted 15 in-depth interviews. These qualitative data informed the development of a mail survey questionnaire.

In the second phase of the project, we collected data using a self-administered mail survey. The questionnaire was mailed to a random sample of 1500 agricultural producers in the two study GWMAs from March through April 2019. The agricultural producer/landowner list of names and addresses was purchased from a private survey sampling firm. The questionnaire included a variety of fixed-choice and scale questions that asked about respondent farm operations, water resource management, and experience with drought. The study included three waves of mailing and used an adapted version of Dillman and others' (2014) tailored design method.

3.2 Measures

Items used to measure perceived vulnerability were adapted from Arbuckle et al. (2013a, b). Perceived vulnerability, the dependent variable in the regression model, reflects an aggregate of three statements measured on a five-point agreement scale (Table 1). Risk perception items (i.e., climate change and drought likelihood beliefs) were adapted from measures used in Arbuckle et al. (2013a, b) and Sanderson and Curtis (2016). Sensitivity items (i.e., concerns about drought impacts to farm and area) were adapted from measures used in Arbuckle et al. (2013a, b), Amberson et al. (2016), and Pradhananga et al. (2018). Adaptive capacity items (i.e., capacity perceptions and reported adaptation behaviors) were adapted from measures used in Arbuckle et al. (2013), Sanderson and Curtis (2016), and Pradhananga and Davenport (2017). We presented eight drought futures scenarios representing various thresholds of drought experiences. This design enabled a futures analysis based on farmer-forecasted responses (i.e., likelihood of adding or expanding irrigation) to a range of scenarios. The scenarios were generated from conversations with agricultural and water resource professionals (phase 1) and our project team's climate modeling.

Table 1
Summary statistics

Constructs	Variables	Mean*	SD	Percent				
Climate change beliefs (Exposure)	There is increasing discussion about climate change and its potential impacts. Please select the statement that best reflects your beliefs about climate change ^5			Human causes	Natural causes	Equally human and natural causes	Climate change is not occurring	Not sufficient evidence to know if it is occurring
		-	-	16.6	16.4	40.0	4.2	22.8
Drought likelihood beliefs (Exposure)	How likely do you think it is that a drought will occur in your local area within the following timeframes? ^1			Not at all likely	Somewhat likely	Moderately likely	Extremely likely	
	a. In 2019?	1.785	0.754	39.6	44.2	14.4	1.8	
	b. Within 5 years?	2.369	0.834	13.1	46.8	30.1	10.0	
	c. Within 10 years?	2.727	0.911	8.4	33.5	35.1	23.0	
	d. Within 30 years?	3.037	1.010	6.8	28.5	18.7	45.9	
Concern about drought-related impacts to farm (Sensitivity)	How concerned are you about the following for your farm operation over the next 10 years?^2			Not concerned	Slightly concerned	Moderately concerned	Extremely concerned	
	a. More frequent dry period and droughts throughout the summer	2.09	0.900	29.7	37.7	26.1	6.5	
	b. More frequent dry period and droughts in the months of August through October	2.03	0.979	33.3	38.4	20.8	7.6	
	c. Increased heat stress on crops	2.06	0.943	33.3	35.8	22.6	8.3	
	d. Decreased access to groundwater	2.15	1.084	36.3	28.3	19.5	15.9	
	e. Increased heat stress on livestock	1.94	0.992	43.4	28.5	19.0	9.0	
	Aggregated score	2.047	0.782					
Perceived ability to cope (Adaptive capacity)	To what extent do you agree or disagree with the following statements?^3			Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
	a. I have the knowledge and technical skills to deal with any drought-related threats to my farm operation	3.176	1.056	8.8	14.4	34.9	34.2	7.7
	b. I have the financial capacity to deal with any drought-related threats to my farm operation	2.876	1.153	16.3	18.6	32.4	26.9	5.9
	c. Crop insurance will protect the viability of my farm operation regardless of weather	2.378	1.092	27.5	23.9	35.3	9.9	3.4
	Aggregated score	2.814	0.785					
Existing irrigation (Adaptive capacity)				Yes	No			
	Do you have irrigation on your farm?^6	1.82	0.383	17.8	82.2			
Planned irrigation (Adaptive capacity)	Listed below are actions farmers can take to respond to changing water availability. Please check the box on each line that best describes your operation’s current and future actions. ^4			Not doing and don’t plan to	Not doing, but might in the future	Doing to some degree	Doing whenever and wherever possible	
	a. Increase irrigated acres	1.26	0.633	82.4	11.1	4.5	2.0	
Perceived vulnerability	To what extent do you agree or disagree with the following statements?^3			Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
	a. My farm operation will likely be harmed by climate-related impacts	3.15	1.083	10.0	14.1	33.9	34.2	7.7
	b. My farm operation is vulnerable to drought	3.31	1.135	7.2	17.2	18.1	32.8	14.7
	c. Drought is a real risk to my area in the future	3.17	1.152	9.1	19.0	30.6	28.3	12.9

Constructs	Variables	Mean*	SD	Percent
	Aggregated score	3.212	0.896	

*n = 464

1Items measured on a 4-point scale from "not at all likely" (1) to "extremely likely" (4)

2Items measured on a 4-point scale from "not concerned" (1) to "extremely concerned" (4)

3Items measured on a 5-point scale from "strongly disagree" (1) to "strongly agree" (5)

4Item measured on a 4-point scale: "not doing and don't plan to" (1), "not doing, but might in the future" (2), "doing to some degree" (3), "doing whenever and wherever possible" (4)

5Item measured on a 5-point scale: "climate change is not occurring", "there is not sufficient evidence to know with certainty whether climate change is occurring or not", "climate change is occurring, and it is caused mostly by natural changes in the environment", "climate change is occurring and it is caused more or less equally by natural changes in the environment and human activities", "climate change is occurring, and it is caused mostly by human activities". Responses were dummy-coded into new variables (0) and (1)

6Item measured on a 2-point scale: "yes" (1) or "no" (2)

3.3 Analysis

Multiple regression was chosen because of its flexibility in analyzing a quantitative dependent variable as a function of multiple independent variables of interest. The analysis yields a measure of the magnitude of the entire relationship of all independent variables to the dependent variable, as well as the partial relationships of each of the independent variables (Cohen and Cohen 1975). Listwise deletion of model variables, as well as deletion of cases where the "don't know" or "NA" option was selected, yielded an effective sample size of 346. Listwise deletion is appropriate because multiple regression requires the same number of cases to be analyzed for each variable. Though the data loss was fairly large, a sample size of 346 is adequate for a multiple regression with 14 independent variables (Cohen and Cohen 1975, Maxwell 2000). Our study variables were checked for correlation and multicollinearity between variables. Intercorrelations between variables were examined to see if any had coefficients of 0.8 or larger (Lewis-Beck and Lewis-Beck 2016). Coefficient values ranged from < 0.001 to 0.790, indicating that our study variables were below the threshold for high multicollinearity.

Results

4.1 Who Are Respondents?

Of the 1,500 questionnaires mailed, 115 were returned undeliverable and 464 completed questionnaires were received, resulting in an adjusted response rate of 34%. A majority of respondents were male (86%). The median age was 63 years old and median farm income for 2018 was between $10,000-$49,000 with 18% of respondents reporting no gross farm sales for 2018. Thirty-two percent of respondents completed high school, 16% had a bachelor's degree, and 5% had a graduate degree. Respondents' farm characteristics varied. More than half (53%) of respondents reported having acreage in corn, 48% have soybeans, and 68% have hay/pasture. Almost one-third (29%) of respondents reported renting farmland. Eighteen percent of respondents reported having irrigation and 33% reported having at least some tile drainage.

4.2 How Do They View Water Scarcity?

About half (48%) of the survey respondents reported feeling their farm operations are vulnerable to drought-related impacts (Table 1). Forty-two percent of respondents agreed (i.e., somewhat to strongly) that their farm operation will be harmed by climate-related impacts. Forty-one percent agreed that drought is a real risk to the area in the future. Almost three-quarters (73%) of respondents believed that climate change is occurring. More respondents believed climate change is caused *equally* by natural environmental changes and human activities (40%) than believed climate change is caused *mostly* by humans (17%) or *mostly* by natural environmental changes (16%).

4.3 What Drives Perceived Vulnerability to Water Scarcity?

Our correlation (Table 2) and regression analysis reveals that perceived vulnerability is a complicated, yet at least partly explicable force. One-third (33%) of the variability in respondents' vulnerability scores was explained by the model (Table 3). Six of the 14 independent variables in the model had statistically significant coefficients ($p \leq 0.5$). Belief in human causes of climate change (exposure) and aggregate concern about drought impacts to the farm (sensitivity), were the strongest predictors of vulnerability scores overall. Belief in the likelihood of a drought in 2019 (exposure) was also a significant and positive predictor of vulnerability scores. Two other climate change belief variables had slight statistical significance, with opposite effects. The belief in human *and* natural causes of climate change had a positive influence on vulnerability scores, and the belief that climate change is *not* occurring had a negative influence. Perceptions of having the financial capacity to deal with drought-related threats had a significant and negative influence on vulnerability scores. Factors that were not predictive of perceived climate vulnerability were believing one has the knowledge and skills to deal with drought-related threats and believing that crop insurance will protect the farm's viability. The adaptive capacity measures, having irrigation or planning to increase irrigated acres, were not significant predictors of vulnerability scores in the regression model.

Table 2. Model correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) Dependent variable - perceived vulnerability	1														
(2) Likelihood of drought in 2019	0.322	1													
(3) Likelihood of drought - 5 years	0.384	0.654	1												
(4) Likelihood of drought - 10 years	0.367	0.476	0.789	1											
(5) Likelihood of drought - 30 years	0.319	0.327	0.622	0.844	1										
(6) Concern about drought-related threats	0.461	0.201	0.307	0.314	0.249	1									
(7) I have the knowledge and skills to deal with drought - related threats on my farm	0.012	0.108	0.017	0.001	0.021	0.037	1								
(8) I have the financial capacity to deal with drought-related threats	-0.164	-0.028	-0.108	-0.142	-0.101	-0.189	0.543	1							
(9) Crop insurance will protect my farm regardless of weather	-0.087	-0.215	-0.233	-0.194	-0.163	-0.133	-0.036	0.195	1						
(10) Plans to increase irrigated acres	0.156	0.145	0.203	0.138	0.2	0.261	0.204	-0.004	-0.104	1					
(11) climate change - human caused	0.221	0.047	0.131	0.135	0.159	0.098	-0.106	-0.114	-0.108	0.009	1				
(12) climate change - natural causes	-0.103	0.044	-0.004	0.01	-0.045	-0.021	0.118	0.076	0.021	0.043	-0.183	1			
(13) climate change - mixed causes	0.156	-0.004	-0.006	0.021	0.012	0.189	-0.06	0.001	0.002	-0.014	-0.351	-0.367	1		
(14) climate change is not happening	-0.215	-0.019	-0.084	-0.08	-0.068	-0.162	-0.011	-0.019	0.032	0.06	-0.09	-0.094	-0.179	1	
(15) Irrigation on farm	-0.11	-0.123	-0.149	-0.193	-0.222	-0.268	-0.271	-0.072	0.077	-0.551	0.061	-0.137	0.022	-0.026	1

Table 3. Multiple regression model

Constructs	Variables	*B*	SE	*p*	std. beta weight
Climate change beliefs (Exposure)	a. human causes of climate change	0.482**	0.134	0.000	0.192
	b. natural causes of climate change	-0.0584	0.129	0.650	-0.024
	c. mixed causes of climate change	0.256*	0.104	0.0147	0.142
	d. climate change is not occurring	-0.506*	0.207	0.0149	-0.116
Drought likelihood beliefs (Exposure)					
	a. Likelihood of drought in 2019	0.191**	0.071	0.0075	0.161
	b. Likelihood of drought within 5 years	0.0934	0.0934	0.318	0.0865
	c. Likelihood of drought within 10 years	0.0245	0.105	0.815	0.0254
	d. Likelihood of drought within 30 years	0.0653	0.0756	0.389	0.0736
Concern about drought-related impacts to farm (Sensitivity)					
	Aggregated concern variable	0.334**	0.0593	0.000	0.291
Perceived ability to cope (Adaptive capacity)					
	a. I have the knowledge and technical skills	0.0558	0.0463	0.23	0.068
	b. I have the financial capacity	-0.0845*	0.0428	0.0492	-0.111
	c. Crop insurance	0.552	0.0375	0.142	0.069
Existing irrigation (Adaptive capacity)	Increase irrigated acres	0.0515	0.0744	0.49	0.038
Planned irrigation (Adaptive capacity)	Irrigation on farm	0.0628	0.628	0.601	0.029
	Constant	1.32**			
	n	464			
	F-statistic	13.2			
	Adjusted R2	0.332			

The belief that climate change is human caused increased perceived vulnerability scores, the dependent variable, by almost 0.5 points or 10%. A one-unit increase in concern about the farm's sensitivity (e.g., from moderately to extremely concerned) increased vulnerability scores by 0.3 points. A one-unit increase in beliefs about exposure to drought within the next year (e.g., from not at all likely to somewhat likely) increased vulnerability scores by 0.2 points.

Analysis of the drought scenarios revealed that at least one-quarter of respondents are at minimum somewhat likely to adopt or expand irrigation under four of the eight scenarios (Fig. 3). Almost 30% of respondents reported they are somewhat likely or more to adopt or expand irrigation if scientific models predict a serious drought will occur every 5 years (29%) or every 10 years (28%). Experiencing one bad drought year every five years on average would compel 27% of respondents to adopt or expand irrigation, while experiencing just one bad drought year would compel 15% of respondents. Comparing respondents currently with and without irrigation reveals that irrigators are more likely to expand existing irrigation under all of the scenarios than non-irrigators to adopt irrigation anew.

Conclusions

This study reveals that many agricultural producers in Minnesota feel vulnerable to climate and drought-related impacts, in part because they believe water scarcity is an imminent problem, humans are at least partially responsible for climate change, near-term droughts are likely, and their farms are particularly sensitive to drought stress. These findings are consistent with Arbuckle and others (2013a, b) and Wheeler et al. (2015) who found that beliefs in climate change positively influence risk perception. Only one adaptive capacity measure influenced vulnerability scores. Although adopting or expanding irrigation appears to be a likely adaptation strategy for at least a quarter of respondents, it does not seem as though irrigation allays feelings of vulnerability. Having irrigation, planning on increasing irrigated acres, having knowledge and skills to cope, or having crop insurance does not reduce farmers' feelings of vulnerability to water scarcity. Having financial capacity only slightly reduces perceived vulnerability. It is plausible that being within a GWMA adds a layer of uncertainty about future government regulations on groundwater withdrawals for agricultural irrigation. Still, when asked to consider a range of scenarios, one quarter of farmers reported being likely to adopt or expand irrigation, especially if they experience drought in the next five years or if scientific models predict a serious drought will occur every five years. Comparisons between irrigator and non-irrigator responses to the drought scenarios reveals adaptation is more likely among irrigators. This finding may be explained by the capital investment needed and perhaps wariness of farmers to switch to irrigation. Expanding existing irrigation systems likely requires less effort and involves lower perceived risk.

We believe three critical questions must anchor an anticipatory governance approach to water scarcity in Minnesota and the Upper Corn Belt: (1) What are future projections of water supply under global climate change and land use change scenarios, (2) How do agricultural producers perceive water scarcity and their own vulnerability, and (3) How will agricultural producers adapt? This study provides some initial answers to the latter two questions.

To be anticipatory, local and state water resource managers may want to explore what irrigation increases of 25% or more across the two groundwater management areas will mean for water budgets, human water users, and local ecosystems. To meet increased agricultural water demand, more efficient irrigation management and less water-intensive crops are needed (Hameeteman 2013). Regions such as the western United States, where irrigated agriculture has been the norm since the early 1900s (Hess 1912, Marshall 1920), are shifting focus to water use optimization and efficiencies to maximize water benefits for the entire population, rather than only crop yields (English, Solomon, and Hoffman 2002). Similar to Guillame and others (2016) and Andriyas and McKee (2015), our study points to perceptions of the likelihood of water availability and farm stress as drivers of farmer irrigation decisions. Other physical, psychological, and social factors not included in our study, such as technological advancements (Levidow et al. 2015), crop prices and production costs (Ng et al. 2011, Foster et al. 2014), attachment to the land (Kuehne and Bjornlund 2008), and civic engagement (Ramirez 2013), warrant further investigation.

Irrigated agriculture is the largest consumer of water globally (Qin et al.), making it a broad target when examining water scarcity. Nearly half the world's population and three-quarters of the irrigated area face at least periodic water shortage (Brauman et al. 2016). The Global Water Institute estimates that the lack of freshwater resources could displace up to 700 million people by 2030 (Hameeteman 2013). One study of the world's groundwater aquifers found that a third are already in distress (Richey et al. 2015). As populations grow, demand for food production and competition for water resources also rise. Irrigation also appears to be on the rise, putting groundwater aquifers at higher risk. More research is needed that investigates farmer drought adaptation decision making across farm type, size, income, soil type, and other characteristics. These factors are likely to influence risk tolerance, management, and agricultural adaptation strategies.

This study offers a method for examining the *social* and *psychological dimensions* of vulnerability that drive adaptation to climate change and water scarcity. Technocratic understanding of water scarcity has dominated water supply planning and management in Minnesota and the Upper Corn Belt. Perceptions of vulnerability among key actors with the potential to influence large-scale restructuring in agricultural landscapes are essential narratives to include in decision-making. The social and psychological dimensions of vulnerability are as important as the physical conditions of climate change when developing future scenarios of social and ecological adaptation. This study provides greater understanding of the nature and extent of drought experiences that serve as thresholds for adaptation behaviors in this central Minnesota context.

Declarations

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Code availability: Not applicable

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Ethics approval: This study complied with the corresponding author's institutional review board process for determining human subjects research compliance with ethical standards.

Consent to participate: The study complied with ethical standards for informed consent.

Consent for publication: The authors consent to publication.

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Figures

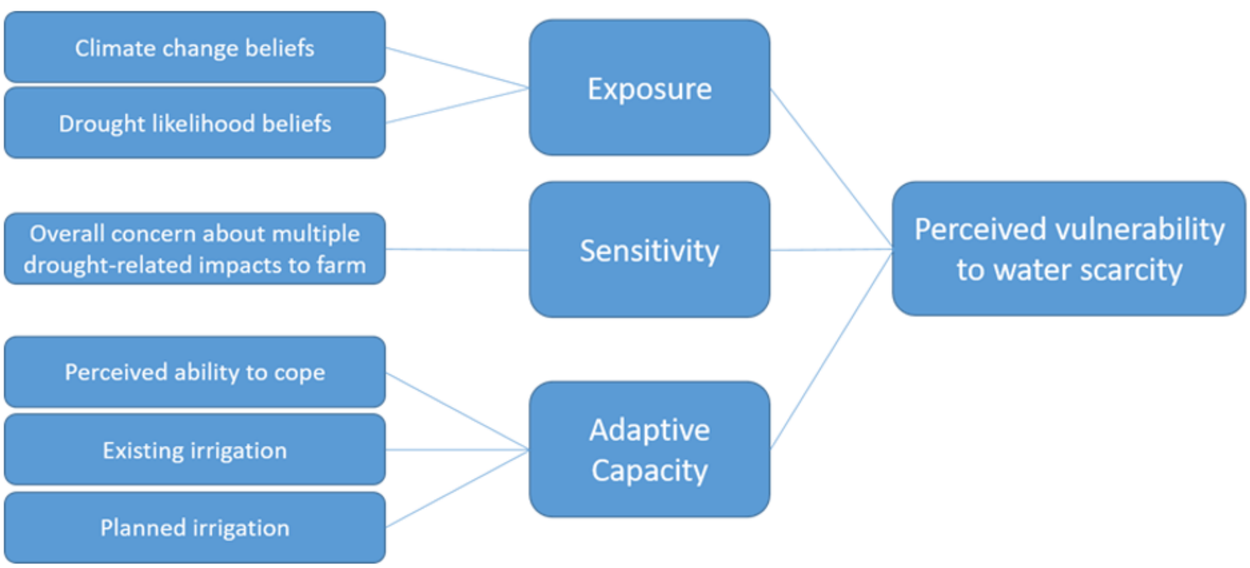

Figure 1

Conceptual model of perceived vulnerability to water scarcity

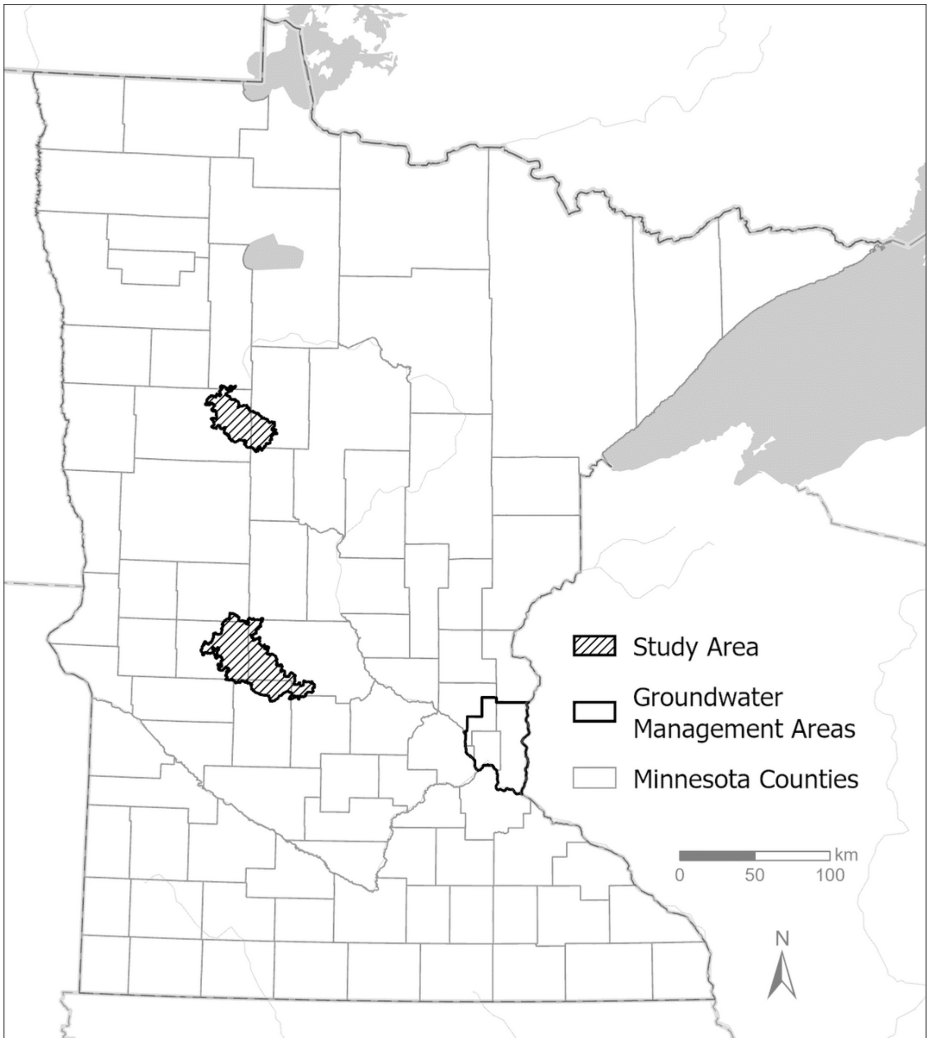

Figure 2

GWMAs in Central Minnesota

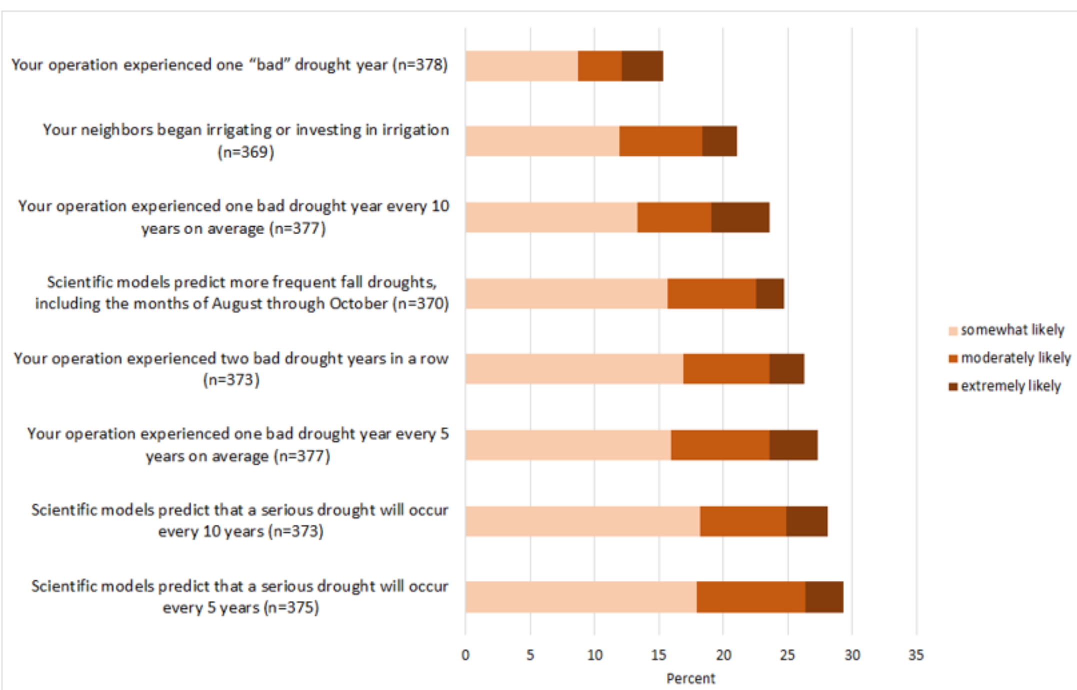

Figure 3

Drought scenarios and reported influence on adoption or expansion of irrigation systems.