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Climate Change and Water Bankruptcy: Agrarian Communities Resilience in District Lower Dir

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Abstract: The study aim is to examine that how climate change induces water bankruptcy reshape agrarian communities' resilience in a local sense at a global level. A cross-sectional quantitative research design was employed. The study was selected 387 respondents (smallholder farmers) based on multi-stage sampling technique. Primary data were collected through a structured interview schedule. Data were analysed using descriptive (frequencies and percentages) and inferential statistical methods (binary logistic regression to estimate the Odds Ratios (OR), 95% Confidence Intervals (CI) and P-values. The study result indicates that in northwestern Pakistan (Lower Dir) agrarian communities face climate change induce water bankruptcy. Farmers have a clear understanding that local water resources can no longer meet to irrigate their agriculture. Statistically water shortages were the most significant predictors of climate change that affects smallholder farmer's agriculture with adjusted odds ratios (AORs) of 8.72 in the less adjusted model and 4.62 in the most adjusted model. Although farmers are using local resilience strategies such as diversifying crops, but it's also do not adequately overcome chronic water shortages. Study also suggested that community-based approaches to managing water resources and implementing climate-smart agriculture policies will help alleviate both climate change and water bankruptcy.

Key Words: Climate Change, Water Bankruptcy, Resilience and Agrarian Communities

Introduction

Climate change represents one of mankind's biggest challenges today and has caused damage to both natural environments and social systems (Khan et al., 2025). Developing countries are experiencing the most severe impacts from climate change due to their dependence upon available natural resources: water and land (Khalid et al., 2024). Pakistan depends upon agriculture to support nearly 40% of the economic output generated by the country's productive workforce, contributing to approximately 19% of the GDP (Hussain et al., 2024). However, due to changing climate induce water bankruptcy make vulnerability agricultural related activities (Ahmed et al., 2025). Water bankruptcy which arises when demand for water exceeds the amount of water available for long-term sustainable use (Idrees & Ali, 2019). The term water bankruptcy is a fitting description for what happens when the local water resources can no longer meet the increased demands of agriculture, the growing population, and other human uses which create crises in food production and rural economies (Sheller, 2021; Lagarias, 2023; Ketabchy, 2022).

The northern side of Pakistan; predominantly agrarian region where smallholder farmers rely on rain feed agriculture (Ahmed et al., 2020). During the past ten years observable changes in the climate of the region (irregular rainfall, prolonged dry periods, higher temperatures, flooding) is noted that have impacted the availability of water resources for irrigation, livestock and domestic uses (Baocheng et al., 2024). These changes caused decreases in agricultural productivity, increases in production costs, and increases in socio-economic vulnerability (Ishaque et al., 2022). Climate change amplifies the already vulnerable status of the communities in parts of the world that do not yet

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have adequate irrigation systems (Ishaque et al., 2022). Limited available irrigation infrastructure and traditional water management systems make these communities particularly susceptible to small climatic changes (Khan et al., 2016). As a consequence, these communities must work to build resilient systems able to sustain their livelihoods despite the interaction of multiple environmental, economic and social stressors (Yasin et al., 2021). The development of resilience strategies will include crop diversification, improved water storage solutions and improved irrigation technologies (Ahmed et al., 2016).

Resilience is a key to understanding how agrarian societies cope with water scarcity. Resilience is defined as the capacity of a system, community or individual to predict, prepare, respond to and recover from adverse events (Shahzad et al., 2020). In the context of agrarian communities, resilience involves both structural and adaptive. The structural aspects of resilience generally involve the creation of physical infrastructures such as building water storage facilities and irrigation systems. Adaptive resilience refers to the creation and implementation of strategies to adapt to changing environmental conditions, including practices such as crop rotation, intercropping and planting new drought-resistant crop varieties (Muzammil et al., 2023; Khan et al., 2024; Mustafa, 2011).

Research on the connection between the impact of climate change, water bankruptcy and farmer resilience has been done in a general sense at a global level; however, localized research is vital for developing good public policy. In Pakistan's context, studies have shown the relationships between inconsistent rainfall dropping water table levels and reduced agricultural outputs over time. Nonetheless, there is a gap in research that has directly addressed the combined effects of climate-induced agricultural water bankruptcy on agrarian community's resilience. The aim of this research is to examine the effects of climate change on agricultural water supply in Lower Dir northwestern Pakistan and how farming communities cope with the decreasing amounts of water available for agriculture (i.e., the loss of water availability) due to climate changes. The major focus of this research is on the perceptions and adaptive strategies of smallholder farmers and how they are able to adapt to these changes. Additionally, the research will look at the reasons for water bankruptcy (water shortages) and how different coping strategies either exacerbate or alleviate these vulnerabilities.

Methodology

A cross-sectional quantitative research design was employed to examine the relationship between climate change, water bankruptcy, and resilience among agrarian communities. This design was appropriate for capturing farmers' perceptions, experiences, and adaptive strategies at a single point in time. The study was based on a sample of 387 respondents (N = 387). A multi-stage sampling technique was used: in the first stage, 7 villages councils were chosen in seven tehsils in the Dir Lower purposively based on their dependence on agriculture and exposure to water scarcity. In the second stage, households were selected using systematic random sampling. The final respondents were smallholder farmers, as they are most vulnerable to climate-induced water stress. Primary data were collected through a structured interview schedule. The schedule was designed to capture climate change awareness and perceptions, water availability and water bankruptcy conditions, causes of water shortages and resilience.

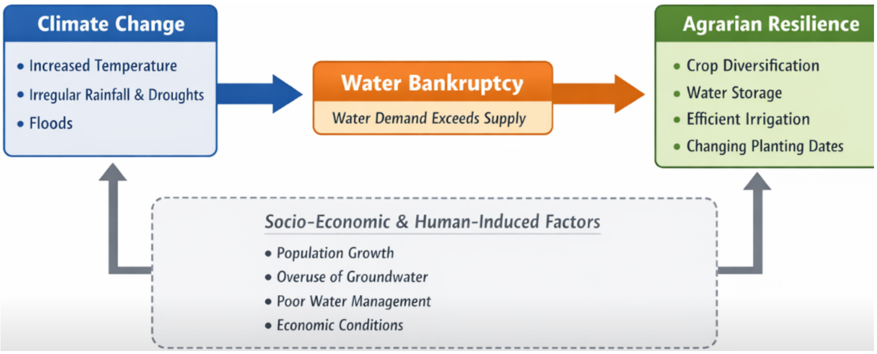
Data were analysed using descriptive and inferential statistical methods. In descriptive analysis frequencies and percentages were used to summarize. In bivariate analysis cross-tabulation was used to examine relationships between climate change variables and water bankruptcy. Binary logistic regression was applied to estimate the Odds Ratios (OR), 95% Confidence Intervals (CI) and P-values. This analysis helped determine the likelihood of water stress under different climatic and socio-economic conditions. In multivariate analysis, a series of multivariate logistic regression models (M1-M5) were developed to control for confounding variables and assess independent effects while the results were presented as Adjusted Odds Ratios (AORs) with 95% CI.

Conceptual Framework

The study is based on a framework linking climate change with water bankruptcy and agrarian resilience strategies. Climate change acts as the primary stressor influencing water availability, which in turn affects agricultural productivity and livelihoods. Resilience strategies mediate this relationship by enhancing adaptive capacity.

Figure 1

Represent the Conceptual Framework of the Study



Theoretical Framework

In examining the vulnerability and adaptive capacity of agrarian communities this research primarily utilizes resilience theory. The term resilience describes a system's (or a community's) capacity to tolerate, accommodate and transform due to disruptive events which disrupt functionality (Van Breda, 2001). Resilience theory also helps explain how agrarian communities with limited water resources through adaptive strategies such as diversifying their crops, storing water and changing their planting schedules. Resilience is dynamic and context-specific; it is continuously formed through environmental stressors (e.g. water bankruptcy) and social interactions (e.g. knowledge, governance, and infrastructure).

Result and Discussion

Results

Table 1

Represent Climate Change, Water Bankruptcy and Agrarian Resilience (Survey Data, N = 387)

S. No	Statements	F	%
Climate Change Awareness			
01	Changes in weather patterns over the past 5 years		
	Yes	332	85.8%
	No	55	14.2%
02	What changes have you observed?		
	Increased temperature	298	77.0%
	Irregular rainfall	315	81.4%
	More floods	210	54.3%
	Droughts	265	68.5%
Water Bankruptcy			
03	What are your main sources of irrigation water?		
	Rainfall	140	36.2%
	River	95	24.5%
	Tube well/groundwater	110	28.4%
	Canal	42	10.9%
04	Have you experienced water shortages in recent years?		
	Yes	301	77.8%
	No	86	22.2%
05	Do you think water demand is greater than supply in your area?		
	Yes	289	74.7%
	No	98	25.3%
06	What are the main causes of water shortage?		
	Climate change	310	80.1%
	Population increase	198	51.2%
	Overuse of groundwater	245	63.3%
	Poor water management	270	69.8%
Resilience			
07	What strategies do you use to cope with water shortages?		
	Crop diversification	220	56.8%
	Water storage	175	45.2%
	Efficient irrigation (drip/sprinkler)	95	24.5%
	Changing planting dates	260	67.2%

Description

The survey of 387 respondents in Lower Dir presents the descriptive findings for community awareness of climate change experiences with water bankruptcy and resilience. The table illustrates the respondents' identifying a significant proportion 85.8% of respondents noticed climate change and (in particular) changes in weather patterns over the last five years. The most common changes respondents identified included: irregularities in precipitation (rainfall) are 81.4%, increases in temperature is 77%, drought is 68.5% and flooding is 54.3%. When examining farmers' irrigation water resources, the respondents reported that the primary sources were as follows: rainfall (36.2%), tube wells (28.4%), rivers (24.5%) and canals (10.9%). Therefore, in response to recent years' water shortages, an overwhelming majority (77.8%) of respondents reported experiencing a water shortage at some point during the last few years. Additionally, the majority of respondents (74.7%) report that water demand in their community is greater than the available water supply. The key contributors to the community's water shortage included: climate change (80.1%), poor water management practices (69.8%), over-extraction of groundwater (63.3%), population growth (51.2%). In response to the aforementioned obstacles, respondents to this survey identified a range of farming strategies to build resilience against adverse climatic events. The dominant practices were altered planting schedule (67.2%), crop diversification (56.8%), water storage (45.2%), and irrigation systems that utilize drip or spray technology (24.5%).

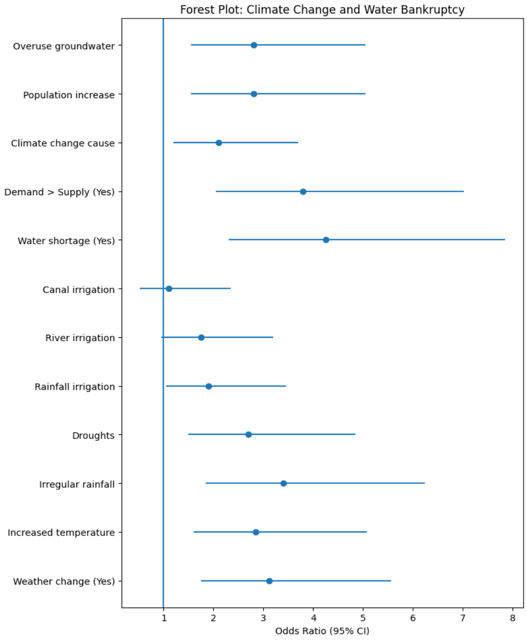
Table 2

Association of Climate Change, Water Bankruptcy and Agrarian Resilience

Water Bankruptcy	Climate Change effect Water I-Not effect II- always effect				
Variables		Not Effect (F%)	Always Effect (F%)	OR95% C.I	P-value
Changes in weather patterns over the past 5 years	Yes	45 (13.6%)	287 (86.4%)	3.12 (1.75–5.56)	0.001
	No	25 (45.5%) |	30 (54.5%) |	Reference	-
What changes have you observed?	Increased temperature	40 (13.4%)	258 (86.6%)	2.85 (1.60–5.08)	0.002
	Irregular rainfall	35 (11.1%)	280 (88.9%)	3.40 (1.85–6.24)	0.001
	Droughts	38 (14.3%)	227 (85.7%)	2.70 (1.50–4.85)	0.003
	Floods	50 (23.8%)	160 (76.2%)	Reference	-
Main sources of irrigation water	Rainfall	30 (21.4%)	110 (78.6%)	1.90 (1.05–3.45)	0.001
	River	22 (23.2%)	73 (76.8%)	1.75 (0.95–3.20)	0.061
	Canal	15 (35.7%)	27 (64.3%)	1.10 (0.52–2.35)	0.790
	Tube well	28 (25.5%)	82 (74.5%)	Reference	-
Experienced water shortages	Yes	40 (13.3%)	261 (86.7%)	4.25 (2.30–7.85)	0.001
	No	30 (34.9%)	56 (65.1%)	Reference	-
Water demand greater than supply	Yes	35 (12.1%)	254 (87.9%)	3.80 (2.05–7.02)	0.001
	No	35 (35.7%)	63 (64.3%)	Reference	-
Causes of water shortage	Climate change	45 (22.7%)	153 (77.3%)	2.10 (1.20–3.70)	0.009
	Population increase	42 (17.1%)	203 (82.9%)	2.80 (1.55–5.05)	0.002
	Overuse of groundwater	42 (17.1%)	203 (82.9%)	2.80 (1.55–5.05)	0.002
	Poor water management	50 (18.5%)	220 (81.5%)	Reference	-

Figure 2

Forest Plot on the Association of Climate Change and Water Bankruptcy



Explanation

In table and figure 02, the analysis goes beyond mere descriptive statistics and considers how changes in the climatic parameters, as well as water bankruptcy through cross tabulation and binary logistic regression with odds ratios (ORs), 95% confidence intervals (CIs), and probability (or P) values. A split was provided that distinguishes the respondents that indicated there was no effect of climate change on water bankruptcy or always effect. The results show that as a direct result of reported climatic change (e.g., changes in weather patterns), farmers who indicated such had over three times the odds (OR of 3.12, $p = 0.001$) of experiencing some type of water availability impact, as compared to farmers who experienced no change due to climate change. Irregularity of rainfall was significantly worse than that of increased temperature (OR = 2.85), but both exhibited odds and statistical significances of greater than or equal to 2.0 (both $p < 0.002$). Irregularity of flooding (the comparison group) impacted farmers' ability to experience negative climate change impacts in terms of water availability, as compared with what has been reported. Farmers who used rainfall for irrigation were at 1.90 times greater risk of experiencing water stress than farmers who had wells ($p < 0.001$). Farmers who had experienced a water shortage had 4.25 times greater risk of experiencing water shortage issues ($p < 0.001$), highlighting the clear link between water scarcity and agricultural vulnerability. Farmers who felt that demand for water exceeded supply were also 3.80 times more likely to report significant problems related to water ($p < 0.001$), underscoring the importance of water availability compared to local demand. As far as reported causes were concerned, climate change was associated with a 2.10 times increased likelihood of experiencing water issues ($p<0.009$).

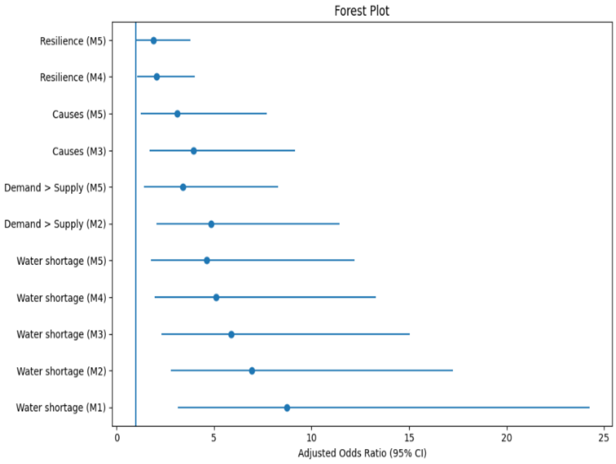
Table 3

Multivariate Association of Climate Change, Water Bankruptcy and Agrarian Communities' Resilience

Water Bankruptcy	M 1 AOR,95% CI	M 2 AOR,95% CI	M 3 AOR,95% CI	M 4 AOR,95% CI	M 5 AOR,95% CI
Experienced water shortages (Yes)	8.72 (3.13–24.25)	6.95 (2.80–17.25)	5.88 (2.30–15.02)	5.10 (1.95–13.30)	4.62 (1.75–12.20)
Water demand greater than supply (Yes)		4.85 (2.05–11.45)			3.40 (1.40–8.30)
Causes of water shortage			3.95 (1.70–9.15)		3.10 (1.25–7.70)
Resilience Strategies				2.05 (1.05–4.00)	1.90 (0.95–3.80)

Figure 3

Forest Plot on Climate Change, Water Bankruptcy and Agrarian Community's Resilience



Explanation

Table and figure 03 demonstrate the outcomes of a multivariable logistic regression analysis showing the Adjusted Odds Ratios (AORs) of multiple variables on the effect of climate change on water bankruptcy. Experiencing a lack of water (water bankruptcy) was determined to be a powerful predictor of water stress in all models. In the most basic model (M1), respondents who experienced a lack of water had an AOR of 8.72 (95% CI: 3.13–24.25), meaning that they were nearly nine times more likely to have reported major water effects than those who did not experience a lack of water. Even in the most confounded model (M5), the effect was still present at an AOR of 4.62 (95% CI: 1.75–12.20). The results of this analysis suggest that experiencing a lack of water significantly and independently increases the risk of being affected by climate-induced water stress in farming communities. The perception that there is a greater demand for water compared to what is available was also significant in models M2 through M5 for farmers' perceptions of water shortages in relation to demand with AORs ranging from 4.85 to 3.40. This means that farmers' perceptions of water shortages in relation to their demand for water is one of the biggest factors influencing the likelihood of experiencing water impacts, even when taking into account other variables such as the reasons for a lack of water. Climate Change was continuously a strong independent predictor of water scarcity in Models M3, M4 and M5, as evidenced by the AOR's between 3.10-3.95. This reinforces that climate change contributes to water stress directly independent of other environmental factors created by humans or other environmental influences.

Discussion

The results from this study contribute to a deeper understanding of how farmers in northwestern Pakistan (Lower Dir) are affected by climate change and resultant water bankruptcy. The three accompanying tables detail the perception of climate variability as well as the practical experience of climate change and water shortages by farmers. The first table illustrates high levels of climate awareness among farmers; approximately 85.8% of farmers reported observing climatic variability within the last five years in the form of increased temperature, irregular rainfall, droughts, and high incidence of flooding. These results support previous studies conducted in Pakistan and other semi-arid regions showing that smallholder farmers perceive changes in climate and how those changes impact their agricultural production (Noureen et al., 2022; Habib, 2021). The second table demonstrates that there is a statistical relationship between awareness of climate variability and the effect of climate change on water bankruptcy. Farmers who reported observing climatic change were 3.12 times more likely than those who did not report observing climatic change, to have experienced an impact from climatic change on the availability of water for agriculture. Similar observation was noted in the study of Fahad & Wang, (2020) that increased temperatures and irregular rainfall patterns provide additional insight into the relationship between climatic variability.

Water bankruptcy and its occurrence through at Lower Dir are explored in this research. As per the analysis provided in Table 01, rainfall and groundwater have become the main resources used by the majority of respondents and thus during climatic fluctuations (e.g. heavy rains, floods, drought) they become increasingly vulnerable. Further analysis indicates that 77.8% of farmers reported having faced some type of water shortage over the past year and that 74.7% of farmers believed that demand for water was greater than what was currently available to them. The association analysis, as presented in Table 02, supports the analysis conducted in Table 01. In particular, farmers that reported experiencing water shortages were found to be 4.25 times more likely to report the effects of diminished water availability and farmers that believed there was excess demand for water were 3.8 times more likely to have experienced water stress. Furthermore, when climate change was identified as the cause of diminished water availability, the probability of farmers experiencing water stress increased by a factor of 2.10, illustrating that when environmental change occurs, the effects are compounded by anthropogenic factors such as over-extraction of groundwater or population pressures. These findings are consistent with a number of studies conducted in Pakistan and South Asia (see Kajishita et al., 2025: Khan et al., 2023). that indicate that the primary drivers of water stress frequently occur at the intersection of climatic variability and unsustainable practices.

The data show that farmers have developed many methods for coping with the current lack of water. Farmers use different methods of adapting to the lack of water by changing their planting season (67.2%), planting different types of crops (56.8%), and storing water (45.2%). However, very few farmers (24.5%) use improved irrigation techniques. The results suggest that farmers rely mostly upon traditional, flexible ways of adapting to the lack of water, as these methods are usually inexpensive but do not help with long-term or extreme lack of water. The next table in the results section provides further information on how effective these methods were when viewed as a group rather than individually. The method of crop diversification did show some statistical significance in the model M4 (AOR = 2.05), although when the model was adjusted for all characteristics in the fully adjusted model M5 the crop diversification method did not retain a statistically significant relationship (AOR = 1.90). Globally, it has been shown that farmers use adaptive methods to buffer against short-term stress related to water shortages, but these adaptive methods alone will not protect farmers against water shortages caused by climate change or system-wide drought unless there are appropriate public policies, infrastructure systems, and management practices in place (Alam et al., 2024; Zeb et al., 2023).

The independent significance of key factors causing water stress was demonstrated using multivariate logistic regression. Experienced water shortages were the most significant predictors of climate change effects on water availability, with adjusted odds ratios (AORs) of 8.72 in the less adjusted model and 4.62 in the most adjusted model. Experience of water demand greater than supply was also significant; and climate change as a cause was connected independently with increasing risk. These findings indicate that water scarcity is the foremost driver of vulnerability among farmers, and that adaptive measures are insufficient to offset systemic shortfalls. Strategies to enhance resilience among farmers must be broader than just individual responses, but must include improved water infrastructure, implementation of water-efficient irrigation systems, and increased capacity for effective water governance (Abdullah et al., 2023; Khan et al., 2023b; Khan et al., 2023d) Community-based approaches to managing water resources, harvesting rainwater for agricultural use, and implementing climate-smart agriculture policies will help alleviate both climate change effects and water bankruptcy (Abdullah et al. 2023).

Conclusion

The vulnerability of agrarian communities in northwestern Pakistan (Lower Dir) to climate related water bankruptcy is high due to numerous factors, including both natural and human effects causing water to be unavailable. Farmers have a clear understanding of how climate is changing, and things that have related to their personal experience with water shortages demonstrate the correlation very well. Although farmers are using local resilience strategies such as diversifying crops and changing when they plant, these strategies do not adequately overcome chronic water shortages. According to the multivariate analysis, the major predictors of agricultural vulnerability are prior experience with water shortages, overuse of water, and climate change. These findings indicate that an integrated strategy (providing long-term solutions through improved water management infrastructure and irrigation technology combined with community adaptation) for sustainable water and agricultural viability needs to be established. This study highlights that awareness alone will not build capacity for agrarian communities to withstand the pressures of climate change and water shortages for food security and sustainable livelihoods in semi-arid structural solutions must also be implemented.

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