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Farmer Contribution to Irrigation-System Maintenance in Concrete-Lined and Unlined Watercourse Communities: A Comparative Study from District Nankana Sahib, Punjab, Pakistan

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ABSTRACT
Sustainable irrigation infrastructure requires collective farmer contributions to maintenance, yet evidence on whether watercourse infrastructure type influences such contributions remains limited in Pakistan. This study compares farmer contributions across concrete-lined and unlined watercourses in Nankana Sahib, Punjab, and identifies their socioeconomic and institutional determinants. Primary data were collected from 100 farming households, including 25 using concrete-lined and 75 using unlined watercourses. Overall, 58% of respondents contributed labour, cash, or in-kind resources to maintenance during the preceding 12 months. A binary logistic regression examined associations with income, education, farm size, ownership, tube-well dependence, watercourse type, and community trust. Trust (OR = 1.72, 95% CI: 1.19–2.48, p = 0.004) and household income (OR = 1.02 per thousand PKR, 95% CI: 1.01–1.04, p = 0.014) were positively associated with maintenance contribution, while tube-well dependence showed a negative association (OR = 0.96, 95% CI: 0.94–0.99, p = 0.016). Education, farm size, ownership, and watercourse type were insignificant. The model was significant (χ^2 = 37.42, p < 0.001; Nagelkerke R^2 = 0.437; AUC = 0.81). Findings highlight trust and income as important predictors, while the unequal infrastructure subsamples limit conclusions regarding channel type. Results support trust-building and livelihood-strengthening interventions locally in comparable rural irrigation settings.

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1. INTRODUCTION

Irrigation infrastructure below the level of the main canal, watercourses, field channels, and outlets, is, in most of South Asia's canal-command systems, maintained not by the state but by the farmers who use it. This makes tertiary-level irrigation maintenance a canonical common-pool-resource (CPR) cooperation problem: the infrastructure is jointly used and jointly degraded by neglect, no single user can be excluded from its benefits once built, and any individual farmer's decision not to contribute labor or money for repair imposes costs on all other users of the watercourse (Ostrom and Gardner, 1993).

The stakes of this cooperation problem are substantial. Pakistan possesses the world's largest contiguous, gravity-fed irrigation infrastructure, concentrated in the arid Punjab plains (Khan et al., 2021), and agricultural productivity in this system is highly sensitive to the condition of tertiary watercourses, where seepage and structural neglect account for a large share of conveyance losses. Reform programs over the past three decades have pursued two parallel strategies to address this: institutional devolution, transferring watercourse-level responsibility from state irrigation

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departments to Khal Panchayats and Farmer Organizations (Khurshid and Butt, 2016; Latif and Tariq, 2009), and physical formalization, notably the lining of previously earthen watercourses with concrete to reduce seepage losses.

Recent international evidence shows that collective action for irrigation maintenance responds to a bundle of factors: trust and social capital (Takayama et al., 2018), income and tenure security (Kidane et al., 2019; Sharaunga and Mudhara, 2018), and the availability of private substitute water sources such as groundwater, which can reduce the incentive to invest in shared canal infrastructure (Nagrah et al., 2016). Within Pakistan specifically, Nagrah et al. (2016) provide the most extensive econometric evidence to date, documenting an inverse-U relationship between groundwater availability and participation and a negative effect of high-quality groundwater access on collective maintenance behavior. More recent evidence extends this trust-based literature both geographically and temporally: in Thailand, social capital similarly predicts farmers' participation in multi-level irrigation governance (Mahaarcha and Sirisunhirun, 2023), and in China, social capital significantly predicts farmers' investment in public irrigation-infrastructure maintenance in rural Xinjiang (Zhou et al., 2025), indicating that trust-based collective-action mechanisms remain an active, cross-regional research question rather than a settled mid-2010s finding.

What remains comparatively unexamined is whether the 'physical formalization' of watercourse infrastructure itself, concrete lining versus unlined earthen channels, is associated with different levels or determinants of farmer contribution, holding other factors constant. This question is directly policy-relevant: watercourse-lining programs are a major and continuing public investment in Punjab, and their success in practice depends not only on engineering performance but on whether farmers continue to organize collectively for the maintenance the infrastructure still requires (silt removal, outlet repair, bank protection).

This study addresses that question using primary survey data from two watercourse communities in District Nankana Sahib, Punjab, one served by a concrete-lined channel, one by an unlined channel, comparing farmer contribution to maintenance and estimating its socioeconomic and institutional determinants via binary logistic regression, while explicitly assessing the statistical power available to detect a channel-type effect given the study's achieved sample sizes. The specific objectives are to (1) evaluate and compare farming-community contribution to irrigation-system management across the two watercourse types, and (2) identify the major determinants of that contribution. The study contributes context-specific, Pakistan-based evidence to a literature that, per the companion review, remains geographically concentrated relative to Pakistan's canal-irrigation setting, and it directly tests, for the first time in this setting, whether channel-lining status itself predicts collective-maintenance behavior once trust, income, and farm characteristics are controlled for, and once the achieved power of that specific comparison is made explicit.

2. LITERATURE REVIEW

The theoretical starting point for this study is Ostrom's (1990, 1993) framework of design principles for long-enduring, self-organized irrigation institutions, developed as a direct response to Hardin's (1968) prediction that shared resources are inevitably overexploited by absent privatization or state control. Ostrom's comparative case work showed that clearly defined boundaries, locally appropriate rules, participatory rulemaking, monitoring, graduated sanctions, low-cost conflict resolution, and nested governance are jointly associated with the long-run sustainability of farmer-managed irrigation systems.

Subsequent econometric work has operationalized specific correlates of this collective-action capacity. Takayama et al. (2018), using ordered probit models on a large panel of Japanese rural communities, found social-capital share and paddy-field composition significantly associated with collective irrigation management, with community size and landholding heterogeneity showing curvilinear rather than linear effects. Sharaunga and Mudhara (2018), applying a Heckman two-step model to smallholder irrigators in KwaZulu-Natal, South Africa, found that plot size, soil quality, water-shortage severity, and institutional position (block-committee membership) predicted participation in collective maintenance. In Nepal, Dhakal et al. (2018) found that successful farmer-managed collective action depends on clearer property-rights design within devolved institutions, not devolution alone.

Within Pakistan, Nagrah et al. (2016) offer the most directly comparable evidence: using the most extensive irrigation-management survey conducted in the country to date, they found that private access to groundwater, a substitute resource to canal water, reduces farmers' participation in collective canal maintenance, particularly where groundwater quality is high. Khan et al. (2021), comparing farmer-managed and government-managed schemes in Punjab, similarly emphasize that institutional design and land-holding structure, more than management-transfer status per se, explain variation in system performance.

This trust–social-capital literature has continued to develop well past the mid-2010s studies on which much of the Pakistani evidence base still rests. Mahaarcha and Sirisunhirun (2023), studying multi-level irrigation governance in Thailand, and Zhou et al. (2025), studying public irrigation-infrastructure investment in rural Xinjiang, China, both find social capital to be a significant, current predictor of farmer participation, directly paralleling the trust-contribution relationship examined in the present study and demonstrating that this remains a live line of inquiry across diverse canal-irrigation settings.

Trust and reciprocity norms recur as a positive correlate of contribution across this literature (Takayama et al., 2018; Tembata and Takeuchi, 2018; Mahaarcha and Sirisunhirun, 2023; Zhou et al., 2025), consistent with the logic that repeated cooperative interaction and confidence in reciprocal compliance reduce the perceived risk of unilateral contribution ("why should I invest if others free ride"). Income and tenure security show a similarly consistent, though not universal, positive association (Kidane et al., 2019; Sharaunga and Mudhara, 2018), plausibly reflecting both greater abilities to bear the cost of contribution and a larger private stake in the system's continued functioning.

What this body of work has not directly tested is whether watercourse infrastructure formalization (lining) itself changes the calculus of collective maintenance contribution. Two competing mechanisms are plausible. Lining could reduce required maintenance effort and thus reduce farmers' felt need to organize collectively, weakening observed contribution. Alternatively, lining could increase the visibility of neglect (seepage and breaches are more conspicuous against a formalized structure) and reduce opportunities for free-riding, thereby increasing contribution. The present study is positioned to test the net empirical relationship between channel type and contribution, net of trust, income, and farm characteristics, in a single institutional and hydrological setting, a comparison the reviewed literature does not directly provide for Pakistan, while also reporting explicitly on the statistical power available for that specific test.

3. THEORETICAL FRAMEWORK

This study follows the CPR/collective-action framework of Ostrom (1990) and Baland and Platteau (1998), which classifies determinants of successful collective resource management into resource characteristics, user/community characteristics, and governance characteristics. The empirical model below operationalizes this framework at the household level: resource characteristics are proxied by tube-well water dependence (a measure of private substitute-resource access) and irrigation-channel type (lined vs. unlined, a measure of infrastructure formalization); user characteristics are proxied by income, education, farm size, and farm ownership; and the institutional/social dimension is proxied by trust among community members. The dependent variable, contribution to irrigation-system maintenance, is treated as the behavioral outcome the framework is intended to explain. Table 1 summarizes this mapping.

Table 1. Mapping of study variables to the CPR/collective-action framework

Framework category	Study variable(s)
Resource characteristics	Tube-well water dependence (% of irrigation water from tube wells); irrigation-channel type (concrete-lined vs. unlined)
User/community characteristics	Household income; education; farm size; farm ownership
Institutional/social characteristics	Trust among community members (co-users of the watercourse)
Behavioral outcome	Contribution to irrigation-system maintenance (binary)

Note. Categories follow Ostrom (1990) and Baland and Platteau (1998).

4. MATERIALS AND METHODS

Study area and sampling

The study was conducted in selected union councils of District Nankana Sahib, Punjab, Pakistan. A multistage sampling procedure was used: the district was purposively selected; two watercourse command areas were then randomly selected, one served by a concrete-lined channel and one by an unlined (earthen) channel; a total of 100 respondents were then randomly selected from these command areas, 25 from the concrete-lined system and 75 from the unlined system.

Data collection and instrument

Primary data were collected through face-to-face interviews using a structured questionnaire developed in English and administered in Urdu/Punjabi, covering respondent socioeconomic characteristics (age, education, income, expenditure, family size), water-source use and reliance, trust and reciprocity (four-point Likert-scale items), and self-reported contribution (type and amount) to irrigation-system maintenance. Informed consent was obtained prior to interview.

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Variables

The dependent variable is farmer contribution to irrigation-system maintenance (binary; coding rule reported below). Independent variables are: percentage of irrigation water sourced from tube wells (continuous), education (level, treated as ordinal/continuous per the original model), farm size in acres (continuous), farm ownership (owner vs. non-owner), household income in thousand PKR (continuous), irrigation-channel type (concrete-lined vs. unlined), and trust among community members (derived from the Likert-item-based questions, construction reported below).

Trust and contribution variable construction

Contribution to irrigation-system maintenance, the dependent variable, was coded 1 if the respondent reported providing labor, cash, or in-kind resources toward watercourse maintenance activities (silt clearance, outlet repair, bank protection, or the equivalent cash levy collected by the Khal Panchayat) at least once during the 12 months preceding the survey, and 0 otherwise. Under this rule, 58 of the 100 respondents (58%) were coded as contributing and 42 (42%) as not contributing.

Trust among community members was constructed from four four-point Likert items (1 = no trust to 4 = complete trust) asking respondents to rate their trust in other water users on the same watercourse that is, a measure of particularized trust among known co-users rather than generalized trust in strangers or institutional trust in irrigation officials regarding honesty in reporting water use, fairness in sharing labor and costs, reliability in honoring maintenance commitments, and willingness to cooperate in future maintenance rounds. The trust index used in the regression is the simple mean of the four items; internal consistency was acceptable (Cronbach's alpha = 0.78).

Analytical framework

Descriptive statistics (mean, standard deviation, minimum, maximum, frequency, percentage) characterize the sample overall and by watercourse type. A binary logistic regression models the log-odds of contribution as a linear function of the seven independent variables above:

$$\log(p / (1 - p)) = \beta_0 + \beta_1(\text{tube-well }\%) + \beta_2(\text{education}) + \beta_3(\text{farm size}) + \beta_4(\text{farm ownership}) + \beta_5(\text{income}) + \beta_6(\text{channel type}) + \beta_7(\text{trust}) + \varepsilon$$

where, p is the probability of contribution. Odds ratios (exp(β)) with 95% Wald confidence intervals are reported to aid interpretation. Model fit is assessed via the likelihood-ratio chi-square test and Nagelkerke R^2.

Model diagnostics

To assess model adequacy beyond the likelihood-ratio chi-square and Nagelkerke R^2, multicollinearity among predictors was assessed using variance inflation factors (VIF), and predictive accuracy was assessed using a classification table and the area under the receiver operating characteristic curve (AUC). With seven predictors and 100 observations (58 events, as reported above), the events-per-variable ratio is approximately 6:1 for the smaller outcome category, below the conventional rule-of-thumb of 10 events per variable; results are interpreted with corresponding caution regarding the stability of individual coefficient estimates.

5. RESULTS

Sample characteristics

The full sample (n = 100) was exclusively male-headed farming households. Mean respondent age was 47.78 years (SD = 9.92; range 27–75), with little difference between the concrete-lined subsample (mean 49.92, SD 8.85) and the unlined subsample (mean 47.07, SD 10.20). Educational attainment was higher among the concrete-lined subsample, where 96% of respondents had at least middle-school education and 84% had matriculation or above, compared with 84% and 40% respectively in the unlined subsample; illiteracy was reported only in the unlined subsample (16%).

Mean monthly household income across the full sample was PKR 42,300 (SD 16,850; range PKR 12,000–95,000), somewhat higher in the concrete-lined subsample (mean PKR 46,900, SD 15,200) than in the unlined subsample (mean PKR 40,800, SD 17,300). Mean monthly household expenditure was PKR 34,600 (SD 13,900) across the full sample, equivalent to approximately 82% of reported income on average.

Farm ownership was predominantly owner-operated (68% overall), with tenancy (10%) and sharecropping/mixed arrangements (22%) less common. Reliance on combined tube-well and canal water was the modal irrigation source overall (68%), with tube-well-only reliance more common in the unlined subsample (24%) than the concrete-lined subsample (28%; canal-only use was 12% and 5.3% respectively).

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Determinants of contribution to irrigation-system maintenance

Table 2 presents the binary logistic regression results estimated to evaluate the impacts of various variables on farmers' contribution to irrigation-system maintenance.

Table 2. Determinants of Farmers' Contribution to Irrigation-System Maintenance: Binary Logistic Regression Estimates (n = 100)

Variable	B	S.E.	Sig.	Odds Ratio	95% CI for OR
Tube-well water (%)	−0.036	0.015	0.016	0.964	0.937–0.993
Education	0.169	0.227	0.456	1.184	0.759–1.848
Farm size	0.027	0.067	0.688	1.027	0.901–1.171
Farm ownership	−0.089	0.691	0.898	0.915	0.236–3.543
Income (000 PKR)	0.023	0.009	0.014	1.023	1.005–1.041
Irrigation-channel type	−0.126	0.694	0.856	0.882	0.226–3.434
Trust	0.541	0.187	0.004	1.718	1.191–2.477
Constant	−4.113	2.093	0.049	0.016	—
Model χ^2	37.421		0.000		
Nagelkerke R^2	0.437				

Note. CI = confidence interval. Odds-ratio confidence intervals are Wald intervals computed as exp(B ± 1.96 × S.E.).

Three variables were statistically significant at conventional thresholds. Tube-well water dependence was negatively and significantly associated with contribution (OR = 0.964, 95% CI 0.937–0.993, $p = 0.016$): each one-percentage-point increase in the share of irrigation water sourced from tube wells was associated with a 3.6% decrease in the odds of contributing to maintenance. Household income was positively and significantly associated with contribution (OR = 1.023, 95% CI 1.005–1.041, $p = 0.014$): each additional PKR 1,000 in monthly income was associated with a 2.3% increase in the odds of contributing. Trust among community members was the strongest significant predictor (OR = 1.718, 95% CI 1.191–2.477, $p = 0.004$): each one-unit increase in the trust measure was associated with a 71.8% increase in the odds of contributing.

Education, farm size, farm ownership, and irrigation-channel type were not statistically significant at the 5% level (p = 0.456, 0.688, 0.898, and 0.856 respectively), though their point estimates were directionally consistent with the wider literature (positive for education and farm size, negative for farm ownership and concrete-lined status). Given the pronounced imbalance between the concrete-lined (n = 25) and unlined (n = 75) subsamples, a post-hoc power calculation indicates that the achieved power to detect even a moderate channel-type effect (odds ratio of 2.0) at the 5% significance level was approximately 33%, well below the conventional 80% threshold. The non-significant channel-type coefficient should therefore be interpreted as inconclusive rather than as evidence of a true null effect, a point we return to in the Discussion and Limitations. The model was jointly statistically significant ($\chi^2 = 37.421$, $p < 0.001$), and the Nagelkerke R^2 of 0.437 indicates that the model explains a moderate proportion (approximately 44%) of the variability in contribution.

Model diagnostics

Variance inflation factors for the seven predictors ranged from 1.15 (trust) to 2.10 (irrigation-channel type), well below conventional thresholds (VIF > 5 or 10) for problematic multicollinearity, although tube-well water share and channel type showed a moderate positive correlation consistent with lined watercourses being disproportionately represented among lower-tube-well-dependence commands (Table 3).

The fitted model correctly classified 78.0% of respondents overall (Table 4), with higher sensitivity for identifying contributors (84.5%) than specificity for identifying non-contributors (69.0%); the area under the receiver operating characteristic curve was 0.81 (95% CI 0.72–0.90), indicating good discriminatory power. Because the events-per-variable ratio (approximately 6:1) falls below the conventional rule-of-thumb of 10, these diagnostics should be read as indicating adequate, rather than excellent, model stability.

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Table 3. Multicollinearity diagnostics (variance inflation factors)

Variable	VIF
Tube-well water (%)	1.83
Education	1.42
Farm size	1.55
Farm ownership	1.28
Income (000 PKR)	1.96
Irrigation-channel type	2.10
Trust	1.15

Note. VIF values below 5 indicate the absence of problematic multicollinearity among predictors.

Table 4. Classification table for the fitted model

Observed	Predicted: Not contributing	Predicted: Contributing	% Correct
Not contributing (n = 42)	29	13	69.0
Contributing (n = 58)	9	49	84.5

6. DISCUSSION

The finding that trust among community members is the strongest predictor of contribution to irrigation-system maintenance is consistent with a substantial and continuing body of collective-action evidence (Takayama et al., 2018; Tembata and Takeuchi, 2018; Mahaarcha and Sirisunhirun, 2023; Zhou et al., 2025) and with Ostrom's (1990) broader argument that self-organized resource governance depends on the social infrastructure of reciprocity as much as on formal rules. It is worth noting that the trust measure used here captures particularized trust among known co-users of the same watercourse rather than generalized trust in strangers or institutional trust in irrigation officials; the strong association observed may not extend uniformly to these other forms of trust, an important qualification when interpreting the underlying mechanism. This suggests that interventions aimed narrowly at formal institutional reform (e.g., restructuring Khal Panchayat elections or Farmer Organization statutes) without complementary trust-building activities, such as facilitated dispute resolution, transparent record-keeping of past contributions, or reputational mechanisms, may achieve limited gains in practice.

The positive association between income and contribution is consistent with Kidane et al. (2019) and Sharaunga and Mudhara (2018) and is compatible with at least two mechanisms this cross-sectional design cannot distinguish: higher income may relax the liquidity constraint on contributing labor or money, or higher-income farmers may simply have a larger private stake in system functioning (e.g., larger irrigated area) that happens to correlate with income. Further research using panel or instrumental-variable designs would be needed to separate these channels; the present finding should be read as an association, not a causal income effect, consistent with the thesis's own caution about causal interpretation.

The negative association between tube-well dependence and contribution is directly consistent with Nagrah et al. (2016), the most methodologically comparable Pakistani study, which similarly found that private groundwater access reduces participation in collective canal maintenance. This convergence across two independent Pakistani samples strengthens confidence that a private-substitute-resource “crowd-out” mechanism, farmers who can privately access water via tube wells have weaker incentives to invest in the jointly used canal/watercourse system, operates in this setting, though it should be noted that the present study measures tube-well water share rather than tube-well ownership directly, a distinction that may matter for the underlying mechanism and that future work should disaggregate. This crowd-out mechanism is also consistent with more recent, directly comparable Punjab-based evidence on private irrigation-technology adoption: Ashfaq and Tehreem (2025), examining determinants of solar-powered irrigation system adoption among rice farmers in Hafizabad, Punjab, similarly show that farm and household characteristics systematically shape access to independent private irrigation technology, reinforcing the broader pattern that private water-access options reshape farmers' incentives to invest in jointly used canal infrastructure.

The non-significant coefficient on irrigation-channel type (lined vs. unlined) is best read as inconclusive rather than as evidence that physical formalization of the watercourse has no bearing on collective-maintenance behavior. As reported in the Results, the achieved statistical power to detect even a moderate channel-type effect was low (approximately 33%) given the 25-versus-75 subsample split, so this study cannot rule out a true effect of lining status that a better-powered, more balanced design might detect. This does not resolve the two competing mechanisms discussed in Section 2 (reduced maintenance need vs. reduced free-riding opportunity); if anything, it suggests only that this specific comparison lacked the power to adjudicate between them, rather than that the two mechanisms offset exactly, although an exact offset remains a formal possibility that future, adequately powered work should test directly.

7. POLICY IMPLICATIONS

Trust emerged as the strongest predictor of farmers' contribution to watercourse maintenance, indicating that weak reciprocity norms are undermining voluntary investment. To address this, the Provincial Irrigation & Drainage Authority (PIDA) and Farmer Organizations should facilitate transparent record-keeping of contributions and establish structured dispute-resolution forums at the Khal Panchayat level in the short term; this is expected to increase farmers' willingness to contribute by reducing free-rider uncertainty.

Income was found to be positively associated with contribution, suggesting that lower-income farmers may under-contribute despite being willing to do so. This points to a policy problem of liquidity constraints, which can be addressed in the medium term by linking agricultural credit and input-support programs to watercourse-command areas through provincial agriculture and rural-credit institutions, thereby relaxing the liquidity constraint on contribution.

Tube-well dependence was negatively associated with contribution, as private groundwater access weakens incentives for canal-system investment. To resolve this, PIDA and Farmer Organizations should explore conjunctive-use management agreements that formally recognize a reduced canal-maintenance burden for groundwater-reliant farmers, rather than assuming a uniform obligation across all farmers; this medium- to long-term intervention is expected to reduce free-riding disputes and produce more equitable sharing of the maintenance burden.

Channel type (lining) was not found to be a statistically significant predictor in this sample, but the comparison was underpowered given the unequal subsample sizes; lining programs should therefore not be assumed, based on this result alone, to leave collective-maintenance behavior unaffected in either direction. As a long-term, structural intervention, PIDA and provincial planning departments should pair infrastructure-lining investment with institutional and trust-building components rather than treating lining as a substitute for governance reform and should support a better-powered follow-up evaluation before drawing firm conclusions about lining's net effect on collective maintenance.

8. LIMITATIONS

This study has several limitations that should guide interpretation of its findings. The cross-sectional design precludes causal inference; all reported associations should be read as such rather than as evidence of causal mechanisms. The concrete-lined and unlined subsamples are unequal in size (25 vs. 75); a post-hoc power calculation indicates the achieved power to detect a moderate channel-type effect (OR = 2.0) at the 5% level was approximately 33%, well below the conventional 80% threshold, so the non-significant channel-type coefficient should be read as inconclusive rather than as a confirmed null result. The sample is exclusively male, limiting insight into gendered dimensions of irrigation labor and decision-making documented elsewhere in the Pakistani literature (Nagrah et al., 2016). The events-per-variable ratio for the logistic model (approximately 6:1 for the smaller outcome category) falls below the conventional rule-of-thumb of 10, so individual coefficient estimates, although broadly consistent with theory and prior Pakistani evidence, should be interpreted with some caution. The trust measure captures particularized trust among known co-users of the watercourse rather than generalized or institutional trust, which may limit how far the trust-contribution association generalizes to other trust referents. Finally, the study is confined to male-headed households in a single district, and findings should not be extrapolated to Punjab's canal-irrigation system as a whole without confirmation in larger, multi-district, gender-inclusive samples.

9. CONCLUSIONS

Trust among community members, household income, and dependence on tube-well water are significant, robust predictors of farmers' contribution to irrigation-system maintenance in this Punjab sample, while education, farm size, and farm ownership are not. The coefficient on watercourse-lining status was also not statistically significant but given the achieved power of only about 33% to detect a moderate channel-type effect at the study's 25-versus-75 subsample split, this should be treated as inconclusive rather than as evidence that watercourse lining has no bearing on collective-maintenance behavior. These findings are broadly consistent with, and extend, the Pakistan-specific evidence base established by Nagrah et al. (2016) and suggest that, within the bounds of a single-district, male-only sample, trust-building and income-support measures deserve at least as much policy attention as continued

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infrastructure lining in sustaining collective maintenance of tertiary irrigation infrastructure in comparable Punjab settings.

Future work should (a) replicate this analysis with larger, gender-inclusive, and multi-district samples to test the generalizability of the trust, income, and tube-well findings across Punjab's canal-irrigation system; (b) recruit larger and more balanced concrete-lined and unlined subgroups specifically to achieve adequate statistical power to detect a channel-type effect, rather than relying on a single, imbalanced comparison; (c) disaggregate generalized, institutional, and particularized trust to test whether the strong association reported here is specific to trust among known co-users or extends to other trust referents; (d) apply panel or quasi-experimental designs around watercourse-lining rollout to test the two competing mechanisms (reduced maintenance need vs. reduced free-riding opportunity) discussed in Section 2 with greater causal leverage; and (e) disaggregate tube-well water share into ownership versus rental/purchase arrangements to clarify the specific channel through which private water access weakens collective-maintenance incentives.

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