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# The linkages between water security, conflict, participation, and governance in smallholder irrigation schemes in KwaZulu-Natal, South Africa: a partial least squares structural equation modelling approach

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The increasing competition for water resources leads to conflict, as utility-maximizing farmers aim to improve their productivity to enhance food security and economic well-being. Conflicts within Smallholder Irrigation Schemes (SIS) are particularly rife due to inequitable water distribution that stems from various factors, leading to water insecurity. Using a sample of 302 farmers, this study investigated the multiple linkages between irrigation scheme governance, participation in scheme management, conflicts, and water security. The study adopted the Partial Least Squares-Structural Equation Modelling (PLS-SEM) approach to analyze the collective dynamic relationships between conflict, water rights, inclusive governance, and water security in SIS in KwaZulu-Natal Province, South Africa. The findings indicate that perceptions of governance, indicated by fairness in water allocation and enforceable water rules, are negatively related to conflicts in irrigation schemes. Furthermore, farmers who do not experience conflict are more likely to be water-secure. Results also indicate a negative relationship between participation in scheme management and conflict. As such, interventions should be targeted toward enhancing good governance, fostering farmer participation, and improving mechanisms of conflict management in SIS. This can be achieved by decentralizing decision-making to include farmers in rule enforcement, leveraging existing traditional authority structures to enhance legitimacy. The development of longitudinal datasets is also needed to track water adequacy, conflict trends, and governance efficacy to inform adaptive management to ensure water security.

KEYWORDS

**water resource governance, water security, farmer participation, water conflict, smallholder irrigation schemes, partial least squares-structural equation modelling**

## 1 Introduction

Irrigation is becoming increasingly important due to the undeniable effects of climate change, which has led to extreme variations in rainfall patterns. Variations in rainfall have made rural farmers more vulnerable to productivity losses and have intensified competition for water resources, making the revitalization and rehabilitation of Smallholder Irrigation Schemes (SIS) a priority for the South African government. SIS are formal irrigation projects that supply water to multiple farmers and were specifically constructed for agricultural and domestic uses for farmers in the rural areas of South Africa (Van Averbeke et al., 2011; Dirwai et al., 2019). The expansion of irrigated agriculture through SIS has been identified as an adaptive strategy to mitigate the adverse effects of climate change on agriculture (Mhembwe et al., 2019), particularly in drier regions where water scarcity is prevalent. Defined as the imbalance between water availability and demand (UN WATER, 2023), water scarcity in SIS refers to the insufficient water supply to meet irrigation, production, and consumption demands (Adela et al., 2019; Giordano et al., 2019). This can be attributed to various factors such as high demand for water, low levels of rainfall, dilapidated irrigation infrastructure, poor water management practices, and proximity to water sources (Yohannes et al., 2017; Fanadzo and Ncube, 2018; Boateng, 2024). Water scarcity directly undermines water security, which encompasses the sustainable access to adequate quantities of water for livelihoods, health, and socio-economic development (Cook and Bakker, 2012). Shah (2021) defines water security as the hydrological attributes and processes involved in water allocation and distribution. It refers to the reliability, availability, and accessibility of adequate water for productive agricultural production (Thabane et al., 2025). Water insecurity has been found to result in reduced production crop yields, food insecurity, heightened vulnerability to climate change, and possibly, conflicts over water (Link et al., 2016; Grasham et al., 2019; Ringler et al., 2022; Amparo-Salcedo et al., 2025).

SIS are recognized as essential for sustainable food production and economic transformation enablers in rain-fed farming systems (Mwadzingeni et al., 2021). Despite significant investments in the revitalization and rehabilitation of SIS globally, numerous schemes have either collapsed or operate below optimal levels due to dilapidated infrastructure, poor water allocation mechanisms, inadequate farmer training, and low participation in decision-making processes (Dirwai et al., 2019; Dlangalala and Mudhara, 2020; Mwadzingeni et al., 2021). Such challenges are not unique to South Africa; similar issues have been documented in SIS across India, where fragmented governance exacerbates water inequities (Shah, 2021), and in Nepal, where infrastructural decay and elite capture limit smallholder access (Shrestha et al., 2022). These systemic issues lead to unsustainable water use and present significant challenges to water management arrangements (Chipfupa and Wale, 2019), necessitating incentives for sustainable water utilization and collective scheme management.

Despite formal and informal institutions to ensure water access and rights, allocation remains a global concern due to rising demand and climate variability (Giordano et al., 2019). Water access among smallholder farmers is critical for agricultural productivity, food security, and socio-economic development (Nakawuka et al., 2018; Bjornlund et al., 2019). Inadequate access reduces production for subsistence and commercial markets, impacting food security and income generation (Osewe et al., 2020). Research highlights that smallholders often operate under water scarcity exacerbated by climate change and competition, as seen in Ghana, where proximity to water bodies dictates access (Boateng, 2024), and in Ethiopia, where inequitable allocation fuels disputes (Negasa et al., 2022). In South Asia, monsoon-dependent systems in Bangladesh face similar strains, with salinity intrusion and groundwater depletion compounding scarcity (Hussain et al., 2019). These examples underscore the global dimensions of water insecurity and its linkages to governance and equity.

Conflict within SIS is rife due to inequitable distribution stemming from undefined water rights, unfair irrigation scheduling, illegal extraction, and inefficient use (Phakathi et al., 2021). Differential access based on canal position further entrenches disparities (Muchara et al., 2016). Conflicts are exacerbated by poor governance, including weak rule enforcement, exclusion of marginalized groups, and limited community engagement (Dlangalala and Mudhara, 2020; Phakathi et al., 2021). Such dynamics are not confined to South Africa; in Indonesia, conflicts arise from overlapping legal and customary water rights (Bakker, 2023), while in Mexico, power imbalances in water user associations perpetuate inequities (Pacheco-Treviño and Manzano-Camarillo, 2024). Water conflicts disrupt agricultural activities, reduce crop yields (Muhoyi and Mbonigaba, 2021), and deepen insecurity, necessitating strategies to harmonize governance, rights, and participation.

Studies in South Africa have examined governance, water rights, and security in SIS (Muchara et al., 2014; Dirwai et al., 2019; Phali et al., 2022). Dirwai et al. (2019) linked water adequacy to governance factors like farmer awareness and payment compliance, while Muchara et al. (2014) identified water scarcity and literacy as barriers to collective action. However, these single-lensed approaches lack a holistic view of interconnected dynamics such as conflict, equity, and security. Globally, integrated frameworks have proven effective: in Brazil, participatory water councils improved conflict resolution (Eakin et al., 2010), and in Kenya, hybrid governance models enhanced smallholder resilience (Bahta, 2021). A multi-perspective analysis is thus crucial to identify linkages and develop strategies for sustainable water use (Bringezu et al., 2016). This study analyzes the relationships between conflict, governance, participation, and water security in SIS in KwaZulu-Natal, South Africa, offering insights relevant to global contexts grappling with similar challenges. The following section highlights the adopted methods, followed by a discussion of the results. The final section presents the conclusions and recommendations of the study.

# 2 Materials and methods

## 2.1 Study area and sampling

The study was carried out across four irrigation schemes in the KwaZulu-Natal Province, South Africa. It specifically examines four distinct irrigation schemes in the region: the Tugela Ferry (TFIS), Ndumo (NIS), Mooi River (MRIS), and Makhathini Flats (MFIS). The Makhathini Flats and Ndumo Irrigation Schemes are located in the Umkhanyakude District within the Jozini Local Municipality of northeastern KZN. TFIS and MRIS are situated in central KZN within the uMzinyathi District and Msinga Local Municipality.

MRIS consists of approximately 840 irrigators that rely on water from a 25 km scheme where irrigation water is diverted via a gravity flow canal from the Mooi River and is sectioned into three sections—upper, middle, and lower tail—comprising 15 blocks in total. Farmers receive water on scheduled days as determined by agreements within their farming blocks, and water availability can be unpredictable. In contrast, TFIS has approximately 1,500 farmers who employ various methods for water access, including gravity-fed canals, short-furrows, and pumps fueled by diesel and electricity. The scheme is made up of seven blocks, with one not in use. In Makhathini Flats, there are about 600 plot-holders across six blocks. The NIS serves 50 farmers who use an underground system for water conveyance. …

A total sample of 302 farmers was used to capture the linkages between conflict, participation, governance, and water security across four irrigation schemes in the KwaZulu-Natal Province. The irrigation schemes comprise blocks and the irrigators were proportionately selected from the respective blocks in the schemes. In MRIS, seven irrigators were selected from each of the 15 blocks; 20 irrigators were selected from the six blocks in TFIS, as one of the blocks was not in use. In MFIS, seven irrigators were selected across five of the blocks, and eight irrigators were selected in Block 6B. The NIS comprises two blocks, where 17 farmers were selected from each. A questionnaire was administered, which captured information on irrigation activities, institutional arrangements, socioeconomic, and agricultural production. Table 1 presents the scheme characteristics:

## 2.2 Analytical model

To analyze the various linkages, this study adopted the Partial Least Squares-Structural Equation Modelling (PLS-SEM) approach, which is commonly used for analyzing complex inter-relationships between observed and latent[1] variables (Memon et al., 2021). A latent variable is a construct that cannot be directly measured or directly observable, but is inferred from or made up of a set of observed variables (indicators). The latent variable represents an underlying concept or construct (Hair et al., 2021). PLS-SEM is a prediction-oriented technique that enables the measurement of paths between concepts. PLS-SEM enables the estimation of complex and multifaceted models, including numerous constructs, indicators, and structural paths, without considering how the data are distributed. Following Riaz et al. (2023), this study analyzed the relationships and interlinkages between conflict, governance, and water security. This enables the development of causal relationships and the simultaneous management of various links between response and explanatory variables simultaneously (Hair et al., 2019; Purwanto, 2021). Two methods of structural equation modelling are usually used in the social sciences: PLS-SEM and Covariance-Based SEM (CB-SEM). PLS-SEM was chosen over CB-SEM due to the exploratory nature of the research, as the latter is used for existing theory or concept confirmation (Hair et al., 2019).

TABLE 1 Smallholder scheme characteristics.

| | Irrigation Scheme | | | |
|---|---|---|---|---|
| Attributes | MRIS | TFIS | MFIS | NIS |
| No. of blocks | 15 | 7 | 6 | 2 |
| Number of irrigators | 840 | 1,500 | 600 | 50 |
| Water extraction mechanism | Gravity flow canal | Various (gravity-fed canals, short-furrows, and pumps fueled by diesel and electricity) | Canal system conveying water to pump stations across the blocks | Underground water conveyance system, |
| Land allocation | Tribal authority | Tribal authority | Farm trusts | Tribal Authority |
| Water access | Scheduled irrigation. | Subject to fee payment | Subject to monthly payment | Water accessible, have to pay for electricity. |
| Conflict management | Scheme committee or tribal authority. | Executive committee or tribal authority. | Co-operative committee or tribal authority | Scheme committee or tribal authority |
| Total farmers selected | 105 | 120 | 43 | 34 |

To measure the consistency and accuracy of the research, tests of validity and reliability were estimated through confirmatory factor analysis within PLS-SEM. Construct validity was determined by the values of the factor loadings of indicators, Cronbach's alpha, composite reliability, and rho-A. Factor loadings greater than 0.7 indicate the validity of the indicators that make up the latent constructs (Hair et al., 2021). The reliability of the estimates was determined by the Average Variance Extracted (AVE) values. The AVE value indicates whether latent/unobserved variables account for adequate variance in its associated indicators. An associated AVE of more than 0.5 is acceptable for convergent reliability (Shrestha, 2021). Discriminant validity was tested using the Heterotrait-Monotrait Ratio (HTMT), where a value lower than the 0.9 threshold is preferred, as it indicates that the constructs are distinct from each other (Rasoolimanesh, 2022). The standardized root mean squared residual (SRMR) was used to measure goodness of fit. PLS-SEM computes partial regression relationships in the measurement and structural models using separate ordinary least squares regressions. Two models are presented: the structural and measurement models. The structural model shows the relationship between the latent variables or constructs, while the measurement model indicates the relationship between latent variables and their indicators (Hair et al., 2021). The analysis was performed using the SmartPLS4 statistical software.

### 2.2.1 Measurement model

The measurement model consists of four constructs: participation in scheme management, governance, conflict, and water security.

#### 2.2.1.1 Participation in management

Participation in the management of irrigation schemes is defined as a process in which farmers influence policy formulation, investment choices and management decisions, in turn, gaining a sense of ownership of the water resource (Khalkheili and Zamani, 2009; Muchara et al., 2014). In this study, this construct captures the extent

1 Latent variables, unobserved variables, and constructs are used interchangeably throughout the manuscript.

to which farmers participate in the regulation and management of a scheme. The indicators chosen are whether farmers engage authorities about scheme-related issues, whether they financially contribute to maintaining the irrigation scheme, whether they are involved in the formation of rules within the scheme, whether they report infrastructure issues, and whether they report negative behavior within the scheme.

#### 2.2.1.2 Governance of the scheme

Following Akuriba et al. (2020), SIS governance is defined as the rules and regulations that guide the use and management of water resources. The World Governance Indicators include both objective and perception-based data to assess governance (Kaufmann et al., 2011). While the informal and formal institutions of scheme governance can be documented, capturing objective governance mechanisms might be challenging, as they often express the regulatory environment, however, these can significantly differ from what end users experience on the ground (Akuriba et al., 2020). As such perceptions of governance data have been widely used to capture on-ground dynamics (Dirwai et al., 2019; Akuriba et al., 2020; Phali et al., 2022). This study considers perception-based governance data and devises a governance construct which relates to how farmers perceive the governance issues around the scheme. The indicators include whether they deem the rules within the scheme easy to enforce, whether the penalties for non-compliance are fair, whether water allocation rules are fair, and whether the general scheme rules are fair. While governance and participation in scheme management are similar concepts, the difference lies in that governance relates to the overall system of formal and informal institutions, while participation refers to the active involvement of farmers (Perret, 2013; Dirwai et al., 2019). For instance, farmers can participate in the formulation of the rules, but not be involved in their enforcement. Additionally, participation in management is a choice, whereas governance or its perception is inherently present, whether the farmer actively participates or not.

#### 2.2.1.3 Conflict

The construct of conflict has only two indicators: whether the farmers experience conflict with other farmers in the scheme and whether they experience conflict with other blocks or sections in the scheme. The conflicts in the irrigation schemes usually arise due to illegal extraction of water, deviations from water scheduling arrangements, and small livestock grazing beyond boundaries. Conflicts are usually between farmers within the same sections of the scheme, or between blocks in the scheme, particularly upper and lower tail disputes. All the disputes across the schemes are reported to the scheme management committee and/or reported to and resolved by the tribal/traditional authorities, who also oversee other aspects such as land allocations. Farmers were also asked whether they deem the conflict mechanisms in place fair and adequate, however, to improve the measurement model (Guenther et al., 2023), the indicator was dropped from both the conflict and governance construct as it bore a non-significant weight to the constructs.

#### 2.2.1.4 Water security

Water security encompasses indicators related to water use. This includes whether they have access to adequate agricultural production needs and rights over water use (by means of payment, allocation, or licenses). Water reliability is included as an indicator that highlights whether a farmer deems its water access reliable for their production needs. The list of indicators used are presented in Table 2:

### 2.2.2 Structural model

The structural model measures the structural paths between the constructs. This study focuses on five direct paths: the relationships between governance and conflict, participation and conflict, conflict and water security, participation and water security, and governance and water security. Indirect effects are estimated between the constructs in which conflict mediates the relationship between governance and participation, and their effect on water security.

#### 2.2.2.1 Governance, conflict, and water security

The manner in which an irrigation scheme is managed and governed influences the behavior of water users. If the rules governing the scheme are in place and followed, the likelihood of effective conflict management is higher. Conflict management has also become an important aspect of governance, guided by enforcing rules (Lecoutere, 2011; Akuriba et al., 2020). Akuriba et al. (2020) showed evidence that conflict management ranked highly in assessing the governance of smallholder irrigation schemes. Lecoutere (2011) found that conflicts within irrigation schemes were managed by finding solutions guided by the institutions governing the scheme. Mdemu et al. (2023) also highlighted that the conflicts caused by the encroachment of human settlements on irrigated land exacerbated conflicts, which were resolved by improving the by-laws governing the scheme. The immediate action was to clear blockages and water pathways in the canals to facilitate water flow. Dirwai et al. (2019) concluded that governance factors within the schemes influenced water adequacy, which is an indicator of water security in this study. As such, this study hypothesizes a negative relationship between governance and conflict constructs and a positive relationship between governance and water security constructs.

**TABLE 2** Summary of constructs and indicator variables.

| Construct | Indicators |
|---|---|
| | Water adequacy |
| | Rights over water |
| | Water reliability |
| Governance | Fair water allocation rules |
| | Fair scheme rules |
| | Rules are easy to enforce |
| | Fair penalties for non-compliance |
| Conflict | Water conflicts with farmers |
| | Water conflicts between blocks and sections |
| | Satisfied with conflict management |
| Participation | Finance maintenance |
| | Engage authorities |
| | Report behavior |
| | Formulation of rules |
| | Report infrastructure issues |

#### 2.2.2.2 Participation, conflict, and water security

When farmers are involved in the management of irrigation schemes, a sense of ownership is ensured, which ultimately leads to sustainable use of resources. Participating in scheme management fosters collective responsibility and rule compliance, which is key in the conflict management of water resources (Salman et al., 2021; Mdemu et al., 2023). Mdemu et al. (2023) posited that participation can enhance the creation of effective solutions for conflict management. Similarly, Salman et al. (2021) also noted that a lack of effective conflict management reflects a weakness in participatory scheme management. This indicates a link between conflict and participation. Basu et al. (2021) suggested that coordination and participation at different levels in scheme management are imperative for sustainable water management and supply. When farmers do not participate in the management of the scheme, they lack a sense of ownership, which leads them to participate less in maintaining the water resources. This results in adverse effects on water security as poorly maintained infrastructure leads to water unreliability and low levels of water access (Shunglu et al., 2022), consequently leading to water insecurity and conflicts. Therefore, this study also tests the hypothesis of a positive and negative relationship between participation in scheme management and water security and conflict.

#### 2.2.2.3 Conflict and water security

Conflicts between water users impede sustainable water management (Janjua et al., 2024). Conflicts undermine governance mechanisms in place, leading to the persistence of water crises (Bishop et al., 2024). Owing to increased water scarcity, water availability in irrigation schemes and communities is steadily declining, and water users resort to conflict (Patrick, 2022). Conflicts ensue owing to inadequate water access, allocation, and reliability, often stemming from non-compliance with scheme rules. This is exacerbated by the lack of infrastructure development, which results in water users fighting over what is left of "working infrastructure" (Lebek et al., 2021). Conflicts among irrigators have the potential to exacerbate water insecurity, sometimes due to vandalism or further deterioration of infrastructure (Muhoyi and Mbonigaba, 2021; Lebek et al., 2021). In this regard, this study hypothesizes a negative relationship between conflict and water security.

In summation, the hypotheses tested are as follows:

- Water governance negatively influences conflicts.
- Participation in scheme management negatively affects conflict
- Conflict negatively affects water security
- Water governance positively affects water security
- Participation in scheme management positively affects water security
- There is a moderation effect of conflict between governance & participation on water security.

Figure 1 presents the reflective form of PLS-SEM, showing the various indicators that comprise the latent constructs of governance, participation, conflict, and water security.

The following section highlights the results of the study, describing the data set and providing estimates from the measurement and structural model of the PLS-SEM.

## 3 Results

### 3.1 Descriptive statistics

The demographic analysis of farmers across four SIS in KwaZulu-Natal reveals critical socio-economic patterns that intersect with governance, participation, and water security dynamics. Below, in Tables 3, 4 is a synthesis of key trends, interpretations, implications,

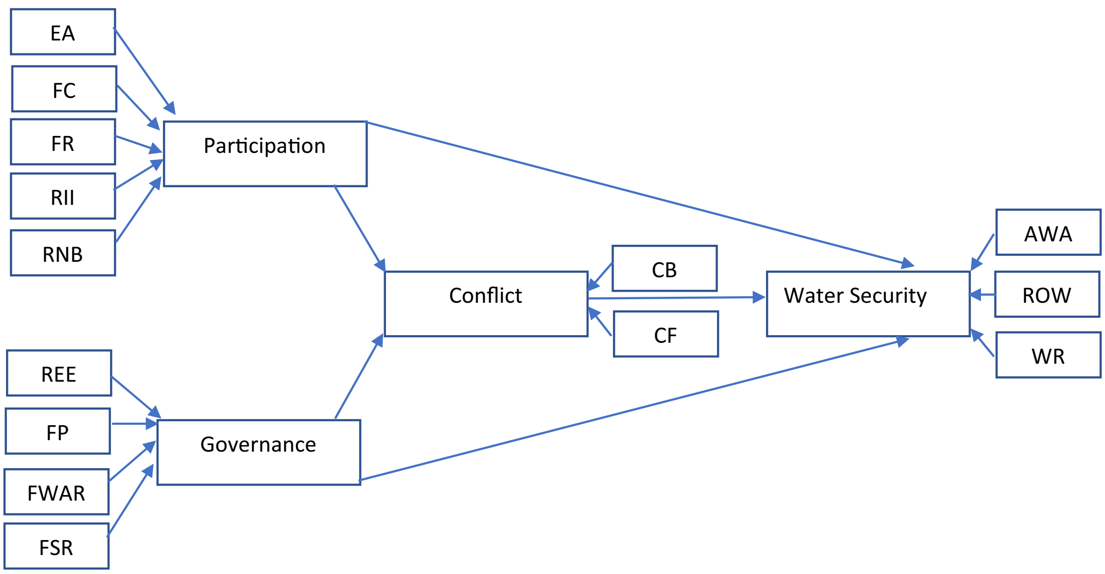


FIGURE 1
PLS-SEM reflective form of linkages between participation, governance, conflict and water security. EA, engage authorities; FC, finance contribution for scheme maintenance; FR, formulation of rules; RRI, report infrastructure issues; RNB, report negative behavior; REA, rules easy to enforce; FP, fair penalties for non-compliance; FWAR, fair water allocation rules; FSR, fair scheme rules; CB, conflict between blocks; CF, conflict between farmers; AWA, adequate water access; ROW, rights over water; WR, water reliability.

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TABLE 3 Descriptive statistics of socio-economic variables.

| Variable | Category | Scheme 1 | | Scheme 2 | | Scheme 3 | | Scheme 4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Frequency ($n$ = 120) | Percentage (%) | Frequency ($n$ = 105) | Percentage (%) | Frequency ($n$ = 43) | Percentage (%) | Frequency ($n$ = 34) | Percentage (%) |
| Gender | Male | 19 | 15.83 | 14 | 13.33 | 32 | 74.42 | 23 | 67.65 |
| | Female | 101 | 84.17 | 91 | 86.67 | 11 | 25.58 | 11 | 32.35 |
| Education | No Formal | 77 | 64.71 | 58 | 55.24 | 11 | 25.58 | 8 | 23.35 |
| | Primary | 23 | 19.33 | 34 | 32.38 | 17 | 39.53 | 8 | 23.35 |
| | High School | 16 | 13.45 | 13 | 12.38 | 12 | 27.91 | 11 | 32.35 |
| | Tertiary | 3 | 2,52 | 0 | 0.00 | 3 | 6.98 | 7 | 20.59 |
| Agricultural training | Yes | 54 | 45.00 | 53 | 50.48 | 34 | 79.07 | 25 | 73.53 |
| | No | 66 | 55.00 | 52 | 49.52 | 9 | 20.93 | 9 | 26.47 |
| Irrigation training | Yes | 26 | 21.67 | 29 | 27.62 | 17 | 39.53 | 18 | 52.94 |
| | No | 94 | 78.33 | 76 | 72.38 | 26 | 60.47 | 16 | 47.06 |
| Water management training | Yes | 35 | 29.17 | 21 | 20.00 | 13 | 30.23 | 15 | 44.12 |
| | No | 94 | 78.33 | 84 | 80.00 | 30 | 69.77 | 19 | 55.88 |
| Satisfaction with land tenure security | Yes | 96 | 80.00 | 77 | 73.33 | 21 | 50 | 30 | 90.91 |
| | No | 24 | 20.00 | 28 | 26.67 | 21 | 50 | 2 | 6.06 |
| Availability of water rights | Yes | 86 | 71.67 | 80 | 79.19 | 31 | 72.09 | 12 | 36.36 |
| | No | 11 | 9.17 | 10 | 9.52 | 5 | 11.63 | 10 | 30.30 |
| | I do not know | 22 | 18.33 | 0 | 0.00 | 7 | 16.28 | 0 | 0.00 |
| Water scheduling | None | 21 | 17.50 | 0 | 0.00 | 9 | 20.93 | 0 | 0.00 |
| | Sometimes | 55 | 45.83 | 22 | 20.95 | 14 | 32.56 | 0 | 0.00 |
| | Always | 44 | 36.67 | 37 | 35.24 | 20 | 46.51 | 0 | 0.00 |
| Access to credit | Yes | 59 | 49.17 | 46 | 43.81 | 23 | 54.76 | 0 | 0.00 |
| | No | 57 | 47.50 | 0 | 0.00 | 19 | 45.24 | 0 | 0.00 |

Source: Author computations (2025).

TABLE 4 Descriptive statistics of indicator variables.

| Variable | Category | Scheme 1 | | Scheme 2 | | Scheme 3 | | Scheme 4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Frequency (*n* = 120) | Percentage (%) | Frequency (*n* = 105) | Percentage (%) | Frequency (*n* = 43) | Percentage (%) | Frequency (*n* = 34) | Percentage (%) |
| Water adequate | Yes | 28 | 23.33 | 97 | 93.27 | 28 | 70.00 | 0 | 0.00 |
| | No | 92 | 76.67 | 7 | 6.73 | 12 | 30 | 0 | 0.00 |
| Water access | Yes | 86 | 71.67 | 99 | 94.29 | 22 | 51.16 | 32 | 94.12 |
| | No | 34 | 28.33 | 6 | 5.71 | 21 | 48.84 | 2 | 5.88 |
| Water reliable | Yes | 120 | 100 | 105 | 100 | 43 | 100 | 34 | 100 |
| | No | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Fair water allocation rules | Yes | 98 | 81.76 | 103 | 98.10 | 26 | 60.47 | 26 | 76.47 |
| | No | 22 | 18.33 | 2 | 1.90 | 17 | 39.53 | 8 | 23.53 |
| Fair scheme rules | Yes | 100 | 83.33 | 102 | 97.14 | 31 | 72.09 | 29 | 85.29 |
| | No | 20 | 16.67 | 3 | 2.86 | 12 | 27.91 | 5 | 14.71 |
| Rule easy to enforce | Yes | 78 | 35.00 | 84 | 80.00 | 13 | 30.23 | 22 | 64.71 |
| | No | 42 | 35.00 | 21 | 20.00 | 30 | 69.77 | 12 | 35.29 |
| Water conflicts with farmers | Yes | 47 | 39.17 | 12 | 11.43 | 7 | 16.28 | 4 | 11.76 |
| | No | 72 | 60.00 | 93 | 88.57 | 36 | 83.72 | 30 | 88.24 |
| Water conflicts between blocks and sections | Yes | 42 | 35.00 | 1 | 0.95 | 1 | 2.33 | 2 | 5.88 |
| | No | 77 | 64.17 | 104 | 99.05 | 42 | 97.67 | 32 | 94.12 |
| Fair penalties | Yes | 105 | 87.50 | 101 | 96.19 | 31 | 72.09 | 29 | 85.295 |
| | No | 15 | 12.50 | 4 | 3.81 | 12 | 27.91 | 5 | 14.71 |
| Fair allocation rules | Yes | 98 | 81.67 | 103 | 98.10 | 26 | 60.47 | 26 | 76.47 |
| | No | 22 | 18.33 | 2 | 1.90 | 17 | 39.53 | 8 | 23.53 |
| Water right | Yes | 22 | 18.33 | 12 | 11.43 | 7 | 16.28 | 11 | 32.35 |
| | No | 98 | 81.67 | 93 | 88.57 | 36 | 83.72 | 23 | 67.65 |
| Satisfied with conflict management | Yes | 79 | 65.83 | 71 | 67.62 | 18 | 41.86 | 28 | 82.35 |
| | No | 41 | 34.17 | 34 | 32.38 | 25 | 58.14 | 6 | 17.6633 |
| Finance maintenance | Yes | 10 | 8.33 | 42 | 40.00 | 25 | 58.14 | 33 | 97.06 |
| | No | 110 | 91.67 | 63 | 60.00 | 18 | 41.86 | 1 | 2.94 |
| Engage authorities | Yes | 79 | 65.83 | 90 | 85.71 | 30 | 69.77 | 29 | 85.29 |
| | No | 41 | 34.17 | 15 | 14.29 | 13 | 30.23 | 5 | 14.71 |

*(Continued)*





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TABLE 4 (Continued)

| Variable | Category | Scheme 1 | | Scheme 2 | | Scheme 3 | | Scheme 4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Frequency ($n$ = 120) | Percentage (%) | Frequency ($n$ = 105) | Percentage (%) | Frequency ($n$ = 43) | Percentage (%) | Frequency ($n$ = 34) | Percentage (%) |
| Report behavior | Yes | 64 | 53.33 | 62 | 59.05 | 32 | 74.42 | 29 | 85.29 |
| | No | 56 | 46.67 | 43 | 40.95 | 11 | 25.58 | 5 | 14.71 |
| Report issues | Yes | 53 | 44.17 | 65 | 61.90 | 31 | 72.09 | 24 | 70.59 |
| | No | 67 | 55.83 | 40 | 38.10 | 12 | 27.91 | 10 | 29.41 |
| Formulation of rules | Yes | 50 | 41.67 | 47 | 44.76 | 27 | 62.79 | 22 | 64.71 |
| | No | 70 | 58.33 | 58 | 55.24 | 16 | 37.21 | 12 | 35.29 |

Source: Author computations (2025).

and situate findings within the broader literature on smallholder irrigation schemes.

### 3.1.1 Gender disparities and participation

The gender distribution across schemes highlights significant imbalances. Schemes 1 and 2 were predominantly female (84.17 and 86.67%, respectively), whereas Schemes 3 and 4 are male-dominated (74.42 and 67.65%, respectively). This aligns with broader observations in sub-Saharan Africa, where women are overrepresented in smallholder farming but face systemic barriers to resource access, such as land tenure security and credit (Mkuna and Wale, 2023). The stark male dominance in Schemes 3 and 4 may reflect institutional or cultural biases favoring male control over productive resources, which can perpetuate income gaps (Mkuna and Wale, 2023). For instance, studies in KwaZulu-Natal have shown that male farmers earn significantly higher incomes because they have better access to inputs and markets (Mkuna and Wale, 2023). Addressing these disparities requires targeted interventions to enhance women's access to land rights, training, and credit—factors directly linked to technical efficiency and income parity (Mkuna and Wale, 2023).

### 3.1.2 Education and training

Educational attainment and specialized training varied markedly across schemes. Over 60% of the farmers in Schemes 1 and 2 lack formal education, compared to ~25% in Schemes 3 and 4. Tertiary education is nearly absent in Schemes 1–2, but it reaches 20.59% in Scheme 4. Agricultural and irrigation training participation was also higher in Schemes 3–4 (79.07 and 73.53% for agricultural training; 39.53 and 52.94% for irrigation training). These disparities underscore the role of education in enhancing farm management practices and technology adoption, as noted in studies that link technical efficiency to farmer training (Phali et al., 2022; Phakathi et al., 2021). For example, irrigation training improves water-use productivity, which is a critical factor in water-scarce regions like KwaZulu-Natal. The low training uptake in Schemes 1–2 suggests institutional gaps in extension services, which could exacerbate inefficiencies in water and land use.

### 3.1.3 Land tenure security and water rights

Land tenure security is the highest in Schemes 1 (80%), 2 (73.33%), and 4 (90.91%), but only 50% in Scheme 3. Secure tenure is a cornerstone of agricultural productivity, as it incentivizes long-term investments in irrigation infrastructure (Dirwai et al., 2019). Conversely, the lack of tenure security in Scheme 3 may contribute to underperformance, as farmers hesitate to adopt water-saving technologies. Similarly, water rights awareness varies: 72.09% in Scheme 3 report having rights, compared to 36.36% in Scheme 4. Unclear water rights often lead to conflicts and over-extraction, undermining water security (Phakathi et al., 2021). These findings align with the literature that emphasizes the need for formalized water governance structures to reduce transaction costs and improve equity (Dirwai et al., 2019).

### 3.1.4 Access to credit and water scheduling

Access to credit is limited across all schemes but is absent in Scheme 4. Credit enables farmers to invest in inputs and technologies that are critical for improving yields and resilience to climate shocks. The absence of credit in Scheme 4 may reflect systemic exclusion from financial institutions, a barrier that disproportionately affects female-headed households (Mkuna and Wale, 2023). Water scheduling practices further highlight governance challenges: inconsistent scheduling in Schemes 1–3 contrasts with Scheme 4's lack of data. Regular water scheduling correlates with efficient water use, as shown in studies linking structured irrigation practices to higher crop productivity (Phakathi et al., 2021).

### 3.1.5 Age and implications for innovation

The average farmer's age (54 years) suggests a potential generational gap in the adoption of innovative practices. Older farmers may rely on traditional methods, limiting their capacity to adapt to climate variability, or adopting water-efficient technologies (Phali et al., 2022). This aligns with the finding that younger farmers are more likely to engage with extension services and modern irrigation techniques (Phakathi et al., 2021).

The analysis of the indicator variables across the four schemes reveals critical insights into water security, governance efficacy, conflict dynamics, and institutional participation, as discussed in Table 2.

### 3.1.6 Water security: adequacy, access, and reliability

Water adequacy varies starkly across schemes: Scheme 2 reports high adequacy (93.27%), whereas Scheme 4 reports none (0%). This dichotomy may reflect disparities in infrastructure capacity or seasonal water scarcity, particularly in Scheme 4, where accessible water (94.12%) is paradoxically deemed inadequate for agricultural needs. Such gaps align with studies highlighting that physical access alone does not guarantee sufficiency for crop demands, especially in drought-prone regions such as KwaZulu-Natal (Patrick, 2020). Water reliability is uniformly reported as 100% across all schemes, suggesting a consistent supply, however, the lack of adequacy in Schemes 1 and 4 underscores a critical disconnect between availability and utility. This mirrors the findings in Sub-Saharan Africa, where reliable but insufficient water perpetuates "perceived scarcity," limiting productivity despite infrastructure investments (Kåresdotter et al., 2025; Lebek et al., 2021).

### 3.1.7 Governance and rule compliance

The fairness in water allocation and scheme rules is highest in Schemes 2 (98.1%) and 4 (76.47%), but lower in Scheme 3 (60.47%). These disparities correlate with enforceability: only 30.23% in Scheme 3 find rules that are easy to enforce compared to 80% in Scheme 2. Enforceability is a linchpin of institutional trust; weak enforcement erodes compliance, even with equitable rules (Jason et al., 2025; Prasad et al., 2024). Penalties for non-compliance follow a similar trend, with Scheme 3 reporting lower fairness (72.09%) than Schemes 2 and 4 (>85%). Consistent penalties are vital for deterring water theft and ensuring equitable distribution, as shown in studies emphasizing adaptive governance frameworks to address socio-political uncertainties (Prasad et al., 2024).

### 3.1.8 Conflict dynamics and management

Water conflicts are most prevalent in Scheme 1 (39.17% between farmers and 35% between blocks), likely linked to low water adequacy (23.33%) and inequitable allocation (18.33% dissatisfaction). Conversely, Schemes 2–4 report fewer conflicts, aligning with a higher perceived fairness and adequacy. Conflicts in Scheme 1 mirror the patterns observed in Ethiopian irrigation systems, where scarcity and poor governance fuel disputes (Patrick, 2020; Kåresdotter et al., 2025; Lebek et al., 2021). Satisfaction with conflict resolution was lowest in Scheme 3 (41.86%), reflecting governance deficits, whereas Scheme 4's high satisfaction (82.35%) suggests effective mediation. Effective conflict management strengthens collective action, which is a cornerstone of sustainable water governance (Lebek et al., 2021; Prasad et al., 2024).

### 3.1.9 Participation and institutional engagement

The financial contributions to maintenance are negligible in Scheme 1 (8.33%) but near-universal in Scheme 4 (97.06%). Willingness to fund maintenance reflects trust in institutional accountability, a factor critical for infrastructure sustainability (Jason et al., 2025; Prasad et al., 2024). Engagement with authorities and reporting of issues were highest in Schemes 2 and 4 (>85%), indicating stronger participatory governance. By contrast, Scheme 3's lower engagement (69.77%) correlates with its governance challenges. Active participation enhances transparency, as demonstrated in Kenyan schemes where farmer involvement reduces mismanagement (Prasad et al., 2024).

## 3.2 Measurement model

The measurement model presents the relationship between indicators and the constructs. It also provides reliability and validity measures. The results presented in Table 5 indicate that all the indicators except the formulation of rules, have factor loadings of more than 0.7. This means that more than 70% of the variation in the construct can be explained by indicator variance. Furthermore, the internal reliability of the model was confirmed by Cochran's alpha, rho-a, and rho-c above the threshold levels. The AVE values of more than 0.5 show that latent constructs of water security, conflict, participation, and governance account for adequate variance in their associated indicators and, therefore, convergent reliability (Shrestha et al., 2022). Table 6 presents the tests of discriminant validity given by the Heterotrait-monotrait ratio (HTMT). All values were below the 0.9 threshold indicating that the constructs were statistically distinct from each other.

## 3.3 Structural model

The structural model reflects the relationship between latent/unobserved constructs. As the reliability and validity of the measurement model were confirmed, the next phase was to estimate the structural model. Table 7 presents the results of the structural model analysis and shows that four of the five direct hypotheses were accepted given the statistical significance of the beta estimates.

The estimates show a negative relationship between governance and conflicts within SIS in KwaZulu-Natal as shown by the negative coefficient estimate of −0.033, which is statistically significant at the 5% level. Similar results for the relationship between participation and conflict were found, as shown by the negative, statistically significant coefficient estimate of −0,042, indicating that participation of farmers in the management of the SIS adversely affects conflicts within the

TABLE 5 Indicator loadings, reliability, and convergent validity.

| Construct and indicators | ^ | Alpha α | rho_a | (rho_c) | AVE |
|---|---|---|---|---|---|
| **Water security** | | 0.794 | 0.789 | 0.745 | 0.802 |
| Adequate water access | 0,879 | | | | |
| Rights over water | 0,816 | | | | |
| Water Reliability | 0,794 | | | | |
| **Conflict** | | 0.794 | 0.794 | 0.906 | 0.829 |
| Conflict between blocks | 0,907 | | | | |
| Conflict between farmers | 0,913 | | | | |
| **Participation** | | 0.725 | 0.771 | 0.811 | 0.563 |
| Engage authorities | 0,840 | | | | |
| Finance contribution for scheme maintenance | 0,740 | | | | |
| Formulation of rules | 0,699 | | | | |
| Report infrastructure issues | 0,790 | | | | |
| Report negative behavior | 0,722 | | | | |
| **Governance** | | 0.855 | 1.012 | 0.894 | 0.687 |
| Rules are easy to enforce | 0,730 | | | | |
| Fair penalties for non-compliance | 0,893 | | | | |
| Fair water allocation rules | 0,946 | | | | |
| Fair scheme rules | 0.879 | | | | |

Source: PLS-SEM analysis output (2025).

TABLE 6 Discriminant validity based on the Heterotrait-monotrait ratio (HTMT) ratio.

| Constructs | Heterotrait-monotrait ratio (HTMT) |
|---|---|
| Governance <– > Conflict | 0.121 |
| Participation <– > Conflict | 0.213 |
| Participation <– > Governance | 0.699 |
| Water <– > Conflict | 0.078 |
| Water <– > Governance | 0.746 |
| Water <– > Participation | 0.824 |

Source: PLS-SEM analysis output (2025).

schemes. The statistically significant coefficient estimate of −0.033 for the relationship between conflict and water security indicates that a negative relationship exists between the two constructs and that improved water security can be achieved through reduced conflict within the schemes. Governance and water security have a statistically significant positive relationship, which validates the assertion that effective governance mechanisms can enhance the attainment of water security for farmers. This study fails to accept the hypothesis of the relationship between participation and water security, as its coefficient estimate is statistically insignificant. The coefficient estimates of the hypothesized indirect relationships were rejected because of the statistically insignificant relationship. This shows that the data do not offer any evidence of conflict playing a mediating or moderating role (partial or otherwise) between governance and water security, or between participation and water security. Participation in scheme management positively affects water security.

# 4 Discussion

Smallholder irrigation schemes were built to ensure access to water for poor-resource farmers in rural areas as an intervention to ensure water security. However, owing to water scarcity, competition for water often results in conflicts related to water allocation, reliability, and adequacy to match production and consumption needs. The dynamics and linkages between scheme governance, participation in management, conflict, and water security were assessed, and the results indicated that all constructs were feasible across the four selected irrigation schemes. The factor loadings of all indicators constituting the latent constructs were above 0.7, indicating their validity. This indicates that farmers engaging authorities, financially contributing to scheme maintenance, involvement in formulating scheme rules, reporting infrastructure issues, and reporting negative behavior within the schemes are all valid indicators of participation in scheme management. Whether farmers perceive rules within the scheme as easy to enforce, that penalties for non-compliance are fair, and that there are fair water allocation rules and general scheme rules, which are valid indicators of governance in the schemes. Additionally, the experience of conflict between farmers and blocks within the schemes is a valid indicator of conflict. Additionally, whether farmers have rights over water use, whether they deem irrigation water adequate for production needs, and whether they deem the reliability of water are valid indicators of water security. The AVE of all constructs above the 0.5 threshold indicates that the latent constructs (water security, conflict, participation, and governance) account for adequate variance within the indicators. This means that the indicators for governance, participation, and water security should be enhanced to achieve better outcomes. This also points to the need for mechanisms to reduce conflict between farmers and blocks, as the indicators are valid

TABLE 7 Results of indirect SEM path relationships.

| Relationship | β | SE | p-values | Hypothesis |
|---|---|---|---|---|
| Conflict - > Water | -0,033 | 0,022 | 0,0137** | Accepted |
| Governance - > Conflict | -0,086 | 0,113 | 0,0443** | Accepted |
| Governance - > Water | 0,003 | 0,006 | 0,0941* | Accepted |
| Participation - > Conflict | -0,042 | 0,100 | 0,001* | Accepted |
| Participation - > Water | 0,011 | 0,009 | 0,155 | Rejected |
| Indirect paths between constructs | | | | |
| Governance-Conflict-Water | 0,003 | 0,006 | 0,631 | Rejected |
| Participation-Conflict-Water | 0,011 | 0,009 | 0,234 | Rejected |

Source: PLS-SEM analysis output (2025).

constructs of conflict. A structural model was used to capture the linkages and dynamics of governance, water security, participation, and conflict. This was the primary aim of the present study. The results showed that improved governance at the scheme level is positively related to water security. This is consistent with the findings of Dirwai et al. (2019), who provide evidence of governance factors influencing water adequacy, suggesting that water security would also be positively affected by good governance. The implication is that governance factors should be improved to ensure better water allocation mechanisms that enhance water access, reliability, and use rights. Governance also has a negative relationship with conflict experiences, suggesting that farmers with a good perception of governance are unlikely to experience conflict. This is consistent with Mdemu et al. (2023), who found that improving governing laws was an effective conflict-management mechanism. As such, institutions governing these schemes should be improved to ensure that the experience of conflict is minimized.

Participation in scheme management positively affects water security. The sense of ownership stemming from participation in scheme management ensures that farmers are involved in formulating rules related to water allocation and general scheme management. This increases the likelihood of water security, as the devised rules would benefit farmers as a collective. Shunglu et al. (2022) highlighted the importance of participation in irrigation maintenance and how the lack of leads to water unreliability and lowered water access. As such, farmers should be encouraged to take ownership of scheme management, financially contribute to scheme maintenance and report negative behavior that affects sustainable water management to enhance water security. The results also indicate that farmer participation has a negative relationship with the experience of conflict. This is in line with Salman et al. (2021), who suggested that farmer participation fosters collective responsibility and rule compliance, which in turn minimises the incidence of conflict.

The results indicate a negative relationship between conflict and water security. Conflicts are usually a result of competition for water, which stems from disruptions in water access and poor water allocation mechanisms. Consequently, this results in unreliability and inadequacy of water for productive use. Not only does conflict undermine existing governance mechanisms in place, but it also exacerbates water insecurity, as pointed out by Lebek et al. (2021). Unresolved conflicts can also lead to vandalism or the misuse of water infrastructure, thus affecting the access and reliability of water (Muhoyi and Mbonigaba, 2021). Therefore, it is imperative for conflict management mechanisms to occur. Despite the rejection of the hypothesis of the mediating or moderating role of conflict between governance and participation in water security, the direct effect shows that the improvement of governance and increased participation in scheme management individually enhance water security and reduce the experience of conflict. As such, their enhancement is key in alleviating conflicts and improving water security. This also indicates the dynamics of the constructs and begs for targeted interventions that collectively and holistically improve the constructs to ensure sustainable water management for better water security outcomes.

## 5 Conclusion

This study employed PLS-SEM to analyze the interrelationships between governance, farmer participation, conflict, and water security in Smallholder Irrigation Schemes (SIS) in KwaZulu-Natal, South Africa. The findings underscore that effective governance—characterized by fair water allocation rules, enforceable penalties, and transparent decision-making—is negatively and positively related to conflicts and water security, respectively. Farmer participation, particularly financial contributions to infrastructure maintenance and engagement in rule formulation, further mitigates disputes and fosters accountability. Conversely, conflicts between farmers and irrigation blocks erode trust in institutions and exacerbate water insecurity. As such, recommendations are that interventions should be targeted toward enhancing good governance, fostering farmer participation, and improving mechanisms of conflict management in SIS. This can be done by strengthening participatory governance by decentralizing decision-making to include farmers in rule enforcement and leveraging existing traditional authority structures to enhance legitimacy. Additionally, investments should be geared toward conflict resolution mechanisms through the establishment of localized mediation committees trained in adaptive negotiation strategies to address disputes swiftly, minimizing disruptions to water access. Furthermore, priority should be put on infrastructure maintenance by linking financial contributions from farmers to transparent auditing systems, ensuring funds are allocated equitably for repairs. Monitoring and evaluation should be conducted to develop longitudinal datasets tracking water adequacy, conflict trends, and governance efficacy to inform adaptive management.

While the study comprehensively assesses governance, participation, water security, and conflict, several limitations exist. The reliance on quantitative self-reported data risks conflating perceived and actual governance efficacy. Farmers' responses may reflect social desirability bias (e.g., overstating participation to align with perceived expectations) or underreport conflicts due to fear of reprisal. The regional focus on KwaZulu-Natal limits direct applicability to SIS in other provinces or countries, where cultural, institutional, and climatic factors may differ. Future research should consider participatory mapping or observational studies would be useful to triangulate subjective perceptions of water adequacy with objective measures (e.g., flow rates and crop yields). This study uses cross-sectional data, which generally cannot establish the temporal order of events, changes in constructs over time, which is important for determining causality. As such, future studies could also adopt a longitudinal design where variables can be tracked over multiple seasons to assess how climate variability (e.g., droughts) and policy interventions (e.g., infrastructure upgrades) affect governance efficacy and conflict trends. This can be achieved by employing methods such as Latent Growth Curve Modeling (LGC), a specialized structural equation modelling approach for analysing longitudinal data. Alternatively, a Panel Fixed-Effects model can control for unobserved heterogeneity in the longitudinal dataset and be incorporated within a structural equation framework. In addition, the application of computational tools is recommended to simulate how changes in governance or participation affect conflict probabilities under future climate scenarios.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

LP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Writing – original draft, Writing – review & editing. DN: Writing – original draft, Writing – review & editing. MM: Conceptualization, Funding acquisition, Project administration, Supervision, Validation, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

## Publisher's note



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