

ECONOMIC AND SOCIAL IMPACTS OF CHANGED WATER USE BEHAVIOUR OF COMMERCIAL WHEAT FARMERS IRRIGATORS TOWARDS CLIMATE VARIABILITY IN SOUTH AFRICA

IMPACT ÉCONOMIQUE ET SOCIAL DE L'ÉVOLUTION DES COMPORTEMENTS EN MATIÈRE D'UTILISATION DE L'EAU CHEZ LES PRODUCTEURS DE BLÉ COMMERCIAUX IRRIGANTS FACE À LA VARIABILITÉ CLIMATIQUE EN AFRIQUE DU SUD

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ABSTRACT

Effective water management and technology adoption are essential for sustainable water management and a catalyst for SDGs 6 (combating climate variability) and 2 (ending hunger and poverty), aligning with the African Union CAADP Strategy and Action Plan: 2026-2035. As water scarcity worsens in South Africa, efficient freshwater management is a critical policy issue. Inefficient water use is partly due to human behaviour, which is not fully understood in South African agriculture. This study addresses a knowledge gap by highlighting the impact of human behaviour on water use and management. It developed an integrated framework and socioeconomic indicators to assess the economic and social impacts of changes in water-use behaviour among wheat farmers in the Hartbeespoort irrigation scheme, South Africa.

To achieve the objective, a survey, Social Accounting Matrix, secondary data, extended Theory of Planned Behaviour, Structural Equation Model, AquaCrop model, and partial equilibrium analysis were applied. Psychological and contextual factors influence adaptation to climate variability. Attitudes drive intentions to adopt adaptive practices, while institutional and legal support strengthen social norms that encourage adaptation. Perceived risks arising from pressures such as load shedding and tariffs affect intentions and increase perceived behavioural control.

Technical factors reinforce intention, indicating that access to technical resources enables adaptive behaviour. These imply that farmers adopt strategies when they perceive risks as serious, have the technical means to act, and receive institutional reinforcement.

The AquaCrop and partial equilibrium model results show minimal yield impact under partial adaptation but significant increases under full adaptation, including increased wheat output, higher labour remuneration in South Africa, and significantly higher household income in the Northwest province, as well as institutional incomes. These findings confirm that, under the right psychological and structural conditions, full adaptation enhances productivity and delivers widespread socioeconomic benefits, making a compelling case for investment in long-term climate resilience.

Keywords: Hartbeespoort irrigation scheme; AquaCrop; institutional and legal support; technical resources; household income.

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RESUME

Une gestion efficace de l'eau et l'adoption de technologies sont essentielles pour une gestion durable de l'eau et constituent un catalyseur pour les Objectifs de développement durable - ODD n° 6 (lutte contre la variabilité climatique) et n° 2 (élimination de la faim et de la pauvreté) - conformément à la stratégie et au plan d'action du CAADP de l'Union africaine pour la période 2026-2035. Alors que la pénurie d'eau s'aggrave en Afrique du Sud, la gestion efficace de l'eau douce devient un enjeu politique crucial. L'utilisation inefficace de l'eau est en partie due au comportement humain, un aspect encore mal compris dans le secteur agricole sud-africain. Cette étude comble une lacune dans les connaissances en mettant l'accent sur l'impact du comportement humain sur l'utilisation et la gestion de l'eau. Elle a élaboré un cadre intégré et des indicateurs socio-économiques pour évaluer les impacts économiques et sociaux des changements de comportement en matière d'utilisation de l'eau chez les producteurs de blé du périmètre irrigué de Hartbeespoort, en Afrique du Sud.

Afin de réaliser cet objectif, on a utilisé différentes méthodes et outils tels qu'une enquête, une matrice de comptabilité sociale, des données secondaires, une version étendue de la théorie du comportement planifié, un modèle d'équations structurelles, le modèle AquaCrop et une analyse d'équilibre partiel. L'adaptation à la variabilité climatique est influencée par des facteurs psychologiques et contextuels. Les attitudes déterminent les intentions d'adopter des pratiques d'adaptation, tandis que le soutien institutionnel et juridique renforce les normes sociales qui encouragent l'adaptation. Les risques perçus découlant de pressions telles que les délestages et les tarifs affectent les intentions et renforcent le sentiment de contrôle du comportement. Les facteurs techniques renforcent ces intentions, ce qui indique que l'accès aux ressources techniques favorise l'adoption de comportements adaptatifs. Cela implique que les agriculteurs adoptent des stratégies lorsqu'ils perçoivent les risques comme graves, disposent des moyens techniques pour agir et bénéficient d'un soutien institutionnel.

Les résultats du modèle AquaCrop et du modèle d'équilibre partiel montrent un impact minime sur les rendements en cas d'adaptation partielle, mais des augmentations significatives en cas d'adaptation totale, y compris une hausse de la production de blé, une augmentation de la rémunération de la main-d'œuvre en Afrique du Sud et une hausse significative des revenus des ménages dans la province du Nord-Ouest, ainsi que des revenus des institutions. Ces résultats confirment que dans le cadre des conditions psychologiques et structurelles favorables, une adaptation complète améliore la productivité et donne lieu aux avantages socio-économiques répandus, ce qui réunit des arguments irréfutables en faveur de l'investissement dans la résistance climatique à long terme.

Mots-clés : Périmètre irrigué de Hartbeespoort; AquaCrop; Soutien institutionnel et juridique; Ressources techniques; Revenu des ménages.

INTRODUCTION

Water scarcity challenges agriculture, particularly in South Africa, where efficient water use is crucial for food security and economic stability. Researchers have explored strategies such as technological innovations (Shah et al., 2024) and economic incentives (Zhang and Oki, 2023) to promote technology adoption. However, despite their potential to reduce water use while maintaining crop yields, adoption rates remain low in many agricultural contexts.

Although water resource management frameworks integrate biophysical, socioeconomic, institutional, economic, and ecological dimensions of food systems, they often overlook psychological aspects of decision-making. This gap limits our understanding of what drives farmers and irrigators to adopt or resist climate variability. The main objective of this study was to develop an integrated framework to assess the social, economic, and psychological implications of changing water-use behaviour among commercial wheat farmers and irrigators in South Africa in response to climate variability. To achieve the main objective, the following sub-objectives need to be fulfilled:

- To identify and assess the key psychological factors influencing irrigators' water-use behaviour on the intention to adapt to climate variability using the extended Theory of Planned Behaviour.
- To simulate different adoption scenarios to assess their impact on crop yields using a biophysical modelling approach.
- To quantify the economic and social implications of changes in water-use behaviour for the broader economy.

The main contribution of this study was to develop an integrated framework that links human decision-making, psychological factors, biophysical outcomes, and economic effects in agricultural systems. The framework provides a practical way to understand how farmers' adaptation decisions to climate variability influence wheat production and the broader economy. The structure and components of the framework are shown in Figure 1.

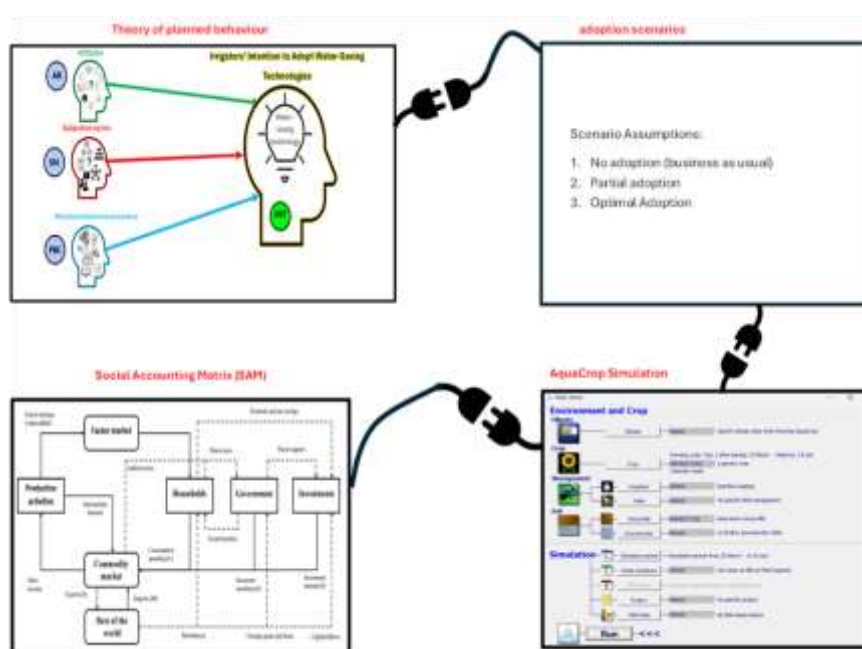


Figure 1. Integrated Framework for assessing the System-Wide Impacts of Farmer Behaviour
Source: Authors compilation

DATA AND RESEARCH METHODOLOGY

The study focuses on wheat due to its economic importance, contribution to agricultural production, reliance on irrigation, trade significance, and water use in production and value chains. Primary data were collected from 64 commercial wheat farmers between 2023 and 2024, with ethical clearance granted by the Research Ethics Committee under reference number UFS-HSD2023/0373/3. Secondary data were obtained from the Agricultural Research Council and other stakeholders.

The model integration was achieved in three stages. First, water-use behaviour and its drivers were identified. Second, scenarios were developed using extended Theory of Planned Behaviour (TPB) results to explain the psychological conditions influencing behaviour. Third, these scenarios were integrated with AquaCrop yield simulations and the Social Accounting Matrix (SAM) to develop the integrated framework shown in Figure 2.

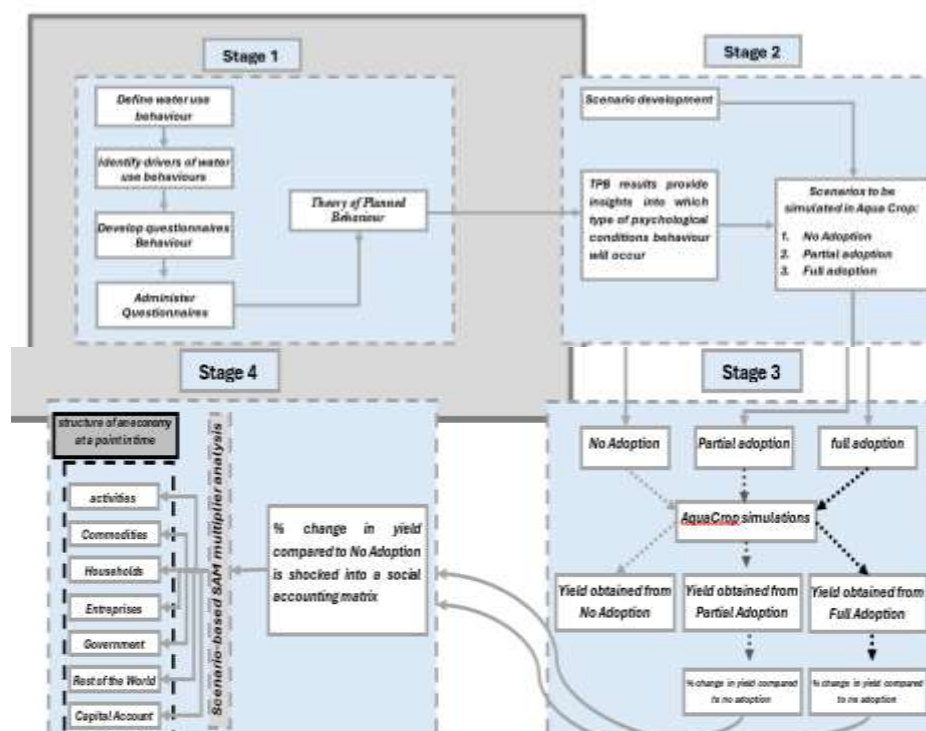


Figure 2. Steps for Integrated Framework (Source: Authors compilation)

Theory of Planned Behaviour (TPB)

To examine farmers' water-use behaviours, this study applied an extended TPB model, including constructs such as attitude, subjective norms, perceived behavioural control, intentions, technical factors, institutional and legal factors, perceived risks and benefits, perceived risks from load-shedding and tariffs, informational factors, trust factors, access to resources, and perceived financial cost. Structural equation modelling was used to test direct, indirect, and total effects among these constructs, following the theoretical framework of Hair et al. (2021) and Ajzen (2011).

AquaCrop model

The AquaCrop model simulation used *climatic data*, including temperature, humidity, solar radiation, wind speed, rainfall, and evapotranspiration, together with *soil characteristics* from dominant soil types such as *Eutric Plinthosols*, *Calcic Vertisols*, and *Ferric Luvisols*. Soil hydraulic properties were estimated using site-specific methods and combined through weighted averages to improve the accuracy of yield simulations.

Default wheat *crop parameters* were used in the AquaCrop model, as the study aimed to develop an integrated framework combining psychological, biophysical, and socioeconomic aspects of food production. *Management practices and irrigation schedules* were based on gross irrigation requirements influenced by crop type, soil characteristics, and climatic conditions.

A weighted average was used to estimate overall yield for the main irrigation zone based on the proportional coverage of each soil type, ensuring that soil variability and its effects on crop growth were accurately represented. Detailed information on the AquaCrop model is available from FAO (2023).

Social Accounting Matrix (SAM) and Multiplier Analysis (Partial Equilibrium Model)

The SAM framework was crucial in understanding the social and economic implications of irrigators' changed water use behaviours in South Africa. In layman's terms, a SAM is a matrix that depicts the relationships between all the various role players in the national economy, including business sectors, households, and the government. It reflects all of the intersectoral relationships within the economy (Bahta, 2013). The authors, with the assistance of stakeholders, developed a SAM for 2020 as both a database and a tool for partial equilibrium (multiplier) analysis. For the multiplier analysis, the scenarios were derived from the AquaCrop model.

Given that the SAM needs disaggregation to meet the study objectives, the study used the disaggregated SAM, which consists of 265 accounts. The main disaggregated accounts include Wheat_North West, North West labour, and irrigation schemes, among others. As a result of the disaggregation, the SAM unbalanced must be balanced. A cross-entropy method is used to balance the SAM with GAMS software (Robinson et al., 2000).

One of the multiplier models based on the combined SAM input-output table/model is the partial equilibrium model, utilised to assess the economic impacts of exogenous changes. The Leontief inverse matrix and the technical input coefficients are utilised for this purpose (Round, 1997).

Scenario formulations

Adapting agricultural systems to climate variability requires water-saving and soil-conserving practices such as mulching, weed management, and field surface improvements to enhance crop resilience and water-use efficiency. Mulching involves covering the soil surface with organic or inorganic materials to conserve soil moisture, regulate temperature, and reduce evaporation. Liao et al. (2022) highlighted the significant benefits of mulching in improving soil and plant conditions in water-limited environments. Weed management is another critical strategy for adapting agricultural systems to climate variability. Bajwa et al. (2015) highlighted the point that weeds pose a significant challenge to crop production, with improper management leading to substantial yield losses.

Another critical strategy for adapting agricultural systems to climate variability is deficit irrigation. This practice involves applying water below the crop's full water requirement, optimising water use while maintaining acceptable crop yields. Mushtaq and Moghaddasi (2011) highlighted that deficit irrigation was an effective adaptive strategy for climate change and increasing environmental water demand. The following scenarios utilised in the AquaCrop model:

1. **No Adoption Scenario:** assumed no adaptive measures with full irrigation requirement allocated based on the relevant water allocation unit, without considering soil-conserving practices and a moderate level of weed management applied to minimise crop competition and optimise resource use.
2. **Partial Adoption Scenario:** mulching applied at a moderate level to control soil temperature and moisture, as calculated in AquaCrop; a moderate level of weed management applied to minimise crop competition and optimise resource use, and deficit irrigation, set at 20% below the gross irrigation requirement for the specific irrigation scheme.
3. **Full Adoption Scenario:** mulching implemented at a significant level to maximise water retention and minimise evaporation, as optimised in AquaCrop; weed management implemented at the highest possible level to prevent competition and enhance crop resilience, and deficit irrigation utilised during the critical growth stages of the crop to optimise water use while maintaining acceptable yields, as determined by AquaCrop's simulation.

RESULTS AND DISCUSSION

Demographic, Farm, and Household Characteristics of Respondents

Demographic variables offer insight into the profile of irrigators, which is pertinent to understanding adoption. The respondents in the study were exclusively male, with the majority being middle-aged or older, particularly within the 41–50 years (31%) and 61 years and above (25%) age groups, while younger irrigators aged 21–30 constituted only 6%. Most respondents were relatively well educated: 55% held undergraduate degrees, 27% had secondary education, and 15% held diplomas, while very few held postgraduate qualifications. Canals (46%) and rivers (37%) were identified as the primary irrigation water sources, with most respondents engaged in crop production (78%) rather than mixed farming. The majority of farmland was located within 1–5 km of the main farm, and most irrigation land was situated less than 1 km from the water source, indicating relatively easy access to irrigation infrastructure. Farm businesses were mainly operated as corporations (41%) or sole proprietorships (26%), and 90% of respondents were sole landowners. Household characteristics showed that 90% of household members participated in farming, 93% of household heads were married, and 85% had no off-farm income, indicating a strong dependence on agriculture as the primary source of income and livelihood.

Augmented TPB Model for the adaptation towards climate variability

The results showed that both specific and total indirect effects were not statistically significant, indicating that mediating variables had little influence on the relationships between predictors and irrigators' intentions to adapt to climate variability. As a result, the total effects were almost identical to the direct effects, indicating that indirect influences had a minimal role in the overall model.

The direct effects (path coefficients) revealed several significant relationships. The relationship between attitudes (A_B) and intentions (INT) were significant ($\beta = 0.163$, $p < 0.01$), indicating that more favourable attitudes towards climate variability adaptation positively influence intentions to adopt such measures. Additionally, the influence of institutional and legal factors (IL) on subjective norms (SN) was also significant ($\beta = 0.255$, $p < 0.05$), suggesting that institutional support enhances social pressure to adapt. Moreover, the perceived risks from load shedding and tariffs (RB) had a substantial effect on intentions (INT) ($\beta = 0.545$, $p < 0.01$), highlighting the importance of these perceived risks in driving adaptive intentions. The relationship between perceived risks (RB) and perceived behavioural control (PBC) was also significant ($\beta = 0.247$, $p < 0.05$), indicating that higher perceived risks are associated with a greater sense of control over adaptation efforts. Lastly, technical factors (TF) significantly influenced intentions (INT) ($\beta = 0.397$, $p < 0.001$), emphasising the role of technical support and resources in shaping the intentions of irrigators to adapt to climate variability in the Hartbeespoort Irrigation Scheme.

The results indicated that the total effects closely mirrored the direct effects, reinforcing our finding that none of the indirect effects were significant. The total effects primarily reflect the direct relationships observed in the analysis, highlighting the strong and direct influence of the various constructs on irrigators' intentions to adapt to climate variability within the Hartbeespoort Irrigation Scheme. While the model effectively captures the variance in intentions to adapt to climate variability, the influence of attitudes, perceived behavioural control, and subjective norms remains comparatively limited.

The effect size (f^2) values of 0.02, 0.15, and 0.35 correspond to small, medium, and large effects, respectively. The results indicate that the construct for perceived risks from load shedding and tariffs ($RB2$) has a substantial impact on the intention to adapt (INT), with an f^2 value of 0.721, indicating a significant effect. This suggests that perceptions of risk significantly influence irrigators' intentions to adopt adaptive behaviours in response to climate variability.

In addition, the trust factors (*TF*) also showed a medium effect on *INT*, with an f^2 value of 0.427. This emphasises the importance of trust in shaping behavioural outcomes related to climate variability adaptation. The other constructs exhibited small to negligible effects on the outcome variables, with f^2 values generally below 0.15.

AquaCrop model simulation

According to the AquaCrop Model Reference Manual (Raes et al., 2023), the Net Irrigation Requirement (NIR) represents the water needed to maintain adequate soil moisture for wheat production, while the Gross Irrigation Requirement (GIR) includes additional losses from evaporation, runoff, and irrigation inefficiencies (Savva and Frenken, 2002). Table 1 presents the NIR used in the simulations for the three dominant soil types.

Table 1. Net Irrigation Requirement for dominant soil types

		Station name: Wildebeesthoek Coordinates: 25°40'06.6"S 28°02'03.1"E			Station name: Brits Coordinates: 25°35'29.0"S 27°46'07.4"E			Average
		2016	2017	2018	2011	2012	2013	
Net irrigation requirement (mm)	Eutric Plinthosols	442.0	391.0	431.6	377.7	260.7	382.7	380.95
	Calcic Vertisols	455.0	397.1	444.7	385.2	275.4	388.4	390.97
	Ferric Luvisols	459.3	411.4	446.9	397.9	275.3	401.9	398.78
	Average	452.1	399.83	441.07	386.93	270.47	391	390.23

Source: Authors compilation

By utilising equation 1 for irrigation efficiency (*E*) and GIR in equation 2 as :

$$E = \frac{ec \times ea}{100} \quad (1)$$

$$GIR_g = \frac{NIR_n}{E} \quad (2)$$

where:

- E Scheme irrigation efficiency (%)
- ec Conveyance efficiency (%)
- ea Field application efficiency (%)

The efficiency ($\frac{95 \times 75}{100} = 71.25$), NIR does not account for application efficiency or conveyance losses; for purposes of this study, it was assumed that most irrigation in the Hartbeespoort Irrigation Scheme is carried out using sprinkler systems and that water is distributed via lined canals. The lined canals are assumed to have a conveyance efficiency of 95%, and the sprinkler systems an application efficiency of 75%, based on these assumptions, the combined overall irrigation efficiency was calculated as 71.25%.

To ensure that the irrigation planning accounts for a worst-case scenario, the NIR values from the year with the highest irrigation demand (NIR 2016 = 452.1 mm (Table 1) were used to calculate the GIR. The year 2016 was selected based on the lowest recorded rainfall and the highest crop water requirements

across the three dominant soil types (Table 1). Irrigation efficiency of 71.25% was then used in Equation 2 ($2 \left(\frac{452.1}{71.25} \right) = 634.53$) to calculate GIR. The NIR and GIR for the production year 2016, which had the highest average, were 452.10 mm and 634.53 mm, respectively.

No adaptation scenario

No water-saving practices such as mulching are implemented, and only moderate weed management is used, allowing for some crop competition. Therefore, the irrigation schedule is not reproduced here.

Partial adaptation scenario

The partial adaptation scenario involves 20% deficit irrigation, moderate mulching, and weed management. As a result, the GIR of 634.5 mm is reduced to 507.2 mm over the growing season, with irrigation scheduled every 10 days at approximately 26 mm per event. Table 2 presents the simulation results for the partial adaptation scenario. A weighted average of the AquaCrop results was calculated based on the area covered by each soil type.

Table 2. Irrigation Schedule for the Partial Adoption Scenario

Soil type		Partial Adoption Scenario						
		2011	2012	2013	2016	2017	2018	Average
Eutric Plinthosols	Biomass (ton/ha)	17.24	17.45	17.71	17.68	18.17	18.18	17.74
	Yield (ton/ha)	8.37	8.48	8.62	8.61	8.82	8.84	8.62
	Irrigation (mm)	494.00	494.00	494.00	494.00	494.00	494.00	494.00
	WP_{ET} (kg/m ³)	1.26	1.34	1.27	1.22	1.26	1.26	1.27
Calcic Vertisols	Biomass (ton/ha)	17.26	17.45	17.71	17.83	18.20	18.18	17.77
	Yield (ton/ha)	8.38	8.48	8.61	8.70	8.84	8.84	8.64
	Irrigation (mm)	494.00	494.00	494.00	494.00	494.00	494.00	494.00
	WP_{ET} (kg/m ³)	1.24	1.32	1.24	1.20	1.24	1.24	1.25
Ferric Luvisols	Biomass (ton/ha)	16.99	17.45	17.41	16.90	17.89	17.90	17.42
	Yield (ton/ha)	8.22	8.48	8.48	8.14	8.64	8.69	8.44
	Irrigation (mm)	494.00	494.00	494.00	494.00	494.00	494.00	494.00
	WP_{ET} (kg/m ³)	1.27	1.35	1.28	1.21	1.27	1.27	1.28
Weighted Average	Biomass (ton/ha)	17.23	17.45	17.68	17.70	18.16	18.16	17.73
	Yield (ton/ha)	8.36	8.48	8.60	8.62	8.82	8.82	8.62
	Irrigation (mm)	494.00	494.00	494.00	494.00	494.00	494.00	494.00
	WP_{ET} (kg/m ³)	1.25	1.33	1.25	1.21	1.25	1.25	1.26

Source: Authors compilation

Full adaptation scenario

This scenario applied full mulching and intensive weed management. A 30% deficit irrigation strategy is used, reducing water availability to 444 mm compared with the full gross irrigation requirement of 634.5 mm, with irrigation targeted at critical growth stages. Table 3 presents the results for the full adaptation scenario.

Table 3. Irrigation Schedule for the Full Adoption Scenario

Soil type		Full Adoption Scenario						
		2011	2012	2013	2016	2017	2018	Average
Eutric Plinthosols	Biomass (ton/ha)	22.31	22.51	22.84	23.09	23.47	23.47	22.95
	Yield (ton/ha)	10.71	10.81	10.98	11.15	11.27	11.28	11.03
	Irrigation (mm)	444.00	444.00	444.00	444.00	444.00	444.00	444.00
	WP_{ET} (Kg/m ³)	1.64	1.74	1.65	1.59	1.64	1.64	1.65
Calcic Vertisols	Biomass (ton/ha)	22.31	22.51	22.84	23.25	23.46	23.47	22.97
	Yield (ton/ha)	10.71	10.81	10.98	11.23	11.27	11.28	11.05
	Irrigation (mm)	444.00	444.00	444.00	444.00	444.00	444.00	444.00
	WP_{ET} (Kg/m ³)	1.63	1.72	1.63	1.58	1.62	1.62	1.63
Ferric Luvisols	Biomass (ton/ha)	22.30	22.51	22.81	22.46	23.37	23.41	22.81
	Yield (ton/ha)	10.71	10.81	10.99	10.92	11.23	11.28	10.99
	Irrigation (mm)	444.00	444.00	444.00	444.00	444.00	444.00	444.00
	WP_{ET} (Kg/m ³)	1.65	1.75	1.66	1.61	1.65	1.65	1.66
Weighted Average	Biomass (ton/ha)	22.31	22.51	22.84	23.13	23.45	23.47	22.95
	Yield (ton/ha)	10.71	10.81	10.98	11.18	11.26	11.28	11.04
	Irrigation (mm)	444.00	444.00	444.00	444.00	444.00	444.00	444.00
	WP_{ET} (Kg/m ³)	1.63	1.73	1.64	1.59	1.63	1.63	1.64

Source: Authors compilation

Summary of AquaCrop Model Simulation Results

Table 4 presents the weighted-average results for the three adaptation scenarios, with yield changes expressed relative to the no-adaptation case. These percentage changes of the final column are used as exogenous shocks in the SAM through multiplier analysis.

Table 4. Summary of Weighted Average Metrics for Adoption Scenarios

		Representative Weighted Average Metrics for Adoption Scenarios in the Main Irrigation Zone				% Change in Yield Compared to No Adoption
		Biomass (ton/ha)	Yield (ton/ha)	Irrigation (mm)	WP_{ET} (Kg/m ³)	
Adoption scenario	No Adoption	17.82	8.66	627.00	1.21	Baseline (0%)
	Partial adoption	17.73	8.62	494.00	1.26	-0.49%
	Full Adoption	22.95	11.04	444.00	1.64	21.55%

Source: Authors compilation

Multiplier Analysis

Partial adaption

The partial adaptation scenario (20% deficit irrigation with moderate mulching and weed management) resulted in R7.95 million wheat output in the North West irrigation scheme. It generated R25.85 million in total labour remuneration in South Africa, including R1.37 million in the North West province and a gross operating surplus of R2.22 million (Table 5).

Household income in the North West province was estimated at R29.91 million. Institutional incomes reached R72.71 million, while households and value added generated R72.71 million and R50.36 million, respectively. These results align with Challinor et al. (2014), who found that climate variability without adaptation leads to yield losses in major crops.

Full Adaption

The full adaptation scenario (30% deficit irrigation with strategic water application, high mulching (75%), and intensive weed management) generated R40.25 million in wheat output in the North West province. It resulted in R113.67 million in total labour remuneration in South Africa, including R4.76 million in the North West and a gross operating surplus of R90.26 million (Table 5).

Household income in the North West province was estimated at R457.73 million. Institutional incomes were R452.37 million, while households and value added generated R452.37 million and R769.15 million, respectively. These findings align with those of Challinor et al. (2014), as indicated above.

Table 5. Summary of Key Socio- Economic Impacts

Variables	Adaptation to Climate Variability	
	Partial (-0.49%)	Full (21.55%)
Wheat in the Northwest	7.95	40.25
Total labour remuneration in SA	25.85	113.67
Northwest province generates labour return	1.37	4.76
Gross operating surplus SA	2.22	90.26
Household income for the Northwest	29.91	289.3
Institution income SA (enterprise + Household)	72.71	454.73
Household generating income SA	58.97	452.37
Value-added generating income SA (Labour + capital + land)	50.36	769.15

Source: Authors compilation

CONCLUSION

Adaptation to climate variability is shaped by psychological and contextual factors, where farmers are more likely to adopt strategies when they perceive high risk, have technical capacity, and receive institutional support. AquaCrop and partial-equilibrium results show limited yield changes under partial adaptation but significant increases under full adaptation, which also improve wheat output, labour remuneration, household income, and institutional incomes. These findings highlight that strong psychological and structural conditions enable full adaptation, delivering major productivity and economic benefits and supporting investment in climate resilience.

Understanding these behavioural and socioeconomic impacts is essential for improving water management policy and designing interventions that promote adaptive behaviour in agriculture. This may be achieved by incorporating psychological dimensions into environmental programmes, enabling more accurate predictions of responses to environmental changes, and supporting the scaling of targeted solutions in agricultural water management.

References

- Ajzen, I. 1991. The theory of planned behavior. *Organ Behav Hum Decis Process*. 50 (2): 179–211.
- Bahta, Y.T. 2013. Modelling the Lesotho Economy: A Social Accounting Matrix Approach. *Int J Food Agric Econ.*, 1:49-62.
- Bajwa, A., G.Mahajan and B.S. Chauhan. 2015. Nonconventional Weed Management Strategies for Modern Agriculture. *Weed Sci.* 63(723):747.
- Challinor, A., J. Watson, D. Lobell, S.M. Howden, D.R Smith and N. Chhetri. 2014. A meta-analysis of crop yield under climate change and adaptation. *Nat Clim Change*. 4: 287–291.
- Food and Agriculture Organisation (2023). Harmonized World Soil Database v2.0. Available from: <https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v20/en//>
- Hair, J.F., G.T.M.Hult, C.M. Ringle and M.Sarstedt. 2021. A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM). 3rd ed. Sage Publishing.
- Liao, Z., K. Zhang, J. Fan, Z. Li, F. Zhang, X. Wang, H.Wang, M. Cheng and Y. Zou. 2022. Ridge-furrow plastic mulching and dense planting with reduced nitrogen improve soil hydrothermal conditions, rainfed soybean yield, and economic return in a semi-humid, drought-prone region of China. *Soil Tillage Res.* 217: 105291.
- Mushtaq, S. and M.Moghaddasi. 2011. Evaluating the potentials of deficit irrigation as an adaptive response to climate change and environmental demand. *Environ Sci Policy*.14(8): 1139-1150.
- Raes, R., E. Fereres, M. García Vila, D.K. Curnel, S.K. Çelik, Y. Ucarf, M. Türk and J. Welle. 2023. Simulation of alfalfa yield with AquaCrop. *Agric Water Mana.* 284:108341.
- Robinson, S., A.Cattaneo and M.El-Said. 2000. Updating and estimating a social accounting matrix using cross entropy methods. *Econ Syst Res*.13(1): 47–64.
- Round, J. 1997. Social Accounting Matrices and SAM-based Multiplier Analysis. In: *The impact of economic policies on poverty and income distribution: Evaluation techniques and tools*. pp.261–276.
- Savva, A.P. and K. Frenken. 2002. Planning, Development Monitoring, and Evaluation of Irrigated Agriculture with Farmer Participation. *Irrigation Manual, Volume II, Module 7*. Food and Agriculture Organization of the United Nations (FAO) Sub-Regional Office for East and Southern Africa (SAFR), SAFR/AGLW/DOC/007.
- Shah, W.U.H., G.Hao, R.Yasmeen, H. Yan and Y. Qi. 2024. Impact of agricultural technological innovation on total-factor agricultural water usage efficiency: Evidence from 31 Chinese Provinces. *Agric Water Manag.* 299:108905.
- Zhang, C.Y. and T.Oki. 2023. Water pricing reform for sustainable water resources management in China's agricultural sector. *Agric Water Manag.* 275:108045.