



**Essays on Water Resources Management in the Agricultural Sector of South Africa:
The Role of Technology, Policy and Institutions in Mitigating Farm Level Water
Scarcity**

Alfred Tunyire Apio

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Supervisors:

Associate Professor Djiby Racine Thiam (University of Cape Town)

Distinguished Professor (Emeritus) Ariel Dinar (University of California, Riverside)

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Abstract

South Africa is a water-stressed country prone to multi-year droughts and water shortages, with varying impacts on several sectors, including agriculture. Agriculture, as the largest user of the country's freshwater resources, is the most sensitive sector to water scarcity and would be the hardest hit by intensifying climate change, droughts, and water shortages. Yet the agricultural sector has the largest potential to make adjustments and take actions to promote resilience to water scarcity by implementing water conservation, water quality regulation, legitimate allocation, and an appropriate management response in the face of growing water scarcity. This thesis, therefore, provides an understanding of how the agricultural sector of South Africa is responding to the water scarcity problem. Its general objective is to further the stock of knowledge in natural resources management, with special emphasis on water resources management in the agricultural sector. It consists of three core chapters (chapters 2, 3, and 4), alongside the introduction (chapter 1) and conclusion (chapter 5).

The first core chapter (Chapter 2) examines the factors that drive farmers' multiple adoption of six water conservation practices (WCPs) and the intensity of their adoption. Using survey data from 555 farmers in the Limpopo River Basin (LRB) of South Africa, a multivariate probit model is estimated to determine these factors, and for the intensity of their adoption, an ordered probit model is estimated. The results show that gender, age, education, and farm size, among other factors, influence the probability and extent of adoption of WCPs. Furthermore, combinations like drip and/or sprinkler irrigations and cover cropping, drip and/or sprinkler irrigations, and intercropping, among other practices, are complements, suggesting the bundling of these WCPs. This chapter provides a clear framework in agriculture not only to prepare farmers to be resilient in the midst of intensifying climate change, droughts, and water shortages but also to enhance their water conservation efforts. This would help farmers become better acclimatized to the growing realities of water scarcity and enhance the sustainability of the resource, enabling them to continue to make meaningful contributions to economic growth.

The second core chapter (Chapter 3) employs a discrete choice methodology to investigate farmers' willingness to accept compensation to control agricultural nonpoint source (agNPS) pollution in the LRB. The LRB is highly polluted, yet it is important for agriculture, mining, and industry, which contribute to employment, income, and poverty alleviation. Reducing this pollution is part of the restoration and protection plan for the basin. However, because agNPS pollution does not easily lend itself to traditional forms of regulation, monetary incentives that

induce farmers to adjust their farming practices to reduce agriculture's impact on water quality are seen as an effective means of controlling it, hence this chapter. Conditional logit and restricted latent class models are used to estimate the survey data of 552 farmers. This chapter identified one random choice class and three preference classes of farmers (low, moderate, and high resistance) with dissimilar compensation requirements to improve water quality. The chapter offers new insights to enrich the efficient design of tailored water quality improvement-related agri-environmental schemes for more persistent environmental benefits that would ultimately result in positive externalities beyond benefits to farmers and the environment.

The third core chapter (Chapter 4) presents a meta-analysis of the empirical literature that investigates the performance of water institutions. This chapter synthesized and quantified the overall water institution-performance effect using data extracted from 23 original studies that reported the effect of water institutions on the performance of the water sector in various regions of the world. The results from the bivariate and multivariate meta-regressions suggest the presence of a publication selection bias that favours a positive impact of water institutions on performance. Also, a genuine positive empirical effect of water institutions on the performance of the water sector is found. In addition, the variations in the primary studies are attributable to differences in the way the primary studies capture water institutions, the dependent variables used to capture performance, and the estimation strategy/methodology, among others. The main novelty of this chapter is its use of meta-analysis to increase the statistical power of this set of literature, which covers different methodologies, geographic and environmental conditions under which water institutions performed compared to single studies.

This thesis concludes by underscoring forcefully that farmers need sustainable supplies of water but must also manage the impact of agriculture on water resources to ensure sufficient quantity and quality of water for production, but robust water management institutions are key. In terms of policy recommendations, this thesis offers several of them, including but not limited to the fact that WCPs are interdependent, and therefore, the design of any effective strategy(ies) aimed at increasing their uptake rate must take this interdependence into consideration. It also advocates the promotion and use of monetary incentives to induce farmers to lessen agriculture's impact on water quality. Finally, it recommends that to engender water sector reforms and/or for the further development, facilitation, and strengthening of water institutions, there is the need to incorporate and strengthen the water law and/or the water policy in policy formulation and reforms for successful water resource management and governance.

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Dedication

To the loving memory of my dear parents Mr. Apio Tunyire and Mrs. Albertina Apio

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List of Acronyms

AESs:	Agri-Environmental Schemes
agNPS:	Agricultural Nonpoint Source
AIC:	Akaike Information Criterion
ASCsq:	Alternative-Specific Constant
AWD:	Alternate Wetting and Drying
BFAP:	Bureau for Food and Agricultural Policy
BIC:	Bayesian Information Criterion
C:	Continuous Variables
Ca:	Categorical Variables
CA:	Conservation Agriculture
CAIC:	Consistent Akaike Information Criterion
CE:	Choice experiment
CLM:	Conditional Logit Model
CNY:	Chinese Yuan
CP:	Compensation payment
CPRs:	Common Pool Resources
CS:	Compensating Surplus
CSA:	Climate-Smart Agriculture
D:	Dummy Variables
DAFF:	Department of Agriculture, Forestry, and Fisheries
DBDC:	Double-Bounded Dichotomous Choice
DCEs:	Discrete Choice Experiments
DOI:	Diffusion of Innovation Theory
DPSIR:	Driver-Pressure-State-Impact-Response Framework
DV:	Dependent Variable
DWSs:	Droughts, and Water Shortages
EFA:	Ecological Focus Area
FAO:	Food and Agriculture Organization of the United Nations
FAT:	Funnel Asymmetry Test
FCLM:	Four-Class Latent Model
FE:	Fixed-Effects Model
FGDs:	Focus Group Discussions

G-to-S:	General-To-Specific
IDA:	Institutional Decomposition and Analysis
IIA:	Independence of Irrelevant Alternatives
IID:	Independent and Identically Distributed
IV:	Independent Variables
KSOM:	Kohonen Self-Organizing Maps
LBPTC:	Limpopo Basin Permanent Technical Committee
LCM:	Latent Class Logit Model
LRB:	Limpopo River Basin
MAER-Net:	Meta-Analysis of Economics Research-Network
MBDC:	Multiple-Bounded Discrete Choice
MEPIDs:	More Efficient Performing Irrigation Methods
MNL:	Multinomial Logit Model
MRA:	Multivariate Meta-Regression
MVN:	Multivariate Normal
MVP:	Multivariate Probit Model
mWTA:	Marginal Willingness to Accept
MXL:	Mixed Logit Model
N:	Nitrogen
NDP:	National Development Plan
NWRS 2:	National Water Resource Strategy 2
OECD:	Organization for Economic Co-operation and Development
OHCHR:	United Nations High Commissioner for Human Rights
OPM:	Ordered Probit Model
P:	Phosphorus
PCC:	Partial Correlation Coefficient
PES:	Payment for Ecosystem Service
PET:	Precision Effect Test
PPP:	Polluter Pays Principle
RE:	Random-Effects Model
REML:	Restricted Maximum Likelihood
RUT:	Random Utility Theory
RWHT:	Rainwater Harvesting Technology
SAPs:	Sustainable Agricultural Practices

SCT:	Social Cognitive Theory
SDGs:	Sustainable Development Goals
SSSA:	Soil Science Society of America
SWAT:	Soil and Water Assessment Tool
SWC:	Soil and Water Conservation
TAM:	Technology Acceptance Model
TN:	Total Nitrogen
TP:	Total Phosphorus
TPB:	Theory of Planned Behaviour
TRA:	Theory of Reasoned Action
UN-Water:	United Nations Water
UNEP:	United Nations Environment Programme
UNESCWA:	United Nations Economic and Social Commission for Western Asia
UNFCCC:	United Nations Framework Convention on Climate Change
USAID:	United States Agency for International Development
USD:	United States Dollar
USEPA:	United States Environmental Protection Agency
WASH:	Water Sanitation and Hygiene
WCPs:	Water Conservation Practices
WCTs:	Water Conservation Techniques
WEF:	World Economic Forum
WFD:	Water Framework Directive.
WGIs:	Weighted Water Governance Indices
WLS:	Weighted Least Squares
WMA:	Water Management Area
WRM:	Water Resources Management
WRM:	Water Resources Management
WSIT:	Water-Saving Irrigation Technology
WTA:	Willingness to Accept
WUE:	Water-Use Efficiency
WWAP:	World Water Assessment Programme
WWC:	World Water Council
ZAR:	South African Rand

Chapter 1: Introduction

Water is a critical resource in all human endeavors and plays vital roles in all sectors of the economy. It is important for ecosystems, production, and economic growth. However, the growing challenges of the effects of intensified climate change on water resources, the issues of reliable access, security of supply, efficiency of use, deteriorating quality, and poor management threaten the sustainability of this all-important resource. These challenges, termed the water problem, is the gravest risk confronting the world today (United Nations Water [UN-Water], 2009; World Economic Forum [WEF], 2020). This problem would continue to exacerbate not just because of intensified climate change alone but also because of other factors such as population growth, increased water demand for agricultural production, urbanization, and industries. These emerging trends would continue to put further pressure on water resources around the world, increasing the severity of water scarcity¹ in many countries. This would pose serious threats to water security goals, agricultural production, vulnerable populations, and environmental sustainability. In addition, the water problem does not only undermine economic growth and resilience, sustainable access to water, sanitation and hygiene (WASH) services, food security and nutrition, and inclusive development, but it is also expected to result in substantial employment cuts across the global economy, impacting particularly heavily on water-dependent jobs, the majority of which are in the agricultural sector (World Water Assessment Programme [WWAP], 2016).

Furthermore, the water problem is seen as a national security threat because, as shortages in river basins become more acute, more social and political tensions are envisaged². Such tensions would cause major threats to peace, human security, and wellbeing at the local, national, and international levels (United Nations High Commissioner for Human Rights

¹ Water scarcity is defined as the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements (including both resource ‘pricing’ and retail charging arrangements and infrastructural conditions) to the extent that the demand by all sectors, including the environment, cannot be fully satisfied. A relative concept that can occur at any level of supply or demand. Further, Seckler et al. (1998), cited in FAO (2012), distinguish two main types of water scarcity: physical scarcity and economic scarcity. Physical scarcity occurs when there is not enough water to meet all demands, including environmental flows. Symptoms of this water scarcity are severe environmental degradation, declining groundwater, and water allocations that favour some groups over others. On the other hand, economic water scarcity is a situation caused by a lack of investment in water or a lack of human capacity to satisfy the demand for water. Symptoms of this water scarcity include scant infrastructure development, either small or large-scale, so that people have trouble getting enough water for agriculture or drinking.

² The 2007 clash between 30,000 farmers and the police in the state of Orissa in India occurred because the government had allowed many industries to draw water from the Hirakud dam, depriving the farmers of their source of irrigation. Also, the confrontations that erupted in 2000 in Cochabamba, Bolivia, which culminated in months of civil unrest, injuries, deaths, and the declaration of a state of emergency throughout the country (OHCHR, 2016), are examples.

[OHCHR], 2016; United States Agency for International Development [USAID], 2021; WWAP, 2016). Further, given the nexus amongst water scarcity, food insecurity, social instability, and social unrest, which in turn can trigger and intensify migration throughout the world, it has been projected that about 200 million people will be forcibly displaced by 2050 due to threats caused by increased water scarcity, extreme weather events, and other phenomena such as desertification and rising sea levels (Stern, 2007; WWAP, 2016). This means by 2050, one in every forty-five people in the world would have been displaced because of water scarcity (Brown, 2008). In addition, it is envisaged that by 2025, 1.8 billion people will be living in countries or regions that experience absolute water scarcity³, and two-thirds of the world's population could be living under severe water-stressed conditions (Hatfield, 2011; Mekonnen and Hoekstra, 2016). Around the same period, water withdrawals have been predicted to increase by 50% in developing countries and by about 18% in developed countries (United Nations Environment Programme [UNEP], 2007).

However, these predictable challenges or potential crises can be largely averted or mitigated by adjusting the way in which water is managed and governed (Moriarty, Butterworth, and Batchelor, 2004). In effect, it is essential for all water users to become more aware of the growing reality of water scarcity and adjust their behaviour accordingly. In view of this, given the increasing demands for water and its continuous declining availability, it is imperative for efforts and awareness in all sectors, especially in the agricultural sector, which is the largest water user worldwide, accounting for 70% of total global freshwater withdrawals (Food and Agriculture Organization of the United Nations [FAO], 2011; 2017b), to formulate measures and strategies to improve the management of water resources. The sector requires the adoption of modern best agricultural water management practices, strategies, and technologies that save, conserve, improve water use efficiency, and lessen or eliminate agriculture's impact on water quality. These critically align with the objectives for water resources management (WRM)⁴, which include but are not limited to achieving more equitable and economically optimized water allocation within basins, improving water quality, managing water quantity, and reducing vulnerability to flooding, drought, and chronic water scarcity (USAID, 2021). Such actions in

³ Water scarcity is absolute when there is an insufficiency of supply to satisfy total demand after all feasible options to enhance supply and manage demand have been implemented. This situation leads to widespread restrictions on water use (FAO, 2012).

⁴ WRM is the process of planning, developing, and managing water resources in terms of quantity and quality within and across water uses for the benefit of humans and ecosystems. It includes the institutions, infrastructure, incentives, and information systems that support and guide water management and use (USAID, 2021).

the agricultural sector would positively contribute to, and ensure that water is sufficiently available, used more efficiently, improve its quality, enhance production, and protect critical ecosystems for the benefit of both humans and the natural environment.

Agriculture will continue to be the most important user of water in many countries (FAO, 2012). This sector, through its links to food production, nutrition and health, income and employment, poverty reduction, rural development, and economic growth, among others, will continue to be a key driver of sustainable and inclusive economic growth (FAO, 2017b). It will also be the sector where a substantial share of the global population will continue to earn their living, especially in developing countries. Thus, it is only when we act to improve water use efficiency in agriculture that we will meet the acute freshwater challenges facing humankind over the coming 50 years (UN-Water, 2009; 2012). Accordingly, no one interested in managing the risks associated with the water problem can afford to ignore the role of WRM in agriculture. It is against this background that this thesis investigates three (3) important strands of WRM that mitigate farm-level water scarcity. That is, the adoption of innovative farm management practices that enhance conservation and quality improvements of water resources, and the effective performance of water management institutions. This thesis, thus, focuses on the role of technology, policy, and institutions in mitigating farm-level water scarcity in South Africa.

South Africa is a water-stressed country prone to prolonged droughts and water shortages, with varying impacts on agriculture. The sector, as the largest user of the country's freshwater resources—accounting for about 60 percent of all freshwater withdrawals (NWRS 2, 2013)—is the most sensitive sector to water scarcity and usually the hardest hit by intensifying climate change, droughts, and water shortages (DWSs). For instance, the recent droughts of 2015 through 2018 in several parts of the country resulted in the loss of large tracts of farmlands and livestock, increased prices of staple food items such as maize, the imposition of harsh water restrictions, and the displacement of over a million smallholder farmers, among others (Bureau for Food and Agricultural Policy [BFAP], 2016; Department of Agriculture, Forestry, and Fisheries [DAFF], 2016). Given these effects, among others, the agricultural sector of South Africa urgently requires a clear framework for actions to promote preparedness and resilience to climate change and water scarcity. This framework would not only enable water conservation, water quality improvements, and/or an appropriate management response in the face of growing water scarcity but would also enable farmers to maintain their production cycles throughout the year, which in turn would guarantee the stability of their income flows

and contribute to reducing poverty and inequality within the farming community (Abdulai and Huffman, 2014; FAO, 2017b).

From the foregoing, this thesis provides an understanding of how the agricultural sector of South Africa is responding to the water scarcity problem in particular and WRM in general. This thesis underscores that farmers need sustainable supplies of water and must also manage the impact of agriculture on water resources to ensure adequate quantity and quality of water, but robust water management institutions are key to achieving these objectives. Thus, the general objective of this thesis is to further the stock of knowledge in natural resources management, with special emphasis on water resources management in the agricultural sector.

To achieve these objectives, this thesis leverages economic and environmental modelling approaches to gain insights or evidence on how South African farmers are adopting multiple water conservation practices (WCPs) to adapt to intensifying climate change, DWSs; their willingness to adopt more sustainable farming practices that might contribute to reducing agriculture's impact on water quality; and finally, a synthesis and quantification of the literature on the effective performance of water management institutions for further development, facilitation, and strengthening of water management institutions. Therefore, this thesis consists of three core chapters (Chapters 2, 3, and 4) on water resources management. Specifically, it provides an analysis of the factors influencing farmers' multiple adoptions of WCPs, their willingness to accept compensation to control agricultural nonpoint source (agNPS) pollution, and a meta-analysis of the performance of water institutions and their implications for water resource management.

1.1 Objectives of this Research

Given that this thesis comprises three core chapters, the three major objectives that guide it are specified as follows:

1. To identify and analyze the factors that motivate farmers' multiple (bundling)⁵ adoption of WCPs, the intensity of their adoption, and their interrelatedness.

⁵ Bundling of agricultural technologies takes place when farmers use two or several technologies and management practices that complement each other instead of adopting one technology or management practice independently (Reints, Dinar, and Crowley, 2020).

2. To determine the appropriate compensation that farmers are willing to accept as being sufficient to engender greater participation in an agNPS pollution control programme to mitigate agricultural water quality deterioration in the LRB.
3. To synthesize, estimate, and determine publication selection bias and the overall empirical effect of water institutions on the performance of the water sector in the water institution-performance literature.

1.2 Justification of this Thesis

South Africa's National Development Plan (NDP) 2030 identifies water as a strategic resource that is critical for the social and economic development of the country (The National Development Plan 2030, 2012). However, being the world's 30th driest country with an annual average rainfall of less than 500 mm, while that of the world is about 850 mm, puts the country's water resources in an endangered position. In addition, the country is not endowed with mighty rivers like other countries. Furthermore, severe or extreme temperatures in some parts of the country cause high evaporation rates that tend to accelerate water losses, so that much of the water that is received as rain soon returns to the atmosphere. This causes high surface water scarcity and diminishes groundwater levels. Also, almost every province in the country since 2013 has suffered some form of DWSs and some form of water restrictions in some urban areas as well as in the agriculture sector. The devastating drought incidents of 2017 that affected the Eastern Cape, Northern Cape, and Western Cape buffeted the City of Cape Town so severely that it was projected to run out of water by June of 2018—an event that was dubbed 'Day Zero'. Day Zero was so eminent that the first ever Water Police in the world, was instituted in the City of Cape Town to police water resources. This makes the South African water scarcity problem a unique one that calls for all hands-on deck to save and conserve water at the provincial and national levels.

Another critical issue that threatens South Africa's long-term water sufficiency and security requirements is the growing water demand from all sectors. This demand is being driven by population growth and improved livelihoods, industrial and agricultural developments, aging infrastructure, limited investment in water infrastructure and projects, mismanagement, weakened social and institutional capacity that threaten effective water resource management and governance, and continuous deterioration of water quality (surface and sub-surface sources) due to anthropogenic-related pollution (Matumba, 2019; Winter, 2018).

All these makes the country more susceptible and vulnerable to the ravaging effects of intensified climate change and long-term DWSs.

From the foregoing, it is obvious that South Africa's water resources are under considerable stress, yet the country cannot change the current climate change emergency, nor can she influence the weather variability and conditions she faces. However, she can do a lot to adapt to the changing realities of climate change, DWSs, increasing water demand, and poor water quality. She must take deliberate and essential steps to manage her limited water resources prudently to ensure sustainability to meet present and future strategic needs. Agriculture, as the most water-intensive industry and one of the biggest polluters of water resources, must be the focal point for such critical efforts to manage this important resource in the country. Water resources management, just like the management of any other natural resource, has to do with managing it in a way that ensures optimum, long-term, environmental sustainability, social and economic benefits for society, from its use now and in the future (National Water Resource Strategy [NWRS], 2004).

Accordingly, the justification of this thesis to investigate how water resources are being managed in the agricultural sector of South Africa, with specific emphasis on the role of technology, policy, and institutions in mitigating farm-level water scarcity, lies in the following reasons: First, is the quest to understand how South African farmers are responding to the water scarcity problem exacerbated by intensified climate change and increased water demand from other sectors of the economy (domestic, industry, mining, transport, energy, and health). Given that South Africa is a water-stressed country prone to multi-year DWSs, this quest is important (i) to understanding the water sustainability behaviour/efforts of farmers to engender water use efficiency and climate change resilience, (ii) to ascertain the WCPs that farmers most often adopt to adapt to climate change and DWSs, (iii) to establish whether South African farmers water conservation efforts support the assertion that farmers who are water conservation conscious generally adopt several practices to adapt to climate change and DWSs instead of just a practice, (iv) to support the crafting of cost-effective and proactive policies in agriculture to incorporate climate change principles in both the planning and management of water resources, and (v) to promote and enhance the adoption and uptake of sustainable farming practices that improve crop yield, water quality, conservation, and sustainable management.

The second rationale for this thesis is its quest to educate, sensitize, and create awareness among farmers and stakeholders of the dangers of agNPS pollution on the operations of farmers, and to demonstrate how financial incentives can be used to motivate farmers to adopt sustainable farming practices that lessen agriculture's impact on water quality. These practices include, but are not limited to, reduced use of fertilizers and pesticides, the construction of ecological ditches, and waste recovery initiatives that contribute to reducing releases of harmful pollutants into surface and groundwater sources. This enquiry would deepen the knowledge of farmers, policymakers, and stakeholders and offer a comprehensive testament with new insights to guide policies and to enrich the efficient design of tailored water quality improvement-related AESs for maximum participation. Such policies will stop the wanton deterioration of water quality and the environmental damages caused by undesirable agricultural farming practices. This is important as it offers a testament that is critical not only for improving water quality at the farm level but for the management of water quality and the preservation of the health of several endangered river systems in the country and beyond.

Finally, recent issues of access, security of supply, allocation challenges, mismanagement, as well as quality deterioration and sustainability of water and water resources in the agricultural sector, bring to the fore the role of the institutions that manage water in the sector space. Thus, an additional justification for this thesis, is its quest to show how important effective performing water management institutions and their institutional aspects are, in lowering the transaction costs that are associated with the development, allocation, and management of water resources in the water space. This is important to contribute to the further development, facilitation, and strengthening of water policies in the water space, and also to provide an appropriate response and adequate arrangements to steer individual and group behaviour toward lowering the high transaction costs in the water sector.

This thesis is crucial and provides useful insights on how to (i) improve water resources management, (ii) engender farmers' resilience to water scarcity to consolidate and enhance the gains from agriculture threatened by intensified climate change, DWSs, and deteriorating water quality, (iii) sensitize and help farmers to lessen agriculture's impact on water quality, and (iv) help guide interventions and policy towards the better design and development of water institutions to improve water resources management in the water sector. This thesis would not only provide insights that promote the effective management of the country's water resources but would also provide insights that guarantee their sustainability to ensure that adequate water

of the right quantity and quality is available for health, livelihoods, ecosystems, production, and equitable economic growth and development as required by the National Development Plan [NDP] 2030 (2012).

1.3 Theoretical and/or Conceptual Framework of this Thesis

The theoretical basis/approaches in the three core chapters of this thesis are built on different theoretical/conceptual frameworks. For instance, core chapters 2 and 3 are built on random utility formulations—expected utility, utility maximization, and random utility theories. However, Chapter 4 draws on the Institutional Decomposition and Analysis (IDA) framework of Saleth and Dinar (1999b; 2004). For the IDA framework, see Chapter 4 of this thesis. However, regarding the random utility formulations, also known as the decision-making theories, which are used to address a range of factors underlying farmer adoption behaviours (Karbo et al., 2024), assume that perceptions of (economic) risks, uncertainties, and profitability associated with a technology are associated with the adoption decision (Karbo et al., 2024). These theories have been applied to explain farmers' decisions to adopt new technology (Dadzie et al., 2022; Danso-Abbeam, Dagunga, and Ehiakpor, 2019; Meda et al., 2018). For instance, in the expected utility theory (EUT), an adoption behaviour is associated with (perceived) risk and uncertainty associated with the adoption decision, such that an individual is likely to adopt a technology if the expected utility from the new technology surpasses the old or existing technology (Mongin, 1998). Similarly, in the utility maximization theory (UMT), it is assumed that adoption behaviours are performed to gain the highest level of satisfaction (i.e., fulfillment) from the technology being adopted (Curwen, 1976). Danso-Abbeam, Dagunga, and Ehiakpor (2019) used the UMT to assess farmers' decisions to adopt Zai soil fertility technology in the Upper East Region of Ghana. The strength of these theoretical approaches is their capacity to capture the potential rating of an individual's expected utility according to the expected benefit to be obtained following the adoption decision.

The Random Utility Theory (RUT), however, assumes that an individual may consecutively adopt a particular technology, and where a different technology is chosen, it may be attributed to unspecified factors (random factors) (Cascetta and Cascetta, 2001). The strength of this theory is its potential to increase the accuracy of predictions in the context of the rationality of choice (Hess, Daly, and Batley, 2018). For further details on the specifications and assumptions

of the RUT beyond those stated in chapters 2 and 3, see Cascetta and Cascetta (2001; 2009) and Luce (1959).

But, according to Karbo et al. (2024), integrating theoretical approaches is essential to capturing the broad range of factors that potentially influence technology adoption. Combining theories from different perspectives or disciplines can potentially help explain farmers' adoption behaviour while avoiding explanatory gaps (Borges, Foletto, and Xavier, 2015; Uaiene, Arndt, and Masters, 2009). Studies such as Dadzie et al. (2022); Momvandi et al. (2018); Musungwini, Van Zyl, and Kroeze (2022) combined theoretical approaches to explain adoption behaviours. Accordingly, apart from the random utility formulations, there are several behavioural theories, like the Diffusion of Innovation Theory (DOI), Social Cognitive Theory (SCT), Theory of Reasoned Action (TRA), Theory of Planned Behaviour (TPB), and Technology Acceptance Model (TAM), among others, that can help to explain the intentions of individuals and their adoption behaviour. In this regard, the theoretical basis of the first two core chapters of this thesis is augmented with the DOI by Rogers (1962).

The DOI is used to show how an innovation diffuses through a social system. It is especially used to explain the transfer and adoption of agricultural technologies among farmers. Given that decisions are not authoritative or collective, each farmer of the social system faces his or her own innovation decision that follows a 5-step process—(i) knowledge about the innovation (person becomes aware of an innovation and has some idea of how it functions), (ii) persuasion (person forms a favourable or unfavourable attitude toward the innovation), (iii) decision (person engages in activities that lead to a choice to adopt or reject the innovation), (iv) implementation of the innovation (person puts an innovation into use), and (v) confirmation of adoption (person evaluates the results of an innovation-decision already made) (Rogers, 1995; 2003). In addition, the theory divides individuals, or adopters into five adoption groups: (i) innovators, (ii) early adopters, (iii) early majority, (iv) late majority, and (v) laggards (Rogers, 1962). Furthermore, adoption practices are evaluated against five criteria, including (i) perceived relative advantage (compared to those offered by existing technologies), (ii) compatibility (the extent to which new technology fits with existing cultural norms, attitudes, and beliefs), (iii) complexity (the extent to which the technology under consideration is easy to understand and use by the potential end-users), (iv) trialability (the extent to which technology can be accessed and 'tried out' by potential end-users), and (v) observability (the extent to which a potential end-user has the opportunity to observe the successful application

of the technology by others) (Rogers, 2003). Studies such as Kamwamba-Mtethiwa et al. (2021) and Kondo et al. (2020) applied the DOI to explain the diffusion of small-scale irrigation pumps among farmers in Malawi and the various dissemination strategies and factors determining farmers' adoption of improved cassava varieties in Ghana, respectively.

This framework, thus, provides a basis for analyzing the factors driving the adoption of sustainable agricultural practices (SAPs), like the adoption WCPs. The adoption of SAPs is borne out of the desire to transition from conventional agricultural practices that often lead to inefficient water use, soil erosion, water pollution, and loss of biodiversity (Durán Gabela et al., 2022; Laurett et al., 2021; Šūmane et al., 2016; Zecca and Rastorgueva, 2017) to SAPs. Accordingly, from the underpinnings of the DOI, farmers are expected to behave right and be more willing to take actions that lead to the adoption of SAPs that include the adoption of WCPs and those practices that reduce agNPS pollution, among others.

1.4 Contribution of this Thesis

This thesis adds to the literature on WRM in the agricultural sector in general. Specifically, however, its contributions are particularly to the literature on (i) the adoption of WCPs and climate change resilience, (ii) agNPS pollution control, and (iii) the performance of water management institutions. It does this, first, by providing evidence and an enhanced understanding of how the agricultural sector of South Africa is responding to the water scarcity problem through the adoption of multiple WCPs to counter the effects of climate change, enhance water use efficiency, and enable farmers to build climate change resilience. Second, it provides further insights on lessening agriculture's negative impact on water quality through the use of monetary incentives that induce farmers to alter their undesirable farming practices, and finally, it shows how effective water management institutions are in ensuring effective water management that promotes sufficient and lower transaction costs in the water space.

The innovativeness of this thesis lies in how it leverages insights from current economic and environmental modelling methods to provide a baseline testament (i) for incorporating the bundling or the multiple adoption of WCPs in agriculture to promote water conservation efforts, efficiency of use and climate change resilience, (ii) for the inclusion of monetary incentives in decision-making in South Africa and beyond to promote the control of agNPS pollution, and (iii) for improvements in the performance of water institutions and the research

cycle in respect of the water institution-performance relationship to improve the quality of research, reporting, review and publication in the water space. This thesis would help farmers build resilience to water scarcity, improve water quality and consolidate and enhance the gains from agriculture threatened by intensified climate change, droughts, and deteriorating water quality in the country.

1.5 The Conceptual Framework that Links the Core Chapters

1.5.1 Driver-Pressure-State-Impact-Response Framework (DPSIR)

The DPSIR framework developed by the Organization for Economic Co-operation and Development [OECD] (1993), is used to provide a flexible structure within which environmental problems or issues are assessed and feedback offered to policymakers on these issues, and the resulting impact of the political choices made or to be made in the future (Alexakis, 2021; Kristensen, 2004). The DPSIR has been widely used in many applications, including the management of water resources, river basin management, marine systems, agro-environments, sustainable development, air pollution, and climate change, among others (Alexakis, 2021; Alexakis et al., 2021; Bagordo et al., 2016; Kagalou et al., 2012).

The DPSIR framework assumes a chain of causal links starting with ‘driving forces’ (the socio-economic and socio-cultural forces driving human activities, which increase or mitigate pressures on the environment) through ‘pressures’ (the stresses that human activities place on the environment, like emissions, waste, etc.) to ‘states’ (the state of the environment—physical, chemical, and biological, etc.) and ‘impacts’ (on ecosystems, water bodies, human health, and functions, etc.), as well as political ‘responses’ (the responses by society or institutions to the environmental situation through prioritization, target setting, and indicators, etc.) (Alexakis, 2021; Kristensen, 2004).

The DPSIR framework in Figure 1.1 is used to show the interrelationships among the three core chapters of this thesis. In addition, it shows the actions taken by water institutions and farmers in South Africa to address, manage, and/or resolve the water scarcity problem.

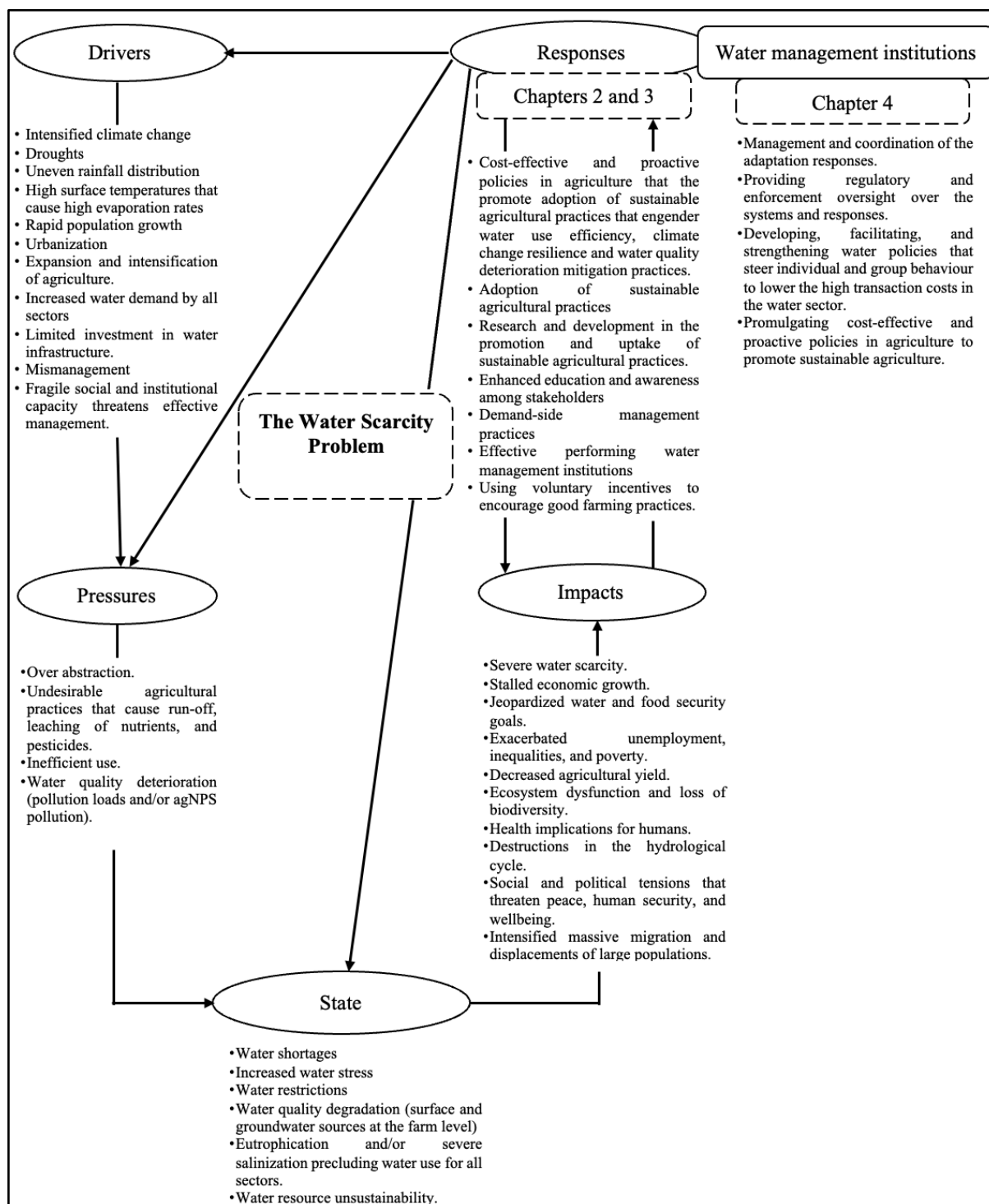


Figure 1. 1: The DPSIR Conceptual Framework

(Adapted and modified from FAO, 2017a; Buaban et al., 2021; Liu, 2018).

The framework shows that South Africa’s water scarcity problem is driven by a number of factors, including but not limited to (i) intensified climate change and droughts, (ii) uneven rainfall distribution, (iii) high surface temperatures that cause high evaporation rates, (iv) rapid population growth, (v) urbanization, (vi) increasing water demand by all sectors, (vii)

expansion and intensification of agriculture, (viii) limited investment in water infrastructure, (ix) mismanagement, and (x) fragile social and institutional capacity, which threaten effective water management, among others.

These drivers then lead to pressures that include (i) over abstraction in agriculture, (ii) inefficient use, (iii) undesirable agricultural practices that cause run-off, leaching of nutrients and pesticides, and (iv) water quality deterioration (pollution loads or agNPS pollution), among others.

These pressures also then create a state that is characterized by (i) water shortages, (ii) increased water stress, (iii) the imposition of water restrictions, (iv) water quality degradation (surface and groundwater sources at the farm level), (v) eutrophication and/or salinization that precludes water use for all sectors, and (vi) water resource unsustainability.

Consequently, the drivers, pressures, and state cause impacts that include (i) stalled economic growth, (ii) exacerbated water scarcity, (iii) jeopardized water and food security goals, (iv) exacerbated unemployment, inequalities, and poverty, (v) decreased agricultural production, (vi) increased prices of staple food items, (vii) ecosystem dysfunction and loss of biodiversity, (viii) health implications for citizens, (ix) destructions of the hydrological cycle, (x) loss of farmlands and livestock, (xi) social and political tensions that threaten peace, human security, and wellbeing, and (xii) intensified massive migration and displacements of large populations.

The impacts then lead to responses by policymakers, stakeholders, and farmers who take actions or actions that are to be taken or implemented at both the provincial and national levels to remedy the water scarcity problem. The responses therefore, include (i) the adoption of sustainable agricultural practices (SAPs) (water conservation, climate smart agricultural and water quality deterioration mitigation practices), (ii) institution of cost-effective and proactive policies in agriculture that promote the adoption of SAPs that engender water use efficiency, climate change resilience and water quality improvement practices, (iii) use of voluntary incentives to encourage good farming practices, (iv) research and development in the promotion and uptake of SAPs, (v) enhanced education, sensitization and awareness among stakeholders and farmers, (vi) demand-side management practices, and (vii) effective performing water management institutions, among others.

The responses, accordingly, link the three core chapters of this thesis—farmers and water institutions providing solutions or attempting to solve different aspects of the same problem—the water scarcity problem. It is these different aspects of the same problem that the three core chapters depict. For instance, first, core chapters 2 and 3 are linked by the fact that both chapters seek solutions to water sustainability, or at best, both are solving the water scarcity problem in agriculture through the efforts of farmers from two different perspectives. Chapter 2 seeks to solve this problem by advocating the promotion and uptake of multiple adoption of WCPs that enhance water use efficiency and climate change resilience. These practices not only ensure that more crops are produced per drop of water (efficient use), but they also ensure the sustainability of the country's water resources in the face of intensified climate change and DWSs. Chapter 3 equally seeks to solve this problem through the promotion, and adoption of more sustainable farming practices that contribute to reducing agNPS pollution. This pollution degrades water quality and causes serious eutrophication in water bodies, precluding water use in all sectors. This pollution decreases the availability of surface and groundwater sources, thus exacerbating the water scarcity problem (Halliday et al., 2014; NWRS 2, 2013). Therefore, the adoption of practices that reduce agNPS pollution will contribute to alleviating the water scarcity problem and improve water resource sustainability, just like in Chapter 2.

Secondly, to successfully accomplish the objectives of chapters 2 and 3, chapter 4, the effective performance of water institutions is important. The chapter highlights the important need for the effective performance of water management institutions to (i) contribute to the further development, facilitation and strengthening of water policies in the water space; (ii) provide adequate response and arrangements to steer individual and group behaviour in lowering the high transaction costs in the water sector; (iii) institute cost-effective and proactive policies in agriculture to promote the adoption of SAPs that engender water use efficiency, climate change resilience and water quality deterioration mitigation practices, and (iv) manage, coordinate, and offer regulatory and enforcement oversights to the adaptation and adoption responses.

It is a known fact that the ability to improve water management in agriculture is typically constrained by inadequate policies, major institutional underperformance, and financing limitations (World Bank, 2012). Critical public and private institutions (encompassing agricultural and water ministries, basin authorities, irrigation agencies, water users', and farmer organizations) generally lack the enabling environment and necessary capacities to effectively carry out their functions (World Bank, 2012). Therefore, this chapter is not only critical to

demonstrate why effective water institutions matter, but also to demonstrate how important water management institutions are in supporting the transition toward the current paradigm of adopting SAPs that enhance water resource management, sustainability, and ecosystem preservation. As a result, the three core chapters in this thesis are all addressing different aspects of the same problem—the water scarcity problem. While Chapter 2 focuses on farmers' water sustainability behaviour and efforts that engender water use efficiency and climate change resilience through the multiple adoption and uptake of WCPs, Chapter 3 focuses on farmers' adoption of sustainable farming practices that lessen agriculture's impact on water quality. Both chapters, importantly, seek to enhance water resource sustainability and management in South Africa. Similarly, Chapter 4, does not only provide a testament on the effective performance of water institutions, but provides insights for the further development and strengthening of the capacities of the right water management institutions to offer the appropriate management, regulatory and enforcement oversights in the adaptation and adoption responses of chapters 2 and 3. Therefore, be it chapters 2, 3, or 4, the end goal is to enhance the country's water resource management and sustainability. Accordingly, the three core chapters have a common objective of addressing not only the water scarcity problem but also water resource management and sustainability in South Africa.

1.6 The Core Chapters

The first core chapter (Chapter 2), titled "**Farming under drought, an analysis of the factors influencing farmers' multiple adoption of water conservation practices to mitigate farm-level water scarcity**" examines the factors that drive farmers' multiple adoption of six WCPs⁶, their interrelationships in mitigating farm-level water scarcity, and the intensity of their adoption. Using survey data from 555 farmers in the Limpopo River Basin (LRB), a multivariate probit model is estimated to determine these factors and the interrelationships of the six WCPs. However, for the intensity of their adoption, an ordered probit model is estimated. A better understanding of these factors, whether they motivate multiple adoption and/or the intensity of adoption, and the interrelationships of the six WCPs are important for understanding the water sustainability behaviour of farmers and to respond with appropriate policy. This chapter underscores that farmers suffer the brunt of the shocks of intensified

⁶ (1) Drip and/or sprinkler irrigation (more efficient performing irrigation methods (MEPIDs)), (2) conservation tillage, (3) cover crops, (4) mulching, (5) intercropping techniques (intercropping and agroforestry), and (6) growing drought-tolerant crops.

climate change, droughts, and water shortages (DWSs). These shocks pose unprecedented water challenges to farmers and impact negatively on agricultural production, food security, and rural employment, among others. If these shocks are left unchecked, they jeopardize the National Development Plan for 2030, which aims at enhancing the quality and quantity of the country's water resources to support the contributions of agriculture to incomes, food security, and unemployment and poverty reduction strategies (The National Development Plan 2030, 2012).

This chapter provides insights that would help South African farmers save, conserve, promote water use efficiency, and build or improve resilience towards farm-level water scarcity. The insights from it would reduce the threats and losses caused by DWSs. The results of this chapter show that gender, age, education, and farm size, among other factors, influence the probability and extent of adoption of WCPs. Furthermore, on the interrelatedness of the six WCPs, a positive correlation is evident for cover cropping and drip and/or sprinkler irrigations (more efficient performing irrigation methods (MEPIDs)), intercropping and MEPIDs, and mulching and MEPIDs, among others. This suggests a significant bundling of these WCPs. The findings in this chapter provide policymakers with key insights that are required for the design of relevant and effective water management strategies that improve water conservation and water use efficiency at the farm level. The framework in this chapter would help farmers become better acclimatized to the growing realities of water scarcity and enhance the sustainability of the resource to enable them to continue to make meaningful contributions to economic growth.

The second core chapter (Chapter 3), titled "**Farmers' willingness to accept compensation to control agricultural nonpoint source pollution in the Limpopo River Basin (LRB) in South Africa**", underscores that South Africa's water resources are, in global terms, scarce and extremely limited. Therefore, an agri-water revolution where farmers adopt farming practices that reduce agriculture's impact on water quality is required. The purpose of this chapter is to investigate the extent to which the adoption of more sustainable farming practices might contribute to reducing agNPS pollution in the LRB of South Africa. Currently, South Africa's policy legislation on preventing, minimizing, or controlling pollution, including agNPS pollution, is the "polluter pays principle" (PPP); however, the characteristics⁷ of agNPS

⁷ Agricultural nonpoint emissions are essentially undetectable (neither the source nor the size of the load can be observed or identified with sufficient accuracy) and highly stochastic due to natural variation in weather and other environmental processes (Han and Zhao, 2010; Horan, Shortle, and Abler, 1999). Efforts to identify the origin or specific loads could be prohibitively costly.

pollution, that they cannot be monitored, creates a moral hazard problem, uncertainty, and incomplete knowledge of the relationship between production choices and nonpoint loadings (Han and Zhao, 2010). As a result, traditional forms of regulation like the PPP are ineffective against agNPS pollution. This is largely because, in many cases, the state lacks the local information and ability to penalize (Dinar et al., 1997; Han and Zhao, 2010). The seemingly lack of strong regulatory and enforcement institutions (Dinar et al., 1997), coupled with the fact that agNPS pollution does not easily lend itself to traditional forms of regulation like the PPP, calls for new methods or policies on how best to control or limit this pollution. These new methods or policies that are effective in controlling or limiting this pollution usually include the use of voluntary incentives, which provide farmers with the motivation to voluntarily change their inherent behaviour and adopt farm management practices that lead to improved water quality. These incentives may include cost-sharing, incentive payments, education to raise awareness, and technical assistance, among others (Feather and Cooper, 1995).

Accordingly, this chapter investigates, through a discrete choice experiment (DCE) methodology, farmers' willingness to accept (WTA) compensation to control agNPS pollution⁸ in the LRB of South Africa. WTA simultaneously measures farmers' decision to participate as well as the minimum amount required to accept a scheme's contract (Dupraz et al., 2003; Martín-Fernández et al., 2010; Owusu-Amankwah, 2019). Therefore, WTA in this thesis refers to the minimum amount a farmer requires or accepts to forgo some undesirable agricultural practices (i.e., fertilizer and pesticide reduction, among others) to reduce agriculture's impact on water quality. Some recent studies that have empirically examined how monetary incentives are used to influence farmers to alter their farming practices to control agNPS pollution include Beharry-Borg et al. (2013), Li et al. (2019), and Lu et al. (2021). These kinds of studies are, however, nonexistent in South Africa, to the best of my knowledge. This lack of empirical studies creates a gap in our understanding of how best to control this canker. Furthermore, it hinders the crafting of cost-effective and proactive water quality improvement policies in the agricultural sector to deal with the issue.

This chapter focuses on the LRB for various reasons. First, South Africa—and especially the LRB—adds an important angle to the study of policy regulations for agNPS pollution under extreme water-scarcity conditions. Second, the LRB is one of the most polluted river systems

⁸ The runoff and leaching into water bodies of fertilizers, pesticides, agricultural waste (film and animal), and soil sediments from farms (Ribaudó, Horan, and Smith, 1999)

in South Africa (Lebepe, Marr, and Luus-Powell 2016; Marr, Mohlala, and Swemmer 2017; Nel and Driver 2015). Yet, the basin is important for agriculture, eco-tourism, mining, and industry, which contribute to promoting employment, income generation, and poverty alleviation (Limpopo Basin Permanent Technical Committee [LBPTC], 2010). If the pollution in the basin is left unchecked, it threatens the ecological security of the basin and the sustainability of the economic activities it supports. This pollution compounds the water-scarcity problem in the country and, therefore, is a threat to the country's water and food security goals. Finally, remedying this pollution is part of major plans for the restoration and protection of the basin (National Water Resource Strategy 2 [NWRS 2], 2013). But the levels to which farmers must alter their agricultural practices to meet river health goals are unknown. Whatever these goals are, reaching them will require changes in the way farmers produce crops and interact with nature, hence this chapter.

A conditional logit model and a state-of-the-art latent class model are used to estimate the relationships from the survey data from 552 farmers. This chapter identified one random choice class and three preference classes of farmers (low, moderate, and high resistance) with dissimilar compensation requirements to alter their status quo farm management practices to improve water quality. The findings support the hypothesis that compensation payments have a positive incentive effect on farmers and increases their willingness to participate in controlling agNPS pollution. Additionally, age, education, farm ownership, and awareness of agNPS pollution, among others, are identified as the main drivers underlying preference heterogeneity in this chapter. This chapter provides a cost-effective framework and robust basis for the formulation of water-quality improvement policies in the agricultural sector to stop the wanton deterioration of water quality caused by undesirable agricultural practices. It also offers new insights to enrich the efficient design of tailored water quality improvement-related agri-environmental schemes (AESs) that would not only ensure the protection and restoration of river health and water quality but would also ensure the sustainability of water resources to enable farmers to make meaningful and continuous contributions to economic and social development.

The third core chapter (Chapter 4) entitled "**A meta-analysis of water institutions and their performance implications for water resource management**" presents a meta-analysis of the empirical literature on the performance of water institutions. Strong water institutions—water law, water policy, and water administration, and/or some aspects of these, like basin

organizations and water user groups, among others—are important for making lasting and continuous improvements to the way water is managed and allocated. In this regard, this chapter synthesized and quantified the overall water institution-performance effect using data extracted from 23 original studies that reported the effect of water institutions on the performance of the water sector. The results from the bivariate and multivariate meta-regressions suggest the presence of a positive publication selection bias in this literature. This indicates that authors, editors, and reviewers of this literature often prefer results that suggest a positive impact of water institutions on performance. This chapter also found evidence of a genuine positive empirical effect of water institutions on the performance of the water sector.

In addition, the variations in the primary studies are attributable to differences in the way the primary studies capture water institutions, the dependent variables used to capture performance, and the estimation strategy/methodology. Specifically, primary studies that use the water law, water policy, and/or some aspects of these to capture the performance of water institutions tend to report a greater impact of water institutions on performance. While primary studies that use a composite index to estimate the performance of water institutions and whether the study is published in a peer-reviewed academic journal or not tend to lower the water institution-performance effect. The main novelty of this chapter is its use of meta-analysis to increase the statistical power of this set of literature, which covers different methodologies and geographic and environmental conditions under which water institutions performed compared to single studies.

The rest of this thesis is structured as follows: The next three chapters—chapters 2, 3, and 4—present the three core chapters explained above. The last chapter, Chapter 5, concludes this thesis by briefly discussing the important findings from the three core chapters and the contributions of this thesis. The chapter further provides policy proposals critical to water resources management in the agricultural sector, the limitations of the research, and suggested areas for further research.

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Chapter 2: Farming Under Drought: An Analysis of the Factors Influencing Farmers' Multiple Adoption of Water Conservation Practices to Mitigate Farm-Level Water Scarcity

Abstract

This chapter investigates the factors that drive farmers' simultaneous adoption of six water conservation practices (WCPs) and the intensity of their adoption. To estimate farmers' adoption of these WCPs a multivariate probit model is used, and for the intensity of their adoption, an ordered probit model is estimated. The results show that gender, age, education, and farm size, among other factors, influence the probability and extent of adoption of WCPs. Furthermore, combinations like drip and/or sprinkler irrigations and cover cropping, drip and/or sprinkler irrigations and intercropping, among others, are complements, suggesting the bundling of these WCPs.

Keywords: climate change, drought, farmers' multiple adoption, multivariate probit, Limpopo River Basin, South Africa, water conservation practices

JEL classifications: Q1, Q2, Q3, and Q5

2.1 Introduction

In many parts of Africa where much of the agriculture is dependent on rainfall, water scarcity as a result of droughts caused by climate change is a major concern for farmers, policymakers, and international organizations. Finding remedies to water scarcity in agriculture is key in the face of unpredictable weather conditions that have often resulted in production uncertainties, severe food shortages, food and nutritional insecurity, poverty, rural unemployment, and low development. In southern Africa, the effects of climate change are becoming more frequent and more severe, with prolonged droughts and extreme temperatures higher than the global average (United Nations Framework Convention on Climate Change [UNFCCC], 2020). Given this climate emergency, it is imperative to protect water resources to consolidate and enhance the gains of agriculture that are threatened by droughts and water shortages (DWSs). Since farmers suffer the brunt of the shocks of intensified DWSs and given that the agricultural sector of South Africa uses the bulk of the country's freshwater resources (about 60%), its farmers are expected to be at the center of all efforts to save, conserve, and promote water-use efficiency. To this effect, this chapter attempts to understand how the agricultural sector in South Africa is responding to the water-scarcity problem, with a focus on the Limpopo River Basin (LRB).

South Africa, as a water-stressed country prone to multi-year DWSs, is at further risk as economic industrialization, agricultural development, and population growth exacerbate the water scarcity problem. The intensified effects of climate change and these shocks not only pose unprecedented challenges to farmers but also have severe negative impacts on the whole agricultural supply chain, food security, and rural employment at large. For instance, the droughts from 2015 to 2018 resulted in the loss of large tracts of farmland and significant amounts of livestock in several parts of the country, increased the price of staple food items such as maize, and induced the imposition of harsh water-restriction measures. In addition to these effects, the drought was so severe that the City of Cape Town was projected to run out of water by June of 2018—an event dubbed 'Day Zero'. This day was so eminent that the first ever Water Police in the world was instituted in the city to police water resources. This definitely makes the South African water scarcity problem a unique one that calls for all hands-on deck to save and conserve water at the provincial and national levels. These DWSs threaten South Africa's National Development Plan (NDP) for 2030, which highlights the important

need for adequate water of the right quality and quantity to support agriculture, equitable economic growth, and development (National Development Plan 2030, 2012).

The LRB covers an area of 416,296 square kilometers and is the second longest river (approximately 1,750 kilometers (1,087 miles)) and most significant river in southern Africa (Nakayama, 2003). The basin has a population of about 14 million people (52% rural and 48% urban) and is shared by four countries—Botswana (19%), Zimbabwe (15%), Mozambique (21%), and South Africa (45%) (Limpopo Basin Permanent Technical Committee [LBPTC], 2010). South Africa's largest share (area of about 184,150 square kilometers) lies predominantly in the Limpopo Province. Agricultural activities constitute a large portion of land use in this part of the basin (LBPTC, 2010). It was estimated that over 273,000 smallholder farmers lived in the Limpopo Province (Statistics South Africa, 2002). While the river is vital to the people of the province, wildlife, and economy, it faces several threats and challenges—climate change and water pollution are major concerns. Changing rainfall patterns and rising temperatures have impacted the river's flow and reduced water availability for agriculture, wildlife populations, and livestock farming. While anthropogenic activities have led to increased levels of pollution in the river, consequently, impacting water quality, aquatic life, and the loss of natural habitats and biodiversity. In addition, the dominance of agriculture in the province is threatened by the fact that the province is a semi-arid to arid region receiving less precipitation (250–500 millimeters of rainfall per year). Not only does the province receive less precipitation, but high surface temperatures in the area cause high evaporation rates, which cause high surface water scarcity and diminish groundwater levels.

All these factors, together with the lagging water infrastructural development in the area, create severe water scarcity in the basin, which does not only endanger the province's economic development strategy, which identifies agriculture as one of the three pillars of economic growth, but also puts severe stresses on farmers, production, incomes, and social welfare.

Droughts are often unpredictable; therefore, preparedness measures are paramount in enabling farmers to cope with their pervasive long-term effects and severity of DWSs. Anticipatory measures include the adoption of water conservation practices (WCPs) that help to conserve water and enhance its efficient use at the farm level. According to International Rivers (2000), agricultural water use in southern Africa is still highly inefficient, and that 2.5 billion cubic meters of water could be saved each year if irrigation water usage could be made only 10%

more efficient. This is in line with the literature on the adoption of WCPs, which shows that the adoption of these practices does more than conserve water (Uygan et al., 2021). These practices have additional benefits, such as increases in water-use efficiency (Cai, Rosegrant, and Ringler, 2003), the preservation and improvement of water quality (Howell, 2001), a decrease in tillage requirements and cultivation costs (both in terms of labor and fuel), and increases in agricultural production (Heilig, Fischer, and Van Velthuis, 2000). Furthermore, the adoption of WCPs enables farmers to build defenses against future droughts and maintain their production cycles throughout the year, which in turn guarantees the stability of their income flows and contributes to reducing poverty and inequality within the farming community (Abdulai and Huffman, 2014; FAO, 2017).

Despite the numerous benefits of the adoption of WCPs in agriculture, the provincial and national campaigns to encourage farmers to adopt these practices to conserve water and promote climate change resilience, their adoption and uptake rate are still very low and undesirable in most areas of the country, especially in the LRB. In addition, agriculture, through its link to food security, nutrition and health, inequality and poverty reductions, and rural development and growth, will continue to be a key driver of sustainable and inclusive growth (FAO, 2017b). This indicates that a substantial share of South Africans will continue to earn their living from agriculture. Accordingly, water conservation must be a priority for farmers, especially those in the LRB, where intensified climate change and DWSs endanger livelihoods, agriculture, and economic growth.

Therefore, the purpose of this chapter is to identify and analyze the factors that motivate farmers' multiple adoption of WCPs, and their interrelatedness in mitigating farm-level water scarcity in the LRB of South Africa and beyond. The chapter is particularly interested in how farmers in the LRB are adopting multiple WCPs simultaneously or the bundling⁹ of these practices to adapt to climate change, improve resilience to DWSs, and promote water-quality improvement. To this effect, using six WCPs¹⁰, this chapter first determined the factors that motivate farmers to adopt multiple WCPs simultaneously to combat the water scarcity problem. Second, it determined the interrelationships among the WCPs that farmers adopt,

⁹ Bundling of agricultural technologies takes place when farmers use two or more technologies and/or management practices that complement each other instead of adopting one technology or management practice independently (Reints, Dinar, and Crowley, 2020).

¹⁰ (1) Drip and/or sprinkler irrigation (MEPIDs), (2) conservation tillage, (3) cover crops, (4) mulching, (5) intercropping techniques (intercropping and agroforestry), and (6) growing drought-tolerant crops.

paying particular attention to those that are complementary. Finally, a determination of the intensity of the adoption (number of practices adopted) of these practices is made. A better understanding of these factors, whether they motivate adoption or the intensity of adoption, is important for understanding the water sustainability behaviour of farmers and to respond with appropriate policies that deliver high payoffs to farmers amid DWSs. South Africa, and especially the LRB, adds an important angle to the study of policy regulations on the promotion and uptake of WCPs under extreme water-scarce conditions.

Accordingly, using survey data of 555 farmers in the study area, a multivariate probit (MVP) model is estimated to determine the factors that influence farmers' multiple adoption of WCPs and the interrelatedness of these WCPs. However, for the intensity of adoption, an ordered probit model (OPM) is estimated. The findings of this chapter are critical for the promotion and uptake of multiple WCPs in South Africa and beyond. The framework in this chapter is not only critical for long-term planning under likely changes in climate but also provides farmers with more flexibility, better resilience, and a range of toolsets to adapt to increased climate volatilities and droughts. This chapter contributes variously to the literature on the adoption of WCPs in particular and agricultural water management in general. First, it provides an enhanced understanding of the water sustainability behaviour of farmers and the factors that influence this behaviour. Second, beyond this chapter's academic contribution to the literature, it provides key insights for the design of relevant and proactive water-management policies in the agricultural sector that not only engender water conservation, use efficiency, enhanced quality, and sustainability but would also enable farmers to cope with absolute as well as relative water scarcity¹¹.

The rest of this chapter is structured as follows: Section 2.2 provides a review of related literature, and a brief description of the study area is in Section 2.3. Section 2.4 comprises the methodology, followed by Section 2.5, which presents the empirical results and their discussion. Section 2.6 concludes, provides policy implications, and discusses the limitations of the chapter and directions for future research.

¹¹ Absolute water scarcity refers to the insufficiency of supply to satisfy existing total demand after all feasible options to enhance supply and manage demand have been implemented (United Nations Economic and Social Commission for Western Asia [UNESCWA], 2020), coupled with the inability to find substitutes. Relative water scarcity is an imbalance between supply and demand that varies according to local conditions (FAO, 2022).

2.2 Review of Related Literature

Farmers tend to adopt technologies and conservation practices that may help them increase their expected profit (De Graaff et al., 2008). The factors that drive or constrain agricultural innovation adoption have been studied extensively (Dinar and Yaron, 1992). In general, the literature shows the adoption of WCPs as a function of a multitude of factors: personal and demographic characteristics, social capital, the natural environment, technical characteristics, institutional characteristics, and farm characteristics, among other factors (Abdulai, Owusu, and Bakang, 2011; Alam, 2015). Specifically, these studies investigated the factors that influence the adoption of WCPs (Amsalu and De Graaff, 2007; Jara-Rojas, Bravo-Ureta, and Díaz, 2012; Alotaibi and Kassem, 2021; Sileshi et al., 2019 among others) and of climate-smart agricultural technologies (Deressa et al., 2009; Dung, 2020; Maguza-Tembo, Edriss, and Mangisoni, 2017; Teklewold, Kassie, and Shiferaw, 2013a, among others) to understand farmers' adaptative strategies to droughts and climate change. Other studies have also investigated barriers to water conservation (Kulkarni, 2011), choices of irrigation technologies to conserve water (Caswell and Zilberman, 1985), and conservation practice programmes to protect water quality in agricultural watersheds (Osmond et al., 2012).

In Table 2.1, an overview of key related studies on the factors that determine farmers' adoption of sustainable agricultural practices to adapt to climate change is presented.

Table 2. 1: An Overview of Key Related Studies Around the World.

Authors	Study area/ sample size (N)	Objective(s)	Variables of study	Empirical model(s)	Summary of findings
Koech and Langat (2018)	Australia N = Not applicable	To review the advancements that have been made to improve irrigation WUE, document the challenges encountered as well as explore opportunities for further development.	Engineering and technological innovations, advancements in plant and pasture science, environmental, and socio-economic factors	A review of advances, challenges, and opportunities	<ol style="list-style-type: none"> 1. The review showed that improvements in irrigation infrastructure through modernization and automation have led to water savings. 2. To achieve net water savings, water-efficient technologies and practices need to be used in combination with other measures, such as incentives for conservation and appropriate regulations that limit water allocation and use. 3. Factors that affect trends in irrigation water-use efficiency (WUE) include engineering and technological innovations, advancements in plant and pasture science, environmental factors, and socio-economic considerations. 4. Challenges that might be encountered include a lack of public support, especially when the methods used are not cost-effective, and the reluctance of farmers to adopt new technologies.
Adusumilli and Wang (2018)	U.S.A. N = 500	To contribute to the literature on natural resource conservation by analyzing the factors that influence simultaneous adoption of soil conservation and water-	<p>DV: soil conservation practices, water-quality protection and water conservation (efficiency practices).</p> <p>IV: relationship between farming practices and water quality, type of farm operation, land ownership, number of acres farmed in the cropping year,</p>	A bivariate probit model	<ol style="list-style-type: none"> 1. Farmers' beliefs about the relationship between farming practices and water quality can play a role in protecting the quality of surrounding waters. 2. Participation in federal programs has a positive and significant effect on the likelihood of adopting conservation practices. 3. Percentage of land owned and number of years in farming have a negative influence on adoption. 4. The type of farm operation, participation in federal programs, and education level have a positive effect on adoption. 5. The higher the education, the greater the understanding of the links between conservation and crop profitability, hence adoption. Age, however, was insignificant.

		efficiency practices.	participation in federal programs, source of technical assistance, years of farming, annual gross farm revenue, education, and age.		
Zhang et al. (2019)	Beijing, China N = 490	To identify the major factors and provide an understanding of farmers' sustainable irrigation practices used to cope with water stress in water-scarce environments of Beijing, China.	DV: water-saving irrigation technology (WSIT) IV: household characteristics (age, education, farming experience), family characteristics (household size, production specialization), farm characteristics (farm size, on-farm demonstration, cooperative), production conditions (agricultural technology training, distance to nearest market, groundwater), perceptions of technology (access to information, cost of adopting WSIT), environmental factors (member of water-user association, drought-prone area, neighboring farmers, policy subsidies).	Binary logit choice model	<ol style="list-style-type: none"> 1. The results revealed that education, farm size, on-farm demonstration, cooperatives, training, groundwater, access to information, water-use associations, drought-prone areas, neighboring farmers, and policy subsidies significantly improved the adaptation to water scarcity. 2. Specifically, the findings showed that older farmers had a lower probability of WSIT adoption. Education had a positive effect on the adoption of WSIT. Production specialization had a significant negative impact on farmers' adoption of WSIT. 3. Farm size had a positive and significant impact on the adoption of WSIT. On-farm demonstrations showed a positive influence in the adoption equation, indicating that farmers who participated in on-farm demonstrations were more likely to adopt WSIT. 4. Being a member of cooperatives improved the likelihood of adoption of WSIT to cope with water scarcity. Attendance at training sessions had a significant positive influence on farmers' WSIT adoption probability.

Pagliacci et al. (2020)	Veneto region, Italy N = 66	To examine the role of the farming factors, technology accessibility, environmental features, policy design and social expertise at the territorial level on early adoption, and to shed light on farmers' attitudes and motivations and on social pressure on their decision to continue or discontinue the practices.	Farming factors (share of farms larger than 30 ha and share of arable crop area), technology accessibility factors (irrigable, irrigation poor, irrigation medium, irrigation no constraints and distance), environmental factors (rainfall and soil type), policy factors (nitrate-vulnerable zones, rural), size control (utilized agricultural area at the municipality level), spatial diffusion patterns (share of other agri-environmental schemes' beneficiaries, spatial lag of share of other agri-environmental schemes' beneficiaries and spatial lag of utilized agricultural area at the municipality level).	Poisson and logit regression models	<ol style="list-style-type: none"> 1. These results showed, among others, that for no-tillage, the number of adopters by municipality is positively affected by the farming factors. In particular, the municipality's specialization in arable crops triggers no-tillage adoption. 2. Among the technology accessibility factors, the share of irrigable area had a negative effect, confirming that farmers who do not have access to irrigation are more inclined to adopt no-tillage. 3. Among the environmental factors, rainfall is not significant. The type of soil matters. A larger number of adopters are associated with clay soils rather than sandy soils. 4. No-tillage on clay soils delivered higher cost savings when compared to traditional tillage practices. With regard to policy factors, those municipalities located in nitrate-vulnerable zones show a larger number of adopters.
Valizadeh, Bijani and Abbasi (2018)	West Azerbaijan Province, Iran. N = 378	To identify and analyze factors affecting farmers' active participation in water conservation (FAPWC).	Farmers' active participation in water conservation, moral norms of water conservation, place attachment, social responsibility toward consequences, attitude toward participation in water conservation, social	Parametric tests were used to analyze their data.	<ol style="list-style-type: none"> 1. Social pressure was one of the most important activators of farmers' active participation in water conservation. It, however, did not have a significant effect on the moral norm of water conservation. 2. The quality of agricultural extension services was positively and significantly associated with farmers' active participation. 3. Satisfaction with water resources management was the strongest predictor of farmers' active participation in water conservation, highlighting the issue of the quality and manner

pressure toward water conservation, quality of agricultural extension services and satisfaction of water resources management.

of interactions and services provided by governmental structures and bodies.

Aryal et al. (2018)	Bihar and Haryana in the Indo-Gangetic Plains of India	To analyze the factors that determine the probability and level of adoption of multiple climate-smart agriculture (CSA) practices.	DV: total number of CSA practices adopted, seeds of stress-tolerant varieties (STV), minimum tillage (MT), laser land leveling (LLL), site-specific nutrient management (SSNM), and crop diversification (DC).	Multivariate probit and ordered probit models	<ol style="list-style-type: none"> 1. The adoption of the various CSA practices is interrelated. Specifically, among other findings of the MVP model, male-headed households were more likely to adopt LLL but less likely to adopt CD and STV. 2. Older household heads were more likely to adopt CD, while they were less likely to adopt MT and SSNM. In addition, older household heads were less familiar with relatively newer technologies. 3. In terms of the intensity of CSA adoption, general caste and literacy are the major household characteristics that favor the number of CSA practices adopted. 4. Crop diversification and minimum tillage are found to be significant and negatively associated, implying that farmers consider these practices as either incompatible or substitutes. 5. Other CSA combinations, such as MT and STV, MT and SSNM, and STV and SSNM, are significantly and positively associated, implying that farmers primarily consider these as complements.
	N = 1,267		IV: household (HH) characteristics (gender, general caste, age, literate, literate spouse, family size, migrant), farm land characteristics (tenure of plot, area of plot, fertile soil, deep soil, gentle slope, distance to plot), economic and social capital (land operated, livestock owned in TLU, asset index, credit access, association in group), access to markets, agricultural extension service and training (distance to market,		

distance to extension service, agricultural training), source of information (farmer to farmer, extension service, ICT seed traders/private company), climate risks experienced by household over the last 5 years (high temperatures, decreasing rainfall, short winters).

Alauddin et al. (2020)	Bangladesh N = 108	To determine the factors that influence the adoption of alternate wetting and drying (AWD) irrigation as a water-saving technology in Bangladesh and whether AWD adoption saves irrigation water use, reduces irrigation cost, and increases or stabilizes crop yield.	DV: AWD adoption IV: Age, education, access to agricultural extension services, access to weather information in advance, access to credit, amount of land irrigated, high elevation, low elevation, soil type, land ownership, irrigation frequency, cost of irrigation.	Logit, propensity score matching and multiple regression models.	<ol style="list-style-type: none"> 1. The study found that AWD adoption varied inversely with the age and level of education of the household head. Younger farmers were more likely to adopt the AWD irrigation technique than older ones. Household heads with less than 6 years of schooling displayed a greater inclination toward AWD adoption relative to those with more than 6 years of schooling. 2. A significant negative effect of access to prior weather information on AWD adoption was evident. 3. AWD adopters were significantly younger, possessed a significantly higher amount of irrigated and cultivated lands, and had higher amounts of high-elevated land and/or land with clay-type soil. 4. Irrigation frequency varied inversely with AWD adoption, and directly with access to prior weather information, and the low elevation of the land. 5. The cost of irrigation varied inversely with AWD adoption, directly with access to credit, and inversely with clay-loam type soil.
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Jara-Rojas et al. (2012)	Central Chile N = 319	To determine the factors that contribute to the adoption of a number of water conservation practices by small-scale farmers in Central Chile.	DV: Water conservation, No-adoption, Techniques, Technologies IV: age, education, family size, farm size, livestock, home consumption, access to credit incentives, water community, social activities, high payment (USD 9,808) per share of irrigation water, low payment (USD 5,954) per share of irrigation water and no payment (does not pay) for irrigation water	Poisson count data model, logit, and multinomial logit models.	<ol style="list-style-type: none"> 1. The results showed that social capital, farm size, and land use played a key role in the adoption of management practices and generated greater efficiency in the use of water for irrigation. 2. Age and education show inconclusive results. 3. Family size is positive and significant. This supports the notion that the likelihood of adopting water conservation practices rises as family labor becomes more abundant. 4. Farm size (land) is significant and positive, which is similar to the results reported by Bekele and Drake (2003). 5. Both land and livestock are positive and consistent with the notion that wealthier farmers are more able to undertake risk and thus are more likely to be adopters. However, home consumption is negative. 6. Access to credit, which exhibits mixed results in the literature, was not significant in their study.
Mango et al. (2018)	Chinyanja Triangle, Zambia, Malawi, and Mozambique. N = 312	To determine the factors that influence the adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on income among smallholder farmers.	DV: irrigation farming, agricultural income IV: gender, age, household size, education, extension, occupation, off-farm employment, credit access, irrigation equipment, reliable water source, awareness of conservation practices, distance to market and land size cultivated, irrigation farming, labor, economically active, group membership, livestock, main crop, literacy,	Binary logistic and ordinary least squares regression models,	<ol style="list-style-type: none"> 1. The results showed that gender, household size, education, extension, casual labor, skilled labor, credit access, and land size cultivated did not significantly influence the adoption of small-scale irrigation farming. 2. Age had a negative impact on the adoption of small-scale irrigation farming, which suggested that the odds of adoption were higher among younger farmers than among older farmers. The odds of adoption were found to decrease if the household head's main occupation was either formal employment or involvement in a small-scale business. 3. Off-farm employment was found to significantly influence the adoption of small-scale irrigation farming. Access to irrigation equipment positively influenced the adoption of small-scale irrigation farming. Access to irrigation equipment and a reliable water source were vital for farmers to try small-scale irrigation farming.

adoption of land, soil and water (LSW).

4. Awareness of WCPs, such as rainwater harvesting, had a positive and significant influence on the adoption of small-scale irrigation farming. The distance traveled to access the nearest market had a significant negative influence on the adoption of irrigation farming.

Hassan and Nhemachena (2008)	11 African countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia and Zimbabwe.	To analyze the determinants of farm-level climate adaptation measures in Africa.	DV: multiple crops under irrigation, multiple crops under dryland, mono crop-livestock under dryland, mono crop-livestock under irrigation, multiple crop-livestock under irrigation, and multiple crop-livestock under dryland.	Multinomial logit model.	<ol style="list-style-type: none"> 1. The results suggest, among other findings, that warmer winters and springs promoted switching to the use of irrigation, multiple cropping, and mixing crop and livestock activities, especially under irrigation. 2. Irrigation was the strongest adaptation measure against warming for all systems; mixing livestock with crop cultivation seems to work only with multiple cropping under dryland conditions. 3. Better access to extension and credit services had a strong positive influence on the probability of adopting all adaptation measures and abandoning the relatively risky monocropping systems. 4. Access to electricity was strongly associated with the use of irrigation. This could also be because the bulk of irrigation water in Africa is supplied from dams that are also used for power generation. 5. More experienced farmers were more likely to adapt than less experienced ones. The age of the farmer did not seem to be of significance in influencing adaptation, as almost all marginal effect coefficients were statistically insignificant.
	N = 8,208		IV: winter temperature, spring temperature, summer temperature, fall temperature, winter precipitation, spring precipitation, summer precipitation, fall precipitation, farmer noticed changes in climate, sex, household size, age, farming experience, access to extension services, access to credit, access to electricity, distance to markets, own heavy machines and farm size (hectares).		

Belachew, Mekuria, and Nachimuthu (2020)	Northwest Ethiopian Highlands N = 150	To identify the factors influencing adoption of soil and water conservation practices.	DV: soil bund, stone bund, check dam and strip cropping. IV: sex, age, educational level, household size, livestock holding (in TLU), land size, access to credit, distance from home to farmland, slope of the farmland, access to extension service and participation in training on SWC practices.	Descriptive statistics and a multivariate probit model.	<ol style="list-style-type: none"> 1. The results revealed that the likelihood of adopting soil bund, stone bund, check dam, and strip cropping was 74%, 56%, 29%, and 56%, respectively. 2. Specifically, sex influenced the adoption of strip cropping significantly, while age influenced the adoption of soil bund negatively. 3. Educational level increased farmers' ability to get and use information and improved farmers' decisions to adopt SWC practices. Household size influenced the adoption of soil bund, and strip cropping, both positively and negatively. 4. Livestock holdings affected the adoption of soil bund positively. Land size influenced the adoption of stone bund and strip cropping positively. Access to credit influenced the adoption of soil bund, stone bund, check dams, and strip cropping.
Jha et al. (2019)	Tanzania N = 701	To better understand and identify the factors that significantly influence the adoption of water conservation techniques (WCTs) in Tanzania.	DV: water conservation measures IV: individual and household characteristics (age, health, gender, ability to read and write, attitude toward risk, region, household size, household water usage), socio-economic characteristics (membership in social networks, access to micro-credits, access to public funds, household savings, off-farm employment, household income	Bivariate logistic regression.	<ol style="list-style-type: none"> 1. The results showed that individual, household, socio-economic, and farmer perception-related variables affected the adoption of WCTs differently. 2. Specifically, women-led households had a lower likelihood of adopting WCTs, and farmers who had access to social networks and public funds had a higher likelihood of adopting WCTs. 3. The farmer's perception of rainfall instability had a significant negative influence on the adoption of WCTs, whereas a positive perception of household wealth and food security by the farmer had a significant positive influence on the adoption of WCTs, as expected. 4. The study found no statistical significance for the variables relating to the adopter's age, health, ability to read and write, attitude toward risk, region, household size, household water usage, access to microcredits, savings, off-farm employment,

			fluctuation), farmer perceptions (perception of change in rainfall, perception of climate change, perception of change in environment, perception of household wealth and perception of household food security).		5. household income fluctuations, farmers' perception and recognition of the changing climate and environment, and adoption of WCTs.
Ntshangase, Muroyiwa, and Sibanda (2018)	Ingwe Municipality in Kwa-Zashuke, Ward 8, KwaZulu-Natal Province, South Africa. N = 185	To understand the factors affecting the adoption of no-till conservation agriculture (CA) among small-scale farmers, including farmers' perceptions of the technology.	DV: adoption of no-till CA IV: age, gender, education, economically active members, experience in farming, training, extension frequency, access to credit, promotion of no-till, land size and income.	Descriptive and inferential statistics, and a binary logistic regression model.	<ol style="list-style-type: none"> 1. The results showed that the age of the farmer positively influenced no-till CA adoption. 2. More educated farmers tended to be younger than less-educated farmers. Among the more educated farmers, the older farmers had a higher tendency toward adoption. 3. Farm size cultivated negatively influenced the adoption of no-till CA. Larger pieces of land were associated with farmers being less likely to adopt the no-till CA in comparison to the group of farmers with a smaller land size. 4. The frequency of extension visits was categorized into four groups. Farmers who had more frequent visits were more likely to adopt farming practices that they were exposed to through extension services.
Mogogana, et al. (2018)	Northwest Province, South Africa. N = 108	To determine the knowledge and adoption of water-use efficiency techniques among women irrigators in the Northwest	DV: water-use efficiency techniques (reduced tillage cover crops, crop rotation, manure and fertilizer). IV: age, marital status, number of dependents, number of members in household, highest level of	Frequency counts, percentages, means, standard deviation, and probit regression model.	<ol style="list-style-type: none"> 1. The findings showed that adoption of reduced tillage had a direct relationship with the frequency of extension visits but an inverse relationship with land tenure, membership in farmers' groups, and the existence of water tariffs. 2. Extension visits were found to have a significant positive effect on the adoption of cover crop techniques. 3. The adoption of crop rotation has a direct relationship with age. Membership in a farmers' group, the existence of water

		Province of South Africa	education, land tenure status, farm size number of plots, location of plots in one area, members of farmers' group, contact with extension agent, frequency of extension visits, extension agency, sources of labor, farming experience, number of years in irrigation scheme, water rate, existence of water tariffs, electricity for water pumping, cropping systems.		<p>rates, and the existence of water tariffs reduced the likelihood of the adoption of crop rotation.</p> <p>4. The age and number of plots owned by women farmers were positive. Farm size, membership in farmers' groups, and the existence of water rates and tariffs were negative, implying an inverse relationship with the adoption of manure and fertilizer.</p>
Baiyegunhi (2015)	Msinga, KwaZulu-Natal Province, South Africa N = 180	To evaluate the determinants of farmers' decisions to adopt rainwater harvesting technology (RWHT) among rural home gardeners.	DV: rainwater harvesting technology. IV: gender of household head, age of household head, household head education, household size, household monthly income, off-farm activity, social capital, contact with extension agent, security of land rights, access to farm inputs, perception/attitude toward RWHT, distance to water tanks and importance of livestock.	Binary logistic regression.	<ol style="list-style-type: none"> 1. The results showed a significant positive relationship between gender and adoption of RWHT, implying that male farmers were more likely to adopt RWHT compared to female farmers. 2. Age had a significant negative effect on the adoption of RWHT. 3. Household income had a significant positive effect on the adoption of RWHT. A higher level of household income implies a greater incentive for investment in agricultural technologies and the ability to bear the risk associated with their adoption. 4. Social capital had a significant positive effect on the adoption of RWHT. Contact with extension had a significant positive effect on the adoption of RWHT. 5. Security of land rights had a significant positive effect on the adoption of RWHT, suggesting farmers who had secured rights to their lands were more likely to adopt RWHT.

Gbetibouo et al. (2010)	Limpopo River Basin, South Africa	To investigate factors affecting the choice of adaptation strategies (practices and technologies) to climate change at the farm level to generate important policy information on how to enhance the adaptive capacities of rural households in stressed environments like the LRB.	DV: Portfolio diversification, irrigation, changing planting dates, changing land area under cultivation, livestock feed supplement and other adaptation methods. IV: household (HH) characteristics (age, education, gender, household size, farming experience, wealth), farm characteristics (farm size, soil fertility), institutional factors (extension service, climate information, credit access, off-farm employment, tenure), other factors (temperature, rainfall, latitudes, longitude, and Limpopo River).	Multinomial logit model.	<ol style="list-style-type: none"> 6. Farmer's perception/attitude toward RWHT had a significant positive effect on adoption of RWHT, implying farmers who had positive perceptions/attitude toward RWHT were more likely to adopt it. <ol style="list-style-type: none"> 1. The results revealed that larger households were more willing to choose "the other" category as an adaptation option, which included adaptations such as the use of soil conservation techniques and chemical treatments that are labor-intensive, especially in small-scale farming. 2. Experienced farmers had an increased likelihood of using portfolio diversification, changing planting dates, and changing land under cultivation. 3. Farm size is significant and positively correlated with the probability of choosing irrigation as an adaptation measure. Large-scale farmers were more likely to adopt irrigation as they have more capital and resources to invest in irrigation technologies. 4. Off-farm income increased farmers' likelihood of buying feed supplements for their livestock. Access to credit increased the likelihood that farmers would take up portfolio diversification to buy feed supplements for their livestock. 5. Households in regions with high temperatures have an increased likelihood of adopting (1) portfolio diversification, including changing their types of crops (from maize to sorghum, a more heat-tolerant crop), (2) intensifying irrigation, and (3) changing planting dates. A decrease in rainfall is likely to push farmers to delay planting.
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Note: DV = the dependent variable(s); IV = the independent variables.

A recent strand of literature of interest looks at the adoption of bundles of technologies and management practices to adapt to climate change. According to Fleischer, Mendelsohn, and Dinar (2011) and Wang et al. (2010), the adoption of bundles provides farmers with more flexibility, which results in better resilience to climate change effects and higher profits. Specifically, Fleischer et al. (2011) used discrete choice analysis to simulate how Israeli farmers, in response to changes in climate, bundle the choice of crop species and technology to simultaneously decide which crop to grow and what type of irrigation to use, among others. Their study concluded that the shift between bundles provides adaptation capacity and enables farmers to be better prepared to handle climate change impacts and maximize profits.

Wang et al. (2010) simulated how farmers' crop choices might change in response to climate change in China. The crux of their study is how farmers have adapted to the different climates across China using different cropping patterns with different water requirements. Their results show that, depending on the region, certain crop bundles provide farmers with flexibility in dealing with climate change impacts and water scarcity. Further, climate change will cause some crops to increase in some regions and fall in others across China.

Reints et al. (2020) examined how avocado growers in California adopt bundles of different management practices and irrigation technologies to deal with water scarcity. The authors used Kohonen Self-Organizing Maps (KSOM) (Kohonen, 2013) and logit models to identify the most common bundles of technologies and management practices that growers are using. One important conclusion from their study is that regional climates and water conditions matter. Therefore, farmers will need to be more flexible in their approach to water management to mitigate climate change effects and improve water-use efficiency.

The review of the literature shows that, first, no study exists of farmers' simultaneous adoption of the unique six WCPs in this chapter. Therefore, this chapter is the first research, to the best of my knowledge, to investigate the factors that motivate the adoption of multiple WCPs simultaneously by farmers in adapting to intensifying climate-change effects in South Africa. Identifying these factors and the possible bundles will contribute to an effective understanding of the water sustainability behaviour of water conservation-conscious farmers to respond with appropriate policies. This is important to add to the debate as to whether farmers should adopt WCPs individually or as bundles. In addition, investigating how farmers bundle WCPs to adapt to climate change and DWSs is not only appropriate but timely to support provincial and

notional water conservation efforts, especially since South Africa was/is the only country in the world to ever announce or declare a ‘Day Zero’ and the formation of the world’s first ever Water Police to police water resources due to the severe effects of DWSs.

Furthermore, despite the importance of water conservation in agriculture, few studies (Baiyegunhi, 2015; Gbetibouo, Hassan, and Ringler, 2010; Mogogana, Olorunfemi, and Oladele, 2018, among others) have investigated the subject in South Africa. Although important, these studies fall short of providing a comprehensive picture of the factors that motivate farmers’ simultaneous adoption of WCPs. Further, farmers are often faced with different crop choices, farm management practices, and environmental factors, among others. Accordingly, they may want to adopt WCPs jointly as complements, substitutes, or supplements to deal with the overlapping constraints that may occur in single adoptions. In addition, farmers consider the way different technological innovations interact and take their interdependencies into account in their adoption decisions. Ignoring these interdependencies can lead to bias estimates and inconsistent policy recommendations (Marenya and Barrett, 2007). This implicates most of the studies on South Africa and provides a justification for this chapter, which accounts for interdependencies among WCPs.

The important differences between this chapter and the studies reviewed is that first, this chapter focuses attention on South Africa, where no studies have been conducted on the bundling of WCPs or their multiple adoption. Second, it differs from all the studies on South Africa and those reviewed by investigating the multiple adoption of WCPs or their bundling and the intensity of their adoption to adapt to climate change intensity. Third, the choice of WCPs, including more efficient performing irrigation methods (drip and/or sprinkler irrigations), conservation tillage, cover cropping, mulching, intercropping, and growing drought-tolerant crops, is unique and further differentiates the current chapter from previous studies. These six WCPs would enrich the discussions on multiple adoption of WCPs that mitigate farm-level water scarcity and enable farmers to guard against the effects of future DWSs. Finally, this chapter’s use of the MVP and OPM methodologies stands out, and further differentiates the current chapter from most of the studies reviewed. This is because most of these previous studies have either used probit and/or logit models, among others, to accomplish their estimations, which according to Marenya and Barrett (2007) ignores the interdependencies among WCPs, thus leading to bias estimates and inconsistent policy recommendations.

2.3 An Overview of the Study Area

The research is conducted in two farming communities, namely Folovhodwe and Tshiombo, as shown in Figure 2.1. Folovhodwe is in the Musina local municipality, and Tshiombo is in the Thulamela local municipality.

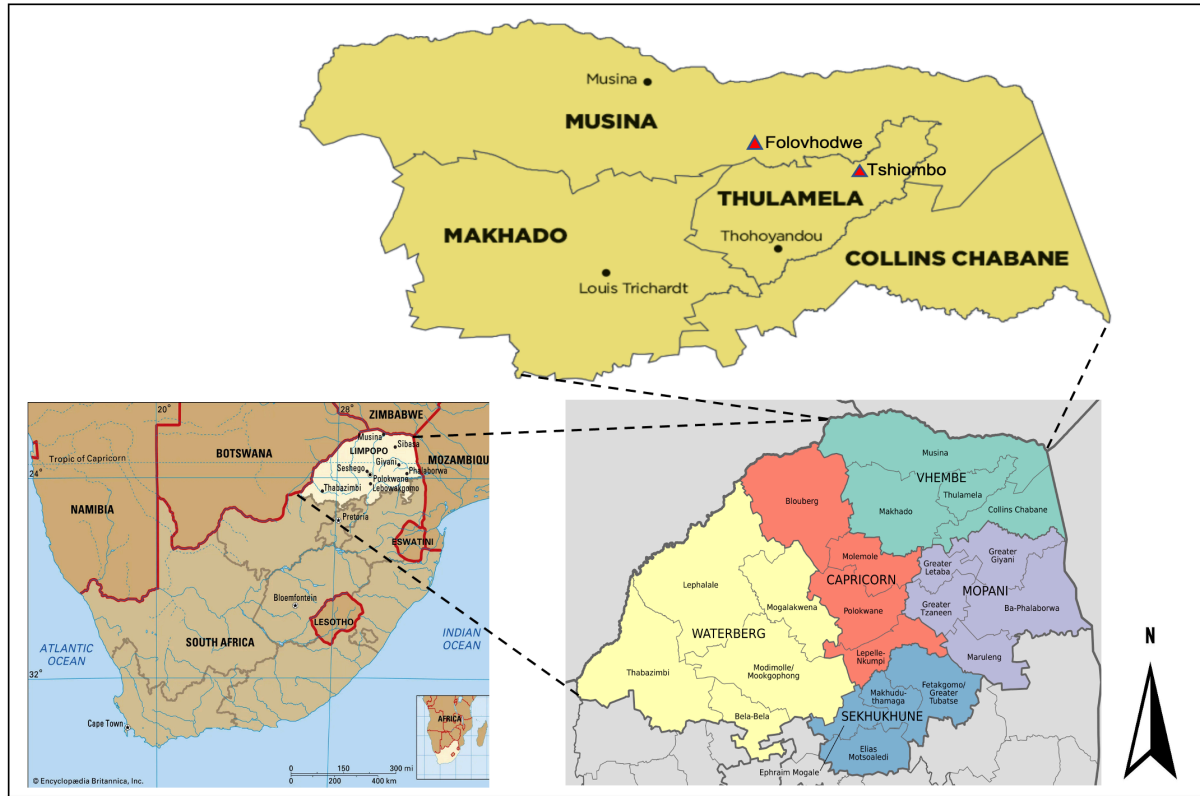


Figure 2. 1: Map of the Study Area
(Adapted and modified from Google Maps, 2022)

Both local municipalities are in the Vhembe District Municipality¹² of the Limpopo Province in South Africa. Much of the agricultural activity in the Limpopo Province occurs in this district, especially in the two farming communities, which are located near important tributaries of the Limpopo River. The Nwanedi River passes through Folovhodwe, which is the site of the Nwanedi Irrigation Scheme. The Tshiombo Irrigation Scheme, one of the largest in Limpopo Province, is in Tshiombo at the western end of the Tshiombo Valley on the south bank of the Mutale River (Lahiff, 1997). Agricultural activities predominantly consist of vegetables, bananas, citrus fruits, maize, melons, peanuts (groundnuts), and poultry and livestock production, among others.

¹² South Africa has a three-tier local government system—provinces (or regions), which consist of district municipalities (or districts), which consist of local municipalities.

2.4 Methodology

2.4.1 Multivariate Probit (MVP) Model

The MVP model is used because it can simultaneously capture the influence of a set of explanatory variables on each of the different WCPs while allowing for the potential correlation between unobserved disturbances. Through these correlations, the possibility of whether the different WCPs are complements (positive correlation) or substitutes (negative correlation) is determined (Belderbos et al., 2004). Following Teklewold et al. (2013a), the observed outcome of the adoption of these WCPs follows a random utility formulation. A farmer is more likely to adopt a particular WCP if the benefits of its adoption are higher than those of its non-adoption. Consider the case where the i^{th} farmer ($i = 1, \dots, N$) faces the decision of whether to adopt or not to adopt the j^{th} WCP on their plot of farm f ($f = 1, \dots, F$). If U_0 represents the utility to the farmer when no adoption is made, and U_j the utility of adopting the j^{th} WCP ($j = me, ct, cc, mu, in, dt$), denoting the choice of more efficient performing irrigation methods (*me*), conservation tillage (*ct*), cover cropping (*cc*), mulching (*mu*), intercropping (*in*), and growing drought-tolerant crops (*dt*), then the i^{th} farmer decides to adopt the j^{th} conservation practice if $Y_{ifj}^* = U_j^* - U_0 > 0$. The net benefit (Y_{ifj}^*) that the farmer derives from the j^{th} WCP is a latent variable that is influenced by observed characteristics of the farmer, the farm, and other factors that affect the farmer's adoption decisions. The MVP model is thus specified as follows:

$$Y_{ifj}^* = X_{if}'\beta_j + \varepsilon_{if} \quad (j = me, ct, cc, mu, in, dt) \quad (2.1)$$

where X_{if} denotes the observed characteristics of the farmer, the farm, and other factors that influence the farmer's adoption decisions, β_j is a vector of parameters to be estimated, and ε_{if} is the unobserved characteristics. Given the latent nature of Y_{ifj}^* , the estimations are based on observable binary discrete variables Y_{ifj} , which indicate whether or not a farmer adopts some particular WCPs. Using the indicator function, the unobserved preferences in equation (2.1) translate into the observed binary outcome for each WCP choice as follows:

$$Y_{ifj} = \begin{cases} 1 & \text{if } y_{ifj}^* > 0 \\ 0 & \text{if } y_{ifj}^* \leq 0 \end{cases} \quad (j = me, ct, cc, mu, in, dt) \quad (2.2)$$

If the adoptions of the WCPs are assumed to be interdependent or if the adoption of several WCPs is possible, the error terms in equation (2.1) jointly follow a multivariate normal (MVN)

distribution with a zero conditional mean and variance normalized to unity (for identification of parameters). That is, $(u_{me}, u_{ct}, u_{cc}, u_{mu}, u_{in}, u_{dt}) \sim MVN(0, \psi)$ and the symmetric covariance matrix ψ is given by:

$$\psi = \begin{bmatrix} 1 & & & & & \\ \rho_{ctme} & 1 & & & & \\ \rho_{ccme} & \rho_{ccct} & 1 & & & \\ \rho_{mume} & \rho_{muct} & \rho_{mucc} & 1 & & \\ \rho_{inme} & \rho_{inct} & \rho_{incc} & \rho_{inmu} & 1 & \\ \rho_{atme} & \rho_{dtct} & \rho_{dtcc} & \rho_{atmu} & \rho_{atin} & 1 \end{bmatrix} \quad (2.3)$$

where ρ is the pairwise correlation coefficient of the error terms of any two potential WCPs. Therefore, the off-diagonal elements in the covariance matrix represent the unobserved correlation among the stochastic components of the different types of WCPs. This specification with non-zero off-diagonal elements allow for correlation across the error terms of several latent equations. If these correlations in the covariance matrix are non-zero, it justifies the use of the MVP instead of a univariate probit model for each individual WCP. These assumptions imply that equation (2.2) provides an MVP model that jointly represents decisions to adopt particular WCPs or not. The six WCPs enter the MVP model as dependent variables.

2.4.2 Ordered Probit Model (OPM)

The OPM is estimated to gauge the intensity of adoption of WCPs among farmers. The intensity of adoption is defined as the number of WCPs adopted on a farm as the dependent variable. It takes values from 0 to 6 (where 0 is the non-adoption of any WCP, 1 means a farmer adopts one WCP, 2 means a farmer adopts two WCPs, and so on). Defining the intensity of adoption as the number of WCPs adopted implies that a Poisson regression model could have been used since the dependent variable—the intensity of adoption—is a count variable. However, the Poisson model's assumption that the probability of adopting any of the WCPs is the same contradicts the assumption of interdependence among the WCPs. This is because the probability of adopting the first WCP might differ from the probability of adopting the second WCP, and so on, since it is believed that with the adoption of the first WCP, the farmer gains some information that influences the adoption of other WCPs, hence the use of the OPM. The OPM is specified as follows:

$$y^* = x'\beta + \varepsilon \quad (2.4)$$

where β is a vector of parameters to be estimated; y^* is unobserved, but the relationship between y^* and the observed variable y is:

$$y = \begin{cases} 0 & \text{if } y^* \leq 0 \\ 1 & \text{if } 0 < y^* \leq \gamma_1, \\ 2 & \text{if } \gamma_1 < y^* \leq \gamma_2 \\ \vdots & \\ K & \text{if } \gamma_{K-1} < y^*. \end{cases} \quad (2.5)$$

where γ s are unknown parameters to be estimated. Because the coefficients of the OPM are less informative¹³, the marginal effects of each outcome (see Greene and Hensher, 2008, for details) are rather estimated. Assuming that ε follows a normal distribution with zero mean and unit variance, the probability of each outcome is then expressed as follows:

$$\begin{aligned} \Pr(y = 0|x) &= \Theta(-x'\beta) \\ \Pr(y = 1|x) &= \Theta(\gamma_1 - x'\beta) - \Theta(-x'\beta) \\ \Pr(y = 2|x) &= \Theta(\gamma_2 - x'\beta) - \Theta(\gamma_1 - x'\beta) \\ &\vdots \\ \Pr(y = K|x) &= 1 - \Theta(\gamma_{K-1} - x'\beta) \end{aligned} \quad (2.6)$$

where $\Theta(\cdot)$ is the standard normal cumulative distribution function. Both parameters γ and β are estimated by maximum likelihood estimation.

The log-likelihood function is specified as follows:

$$\log \mathcal{L} = \sum_{i=1}^N \sum_{\omega=1}^I \ln (\Theta(\gamma_i - x'\beta) - \Theta(\gamma_{i-1} - x'\beta)) \quad (2.7)$$

¹³ The coefficients in an ordered choice model, in isolation, provide almost no useful information about the phenomenon under study. There is no natural conditional mean function in the model. The outcome variable, y , is merely a label for the unordered, non-quantitative outcomes. As such, there is no conditional mean function, $E[y|x]$, to analyze (Greene and Hensher, 2008). A moment's inspection shows that neither the sign nor the magnitude of the coefficient is informative, so the direct interpretation of the coefficients is fundamentally ambiguous. (A counterpart result for a dummy variable in the model would be obtained by using a difference of probabilities, rather than a derivative). Suppose D is a dummy variable in the model (such as Married) and γ is the coefficient of D . The effect of a change in D from 0 to 1, with all other variables held at the values of interest (perhaps their means), is measured using $\Delta_j(D) = [F(\mu_j - \beta'x_i + \gamma) - F(\mu_{j-1} - \beta'x_i + \gamma)] - [F(\mu_j - \beta'x_i) - F(\mu_{j-1} - \beta'x_i)]$. The implication of the result is that the effect of a change in one of the variables in the model depends on all the model parameters, the data, and which probability (cell) is of interest. Thus, neither the signs nor the magnitudes of the coefficients are directly interpretable in the ordered choice model (Greene and Hensher, 2008).

2.4.3 Variables and Justification

2.4.3.1 Dependent Variables

Six WCPs are used as dependent variables in the MVP model. First, more efficient performance irrigation techniques (MEPIDs) involve the use of advanced water conserving/saving methods, such as drip and sprinkler irrigations. In drip irrigation, water is conveyed from the source and delivered drop by drop, at or near the root zone of plants, where it is most needed (Dasberg and Or, 1999). This method enhances water-use efficiency by reducing or eliminating water loss caused by excess deep percolation, evaporation, and runoff. Its field water-use efficiency is about 90% (Howell, 2003). Additionally, it increases fertilizer-use efficiency (fertigation), reduces labor costs, improves disease and pest control, and is suitable for undulating sloped lands (Michael, 2008). With sprinkler irrigation, water is applied to crops from overhead by high-pressure sprinklers (movable or stationary) that simulate natural rainfall. This method has a field water use efficiency of about 70–80% (Dasberg and Or, 1999).

Second, conservation tillage (minimum tillage and/or no tillage) improves resilience to climatic change adaptation through a shift in tillage practices from repetitive annual tillage to minimal or zero tillage practices. The method deliberately leaves at least 30% of the previous crop residue on the soil surface to protect the soil from extreme heat events, reduce surface runoff, and improve crop productivity through increased water and nutrient retention (Clements et al., 2011). The method also saves fuel, labor and machinery costs, improves soil organic carbon, and increases fertilizer-use efficiency (Clements et al., 2011; Recha et al., 2014).

Third, cover crops are close-growing crops that are used primarily to slow erosion, improve soil health and infiltration, and smother weeds, among others (Soil Science Society of America [SSSA], 2008). It decreases evaporative losses through a mulching effect, both after cover crop termination and during growth (Basche et al., 2014).

Fourth, intercropping is the practice where two or more crop species are grown simultaneously on the same field with definite or alternate-row pattern types (Willey, 1990). The method provides better coverage for the soil surface, enhances light interception, reduces the direct impact of raindrops, protects the soil from erosion, and decreases water evaporation (Mobasser, Vazirimehr, and Rigi, 2014). In addition, agroforestry is classified as a type of intercropping synonymous with polyculture, following Geno and Geno (2001). In agroforestry, woody

perennials are integrated spatially or temporally with crops and/or animals on the same land management unit (Recha et al., 2014). The trees reduce the direct impact of raindrops and sunlight and protect the soil from erosion. The leaf litter acts as a protective layer over the soil, decreasing evaporative losses and improving soil water storage capacity (Clements et al., 2011; Recha et al., 2014).

Fifth, mulching is the process of spreading organic or inorganic materials to cover the soil surface to protect it from erosion, reduce evaporation, and thereby conserve soil moisture (Govindappa and Seenappa, 2015).

Finally, growing drought-tolerant crops that can endure water stress and survive periods of drought (Blum, 2005) is another way farmers can cope with the effects of DWSs.

In all, farmers were required to provide information on their adoption or non-adoption of thirteen (13) WCPs (drip irrigation, sprinkler irrigation, conservation tillage, deficit irrigation, irrigation scheduling, agroforestry, stone bunds, crop rotation, cover cropping, intercropping, drought-tolerant cropping, mulching, and rainwater harvesting) in the past three years. A picture album of these practices was given to farmers to facilitate their understanding. However, as an additional requirement during the interviews, enumerators had to inspect the farms of farmers to ascertain whether these practices mentioned by farmers were actually being practiced or adopted and the number of them that were being adopted. It was observed that a number of these practices were being used together. It was at the estimation phase, however, that it was noticed that the six practices used in this chapter were common practices preferred amongst farmers. Accordingly, these six WCPs were used in the chapter.

2.4.3.2 Explanatory Variables

Economic theory and the empirical literature on the adoption of agricultural technology (Kassie et al., 2015; Teklewold et al., 2013b) provided the basis for selecting the explanatory variables described below for the empirical models of this chapter. The first set of these variables is the farmer's characteristics. It includes the gender of the farmer, age, education, spousal education, farming experience, farm ownership, farm and off-farm incomes, farmer's membership in an association, and household size of the farmer.

Gender of the farmer shows that males are more likely to adopt agricultural technologies than their female counterparts (Obisesan, 2014). In sub-Saharan Africa, due to socio-cultural values and norms, males—mostly as the head of the household and primary decision-maker—are known to have more access to and control over vital production resources than women (Mignouna et al., 2011). Given this, gender of the farmer can have a positive or negative influence on the adoption of WCPs.

Age is found to either influence the adoption of agricultural technologies positively (Kariyasa and Dewi, 2013; Mignouna et al., 2011) or negatively (Mauceri et al., 2007). Thus, age is expected to exert a positive or negative influence on the adoption of some of the WCPs.

Educated farmers are more likely to be aware of and better appropriators of new technologies (Ndiritu, Kassie, and Shiferaw, 2014). Therefore, education is perceived to influence the adoption of WCPs positively. However, the education of the farmer may not be enough, as the education of the farmer's spouse is also thought to be an important determinant in the adoption of agricultural innovations. Thus, spousal education is also expected to exert a positive influence on the adoption of some of the WCPs.

Farming experience influences farmers' adoption positively. According to Alam (2015), the greater the experience, the more likely farmers are to adopt alternative adaptation strategies. Therefore, farming experience is expected to positively influence the adoption of WCPs.

Farm ownership increases the assurance of future access to the return on investments (Kassie et al., 2009). Therefore, farm owners are perceived to be greater adopters of WCPs than tenants.

Further, on farm income, Gebregziabher et al. (2014) asserts that farmers with limited incomes are reluctant to adopt unfamiliar technologies due to the risks of possible low crop yields. Given this, farmers with adequate farm income are expected to be more adopters of modern technologies than those with inadequate farm income. Also, off-farm income is known to exhibit a positive influence on farmers' adoption behaviour. It provides farmers with an additional source of critical liquid capital needed to stimulate adoption and purchase productivity-enhancing inputs (Diirro, 2013). However, this income may also exert a negative influence on agricultural adoptions. According to Namara, Nagar, and Upadhyay (2007), the pursuit of off-farm income may undermine the adoption of modern technology by farmers,

especially if it becomes their main source of livelihood. Therefore, off-farm income is perceived to be positively or negatively associated with the adoption of some of the WCPs.

A farmer's membership in an association or a cooperative engenders social networking, through which farmers can obtain information about new technologies, which tends to enhance adoption rates (Bandiera and Rasul, 2006; Mariano, Villano, and Fleming, 2012). However, social effects can be negative when networks are very large, perhaps due to strategic delays (Bouma, Bulte, and Van Soest, 2008)—waiting and adopting only if one is certain about the new technology's higher returns (Dong and Saha, 1998). This variable is expected to exert a positive or negative influence on the adoption of some of the WCPs.

Household size (measured as the number of people in a household) is often used to depict labor endowment (Kassie et al., 2009; Ndiritu et al., 2014). The larger the household, the higher the availability of labor. This makes the adoption of labor-intensive technologies possible. However, some studies report a negative relationship between this variable and the adoption behaviour of farmers (Amsalu and DeGraaff, 2007; Belachew, Mekuria, and Nachimuthu, 2020). Therefore, household size is expected to have a positive or negative influence on the adoption of some of the WCPs.

The second group of explanatory variables is the farm characteristics, which comprise farm size, diversified farming, distance to market, location of the farm, source of water, proximity to water, and secured land rights, among other factors. Farm size is used to depict the impact of wealth (assets) on the adoption decision process (Abdulai et al., 2011). Farmers with larger farms could have greater wealth (assets) to stimulate the adoption of WCPs positively (Berhanu et al., 2016) compared to those with smaller farms. However, farm size may be negative because not all agricultural technologies are feasible on large or small farms. Thus, farm size is expected to have a positive or negative influence on the adoption of some of the WCPs.

Diversifying production increases the likelihood of adopting integrated irrigation technologies (He, Cao, and Li, 2007). However, where production is highly specialized, it can lead to a low probability of adoption, as farmers are less likely to have the ability to withstand the risks arising from the adoption (Zhang et al., 2019). This variable is perceived to have a positive influence on the adoption of some of the WCPs.

Distance to the market is associated with the transaction cost of purchasing inputs and transporting farm produce to the market. It can influence the availability of information on new technologies and enhance adoption (Kassie et al., 2013). Mariano et al. (2012) noted that a greater distance between the farm and the nearest market indicates poor access, which constrains adoption. Thus, the adoption of WCPs is expected to increase with proximity to the market, as emphasized by Sarker et al. (2021), among others.

In addition, the location of the farm (upstream or downstream) is important in determining farmers' adoption of WCPs. Upstream farmers have better access to water resources compared to downstream farmers in terms of water availability, quality, and timing (Chuchird, Sasaki, and Abe, 2017). Given that downstream farms are the most adversely affected by water shortages, it is expected that downstream farmers would be greater adopters of WCPs.

The source of water (surface or groundwater) significantly influences the adoption of water-saving technologies. Farmers who exclusively use groundwater are more likely to adopt MEPIDs (Alam, 2015; Caswell and Zilberman, 1985). This variable is expected to have a positive influence on the adoption of some of the WCPs in this chapter.

Proximity to water shows that a greater distance from the water source means a lower likelihood of the adoption of some WCPs (Sithole, Lagat, and Masuku, 2014). Therefore, this variable is expected to exert a positive influence on the adoption of some of the WCPs.

Farmers with secured land rights were likely to take up adaptation strategies, particularly when they pertained to long-term investment—capital and maintenance (Deressa et al., 2009). Therefore, this variable is perceived to have a positive influence on the adoption of some of the WCPs.

The third group is the crop choice characteristics. It comprises the production of vegetables, maize, fruits, spices, and beans, among others. Some of these crops require the adoption of integrated technologies. Therefore, crop choice is expected to exert positive influences on the adoption of some of the WCPs.

The fourth group is the cost characteristic, which comprises the perceived cost of implementing WCPs. Farmers who perceive the incremental net benefits of modern technology to exceed its

cost would adopt it (Bandiera and Rasul, 2006), irrespective of the cost. Therefore, this variable is anticipated to have a negative influence on the adoption of some of the WCPs.

The fifth group is the environmental factors, which comprise drought experience and the perception of future droughts getting worse. Farmers who either have experienced drought or perceive droughts getting worse are more likely to adopt WCPs. This is in accordance with the literature's assertion that technologies that save water are more likely to be adopted when water resources are scarce because of droughts (Caswell and Zilberman, 1986).

The last set is the institutional factors, which include extension services, access to credit, and market access. Most farmers access information on new technologies through contact with extension service officers. While some studies noted that access to extension services positively influenced adoption (Damtew, Husen, and Demeku, 2015), others, such as Belachew et al. (2020) and Berhanu et al. (2016), reported a negative relationship between this variable and the adoption of soil and water conservation (SWC) practices. Therefore, this variable is expected to have a positive or negative influence on the adoption of some of the WCPs.

Access to credit helps to alleviate liquidity constraints and thus enhances access to complementary technical, mechanical, and capital inputs (Deressa et al., 2009). It thus facilitates the adoption of improved production technologies (Abdulai et al., 2011). As a result, credit access is expected to influence WCPs adoption positively.

Market access, measured as whether a farmer sells to some main customers in the country, like Tiger Brands Limited (a major distributor of food products in 22 African countries and one of the top 40 companies on the Johannesburg Stock Exchange) or the major supermarkets, is an important determinant of modern agricultural adoptions (Feder, Just, and Zilberman, 1985). Lack of market access is a barrier to market participation by resource-poor smallholders and is responsible for significant market failures in developing countries (Sadoulet, Janvry, and Wehrheim, 1996). Market access is expected to have a positive influence on the adoption of some of the WCPs.

A summary description of the variables and their expected signs is shown in Table 2.2.

Table 2. 2: Explanatory Variables, Description, and Expected Signs

Variable	Type	Description	Expected sign
<i>Farmer's characteristics</i>			
Gender (Female = 1)	D	1 = female, and 0 otherwise.	+/-
Age	C	Age of the farmer.	+/-
Age squared	C	Age squared.	+/-
Education	D	1 = literate farmer, and 0 otherwise.	+
Spousal education	Ca	Educational status of farmer's spouse: 0 = spouse is non-literate, 1 = spouse is literate, and 2 = has no spouse or is single.	+
Farm experience	C	Years of farming	+
Farm ownership	D	1 = land owned by farmer, and 0 otherwise.	+
Farm income	D	1 = total annual farm income is greater than USD 733 ¹⁴ , and 0 otherwise.	+
Off-farm income	D	1 = farmer has off-farm income, and 0 otherwise.	+/-
Member cooperative	D	1 = member of a cooperative, and 0 otherwise.	+/-
Household size	C	Total number of people in the household.	+/-
<i>Farm characteristics</i>			
Farm size	C	Total farm size cultivated in hectares.	+/-
Diversified farming	D	1 = farmer grows different crops, and 0 otherwise.	+
Distance to market	C	Distance to the nearest market or urban center.	+
Location of farm	D	1 = farm is upstream, and 0 otherwise.	+
Source of water	D	1 = surface water is main source for farming, and 0 otherwise.	+
Proximity to water	D	1 = ≤ 1 kilometer from source, and 0 otherwise.	+
Secured land rights	D	1 = farmer has secured rights, and 0 otherwise.	+

¹⁴ This USD 733 [11, 000 South African Rands (ZAR) converted to United States Dollars (USD) 733.33 using the exchange rate 1 USD = 15 ZAR, prevailing during the survey in April 2021] annual farm income in the study area is in accordance with Statistics South Africa (2022) and De Cock et al. (2013), who report that total farm income per month of smallholder farmers in the Limpopo Province may range from USD 14 (minimum) to about USD 2,334 (maximum). The data for the income variable was initially solicited based on income groups. However, these income groups did not behave as expected in the estimations. The variable was thus converted into a dummy variable, where the lower bound of the modal class became the basis for sectioning the data. The USD 733 was the lower bound of the modal class. Accordingly, farmers earning annual farm incomes less than this threshold (USD 733) were labelled '0' (farmers with annual farm income less than USD 733), whereas those earning annual farm incomes greater than this threshold were labelled '1' (farmers with annual farm income more than USD 733). This was done because, in statistical theory, the mean (average) and the median are mostly located in the modal class for data that follows a normal distribution.

Table 2.2: (continued)

Variable	Type	Description	Expected sign
<i>Crop choice characteristics</i>			
Vegetables	D	1 = farmer allots largest land share to vegetables, and 0 otherwise.	+
Maize	D	1 = farmer allots largest land share to maize, and 0 otherwise.	+
Fruits	D	1 = farmer allots largest land share to fruits, and 0 otherwise.	+
Spices	D	1 = farmer allots largest land share to spices, and 0 otherwise.	+
Beans	D	1 = farmer allots largest land share to beans, and 0 otherwise	+
<i>Cost characteristics</i>			
Perceived cost	D	1 = perceives cost of implementing WCPs as expensive, and 0 otherwise.	-
<i>Environmental factors</i>			
Drought experience	D	1 = experienced droughts in the last 5 years, and 0 otherwise.	+/-
Perception of droughts	D	1 = perceives future droughts to get worse, and 0 otherwise.	+/-
<i>Institutional factors</i>			
Extension services	D	1 = access to extension services, and 0 otherwise.	+/-
Access to credit	D	1 = farmer has access to credit, and 0 otherwise.	+
Market access	D	1 = market access (sells to main customers and supermarkets), and 0 otherwise.	+

Note: D, C and Ca mean “dummy”, “continuous,” and “categorical” variables.

2.4.4 Sampling and Data

A two-stage sampling approach involving purposive and random sampling procedures were used in selecting the study area and the farmers. In the first stage, Folovhodwe and Tshiombo farming communities in the Musina and Thulamela local municipalities, respectively, were purposively selected not only because these are agrarian hubs in the Vhembe District of the Limpopo Province, but also because the two farming communities are located near important tributaries of the Limpopo River and house major Irrigation Schemes (the Nwanedi and Tshiombo Irrigation schemes), the frequent droughts in the area, the imposition of water use restrictions, how farmers are responding to water scarcity in the area as well as having a large number of documented and undocumented farmers and well organized farmer associations that are readily accessible. According to Statistics South Africa (2022), the Vhembe District has a total agricultural household population of 74,073. In the second stage, a simple random

sampling technique was applied to select farmers from a population of both documented and undocumented farmers on the farming blocks in the study area. Each farmer in the research area, whether documented or undocumented, had an equal chance of being part of the sample. In coordination with the farmers' leaders and extension services officers in the area, farmers were informed of the impending interviews for the research. The data was collected with the aid of structured questionnaires. Enumerators conducted a one-on-one interview with the farmers at their premises.

The data collection exercise spanned one month, between March and April 2021. A total of 559 questionnaires were used in the survey. However, at the data entry stage, four (4) were rejected because of inconsistent and incomplete information. Thus, a total of 555 valid questionnaires were retained. This high rate of questionnaires returned was a result of the training given to the enumerators and the thorough checks put in place to scrutinize each questionnaire before accepting it each day. In these checks, if any errors or incomplete fills were detected, the enumerators were made to go back to the respective farmer(s) to complete the questionnaire before it was received. The response rate of the survey was then compared to the minimum sample size required for adequate power analysis, following Cochran (1963) and Yamane (1967).

In Equation 2.8, Cochran (1963) assumes there is a large population, but the variability in the proportion that will adopt a practice is unknown, just as in the case of this chapter. Therefore, assuming a $p = 0.5$ (maximum variability), a 95% confidence level and $\pm 5\%$ precision, the resulting sample size required is given as

$$n_0 = \frac{Z^2 pq}{e^2} = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 385 \text{ farmers} \quad (2.8)$$

where n_0 is the sample size, Z^2 is the abscissa of the normal curve that cuts off an area α at the tails ($1 - \alpha$ equals the desired confidence level, e.g., 95%), e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population and q is $1 - p$. The value for Z is found in the statistical table which contains the area under the normal curve.

Similarly, in Equation 2.9, the sample size is calculated following Yamane (1967) and using the population of 74,073, which is number of agricultural households in the Vhembe District Municipality.

$$n = \frac{N}{1 + N(e)^2} = \frac{74073}{1 + 74073(0.05)^2} = 398 \text{ farmers} \quad (2.9)$$

where n is the sample size, N is the population size and e is the level of precision.

Furthermore, if it is even assumed that both documented and undocumented farmers total about 90,000, which is unlikely because it is estimated that in the entire Limpopo Province there were about 273,000 smallholder farmers (Statistics South Africa, 2002), Accordingly, this estimation yields a representative sample of 398 farmers.

$$n = \frac{N}{1 + N(e)^2} = \frac{90000}{1 + 90000(0.05)^2} = 398 \text{ farmers} \quad (2.10)$$

Consequently, based on these estimations, financial and time constraints a sample of 555 farmers was decided. This sample passed the minimum sample size requirements for adequate power analysis of Cochran (1963) and Yamane (1967). This sample is thus, representative of farmers in the Vhembe District Municipality and is also good for power analysis.

Prior to finalizing the questionnaires for the face-to-face engagements with farmers, two focus group discussions (FGDs) were conducted—one with farmers and extension service officers, and the other with stakeholders and industry experts from the Department of Agriculture, Forestry, and Fisheries (DAFF) and the DeBeers Group (the world's largest producer and distributor of diamonds, but with a special interest in the water quality and quality farming practices in the LRB). The purpose of the research was discussed, and experts' opinions were sought on how to make the questionnaires more relevant and appealing to farmers.

2.4.5 Descriptive Statistics

The descriptive statistics in Table 2.3 show that 45% of farmers used MEPIDs, 30% used conservation tillage, and 81% practiced cover cropping, while 85%, 43%, and 54% used intercropping, mulching, and drought-tolerant crops, respectively. For the intensity of adoption, less than 1% of the sample were non-adopters of any form of WCP, whereas those adopting 1, 2, 3, 4, 5, and 6 WCPs constituted 4.7%, 17.7%, 26%, 29%, 18%, and 3.9%, respectively. With respect to the explanatory variables, females constituted 55% of the sample.

This is not surprising, as the 2011 population census shows that women constituted 54.4% of the population of Folovhodwe and 53.7% in Tshiombo (Census, 2011).

Table 2. 3: Descriptive Statistics of both Dependent and Explanatory variables

Variables	% Sample (N=555)	Min	Max	Mean	Std D.
Dependent variables					
MEPIDs		0	1	0.553	0.497
<i>No</i>	45				
<i>Yes</i>	55				
Conservation tillage		0	1	0.297	0.457
<i>No</i>	70				
<i>Yes</i>	30				
Cover cropping		0	1	0.813	0.391
<i>No</i>	19				
<i>Yes</i>	81				
Intercropping		0	1	0.852	0.355
<i>No</i>	15				
<i>Yes</i>	85				
Mulching (MU)		0	1	0.427	0.495
<i>No</i>	57				
<i>Yes</i>	43				
Drought-tolerant crops (DTCs)		0	1	0.541	0.498
<i>No</i>	46				
<i>Yes</i>	54				
Total number of WCPs adopted		0	6	3.482	1.245
<i>Does not adopt WCP</i>	0				
Adopts 1 WCP	5				
Adopts 2 WCPs	18				
Adopts 3 WCPs	26				
Adopts 4 WCPs	29				
Adopts 5 WCPs	18				
Adopts 6 WCPs	4				
Explanatory variables					
Gender		0	1	0.553	0.497
<i>Male</i>	45				
<i>Female</i>	55				
Age		20	95	50.98	15.11
Age squared		400	9025	2826.9	1620.3
Education		0	1	0.940	0.237
<i>Non literate</i>	6				
<i>literate</i>	94				
Spousal education		0	3	3.304	1.360
<i>Non literate spouse</i>	6				
<i>Literate spouse</i>	84				
<i>Without spouse</i>	10				

Table 2.3: (Continued)

Variables	% Sample (N=555)	Min	Max	Mean	Std D.
Explanatory variables					
Experience		1	55	16.22	9.88
Farm ownership		0	1	0.929	0.256
<i>Leased/rented/government land</i>	7				
Owned by the farmer or family	93				
Farm size		0.15	27	3.262	3.927
Vegetables		0	1	0.811	0.392
<i>No</i>	19				
Yes	81				
Maize		0	1	0.544	0.498
<i>No</i>	46				
Yes	54				
Fruits		0	1	0.117	0.321
<i>No</i>	88				
Yes	12				
Spices		0	1	0.306	0.461
<i>No</i>	69				
Yes	31				
Beans		0	1	0.241	0.428
<i>No</i>	76				
Yes	24				
Diversification of farm		0	1	1.376	0.485
<i>Specialized farming</i>	7				
Diversified farming	93				
Market access		0	1	0.807	0.395
<i>Had no access to markets</i>	19				
Had access to markets	81				
Distance to market		10	97	55.70	27.42
Location of farm		1	2	1.376	0.485
<i>Upstream</i>	62				
Downstream	38				
Source of water		1	2	1.104	0.306
<i>Surface</i>	90				
Underground	10				
Proximity to water		1	2	1.259	0.438
Less than a kilometer	74				
More than a kilometer	26				
Farm income		0	1	0.800	0.400
<i>Annual farm income less than USD 733</i>	20				
Annual farm income more than USD 733	80				
Off-farm income		0	1	0.313	0.464
<i>No off-farm income</i>	69				
Had off-farm income	31				
Household size		1	16	6.281	2.549

Table 2.3: (Continued)

Variables	% Sample (N=555)	Min	Max	Mean	Std D.
Explanatory variables					
Member of a cooperative		0	1	0.622	0.485
<i>No membership in a cooperative</i>	38				
Membership in a cooperative	62				
Drought experience		0	1	0.995	0.073
<i>No</i>	1				
Yes	99				
Perception future droughts		0	1	0.541	0.498
<i>Don't know</i>	46				
Would get worse	54				
Perceived cost of WCPs		0	1	0.657	0.474
<i>Not costly</i>	34				
Very costly	66				
Access to extension services		0	1	0.969	0.172
<i>No</i>	3				
Yes	97				
Access to credit		0	1	0.205	0.404
<i>No</i>	79				
Yes	21				
Secured land rights		0	1	0.756	0.429
<i>No</i>	24				
Yes	76				
Community of farmer ¹⁵		1	2	1.458	0.498
<i>Folovhodwe</i>	54				
Tshiombo	46				

Source: Authors' estimations based on the survey data (April 2021).

Note: USD is the United States dollar.

The average age was 51 years. With regards to education, 94% of the sample had received at least six years or more of formal education; 84% of spouses were literate; and 10% of the sample were without spouses. The average farming experience was 16 years. Farmers who cultivated their own farmlands or family lands constituted 93%. The average farm size was 3.27 hectares. On crop choice, 81% of farmers grew vegetables (tomatoes, green chillies, spinach, cabbage, okra, green beans, lettuce, eggplants, and carrots, among others). Some 54% grew maize, while 12% grew fruits (mangoes, oranges, and bananas, among others). Some 31% grew spices (garlic, ginger, and hot chillies, among others), while 24% grew legumes (especially beans).

¹⁵ This variable was however, not used in the MVP and ordered probit models because of the objectives of this chapter. The variable was just for the purposes of providing descriptive statistics on the percentages of farmers in the respective farming communities—Folovhodwe and Tshiombo.

Furthermore, 93% of the sample had diversified farms, growing a mixture of the crops mentioned above. Of the sample, 81% had access to markets, supplying a few main customers. The mean distance to the nearest market was 56 kilometers. For location, 63% were upstream farmers, and 90% used surface-water sources for farming. For proximity to water, farmers less than a kilometer away from the water source constituted 74% of the sample. Farmers with an annual farm income greater than USD 733 (in April 2021) constituted 80% of the sample, while 69% had no off-farm income. The average household size was six members. Those with membership in cooperative associations constituted 62%. On drought experience, 99% affirmed that they had experienced some droughts in the last seven years, while 54% of farmers perceived future droughts to get worse. The cost of irrigation, especially drip and sprinkler irrigation, and mulching was perceived as high by 66% of farmers. Of the sample, 79% did not have access to credit, while 97% reported having access to extension services, and 76% had secured land rights to their farmlands. With respect to the community of the farmer, 54% of farmers lived in Folovhodwe, while 46% lived in Tshiombo.

These descriptive statistics, in most cases, matched well with those of the 2011 population census for the study area and even in some cases at the national level, thus indicating a fairly representative sample of farmers of the study area.

2.5 Results and Discussions

2.5.1 Results of the Multivariate Probit Model (MVP)

The results of the MVP model reported in Table 2.4 show, first, that the likelihood ratio test [$\chi^2(15) = 77.14$; $\text{prob} > \chi^2 = 0.0000$] rejects the null hypothesis that the covariance of the error terms across the equations are not correlated. This indicates that the pair-wise correlation coefficients across the error terms of the multiple decision equations are correlated. Second, the Wald test's [$\text{Wald } \chi^2(180) = 647.62$; $\text{Prob} > \chi^2 = 0.000$] rejection of the null hypothesis that all regression coefficients in each equation are jointly equal to zero shows that the MVP model fits the data well. These statistics justify the use of the MVP model in analyzing farmers' bundling of WCPs in the LRB instead of using the univariate models.

Table 2. 4: Results of the Multivariate Probit Regression

Variables	MEPIDs		Conservation tillage		Cover cropping		Intercropping		Mulching		Drought-tolerant crops	
	Coeff.	z	Coeff.	z	Coeff.	z	Coeff.	z	Coeff.	z	Coeff.	z
<i>Farmer's characteristics</i>												
Gender (Female = 1)	-0.041	0.31	0.027	0.22	0.189	1.21	0.077	0.48	-0.298**	2.30	0.119	0.93
Age	-0.007	0.25	0.054**	2.02	-0.075**	2.10	0.084***	2.67	-0.007	0.28	-0.017	0.67
Age squared	0.00004	0.14	-0.0005*	1.80	0.0007**	2.19	-0.0008***	2.56	-0.00002	0.08	0.0002	0.80
Education	0.613**	2.01	0.251	0.82	0.139	0.39	-0.651	1.42	0.428	1.44	0.122	0.42
Spousal education												
<i>Literate spouse</i>	-0.784***	2.74	-0.444*	1.67	-0.008	0.02	0.518	1.61	-0.763***	2.68	-0.236	0.86
<i>Without spouse</i>	-0.994***	2.80	-0.127	0.38	-0.400	0.95	0.584	1.44	-0.617*	1.73	-0.261	0.75
Farm experience	0.003	0.32	-0.010	1.14	0.002	0.19	0.002	0.14	0.013	1.40	-0.023**	2.46
Farm ownership	0.508**	2.02	0.649**	2.36	-0.578*	1.71	0.294	1.02	-0.014	0.05	0.233	0.94
Farm income	0.728***	4.24	-0.173	1.01	0.122	0.54	0.203	0.97	0.137	0.77	0.093	0.52
Off-farm income	0.422***	2.91	-0.380***	2.59	0.048	0.28	0.0001	0.01	0.163	1.11	-0.118	0.81
Member cooperative	0.134	0.86	-0.054	0.36	-0.635***	3.11	-0.276	1.33	-0.430***	2.76	-0.062	0.39
Household size	-0.006	0.22	-0.002	0.10	0.036	1.15	0.002	0.06	-0.014	0.55	0.055**	2.21
<i>Farm characteristics</i>												
Farm size	0.032	1.62	0.018	1.05	0.013	0.56	0.005	0.21	0.069***	3.45	-0.049***	2.71
Diversified farming	-0.382	1.44	0.199	0.74	1.675***	6.17	1.072***	4.10	-0.268	0.98	-0.251	0.98
Distance to market	0.018***	4.88	0.002	0.65	0.004	0.90	-0.004	1.01	0.024***	6.50	-0.004	1.03
Location of farm	-0.132	0.95	-0.315**	2.28	-0.247	1.54	-0.069	0.41	0.073	0.52	0.123	0.89
Source of water	1.079***	4.49	-0.057	0.27	-0.522**	2.39	-0.339	1.49	0.036	0.17	0.263	1.21
Proximity to water	0.088	0.52	0.295*	1.88	0.178	0.94	0.164	0.85	-0.165	1.00	0.269*	1.71
Secured land rights	0.675***	3.58	-0.246	1.31	0.138	0.64	0.500**	2.36	0.259	1.33	0.360*	1.91
<i>Crop choice characteristics</i>												
Vegetables	0.275	1.48	0.207	1.12	-0.065	0.30	0.332*	1.76	0.428**	2.11	0.207	1.13
Maize	0.052	0.37	-0.113	0.83	0.140	0.82	-0.482***	2.61	0.184	1.31	1.259***	8.87
Fruits	0.245	1.00	-0.205	1.21	0.332	0.98	0.797*	1.66	0.003	0.01	-0.470***	2.69
Spices	-0.769***	4.28	0.056	0.26	-0.336	1.56	0.546**	2.14	-0.355**	2.12	-0.244	1.02
Beans	-0.068	0.42	0.003	0.02	0.598***	2.62	0.061	0.29	0.134	0.85	-0.092	0.58
<i>Cost characteristics</i>												
Perceived cost	0.227	1.61	-0.303**	2.25	0.409**	2.48	-0.619***	3.18	0.049	0.36	-0.309**	2.22

Table 2.4: (Continued)

Variables	MEPIDs		Conservation tillage		Cover cropping		Intercropping		Mulching		Drought-tolerant crops		
	Coeff.	z	Coeff.	z	Coeff.	z	Coeff.	z	Coeff.	z	Coeff.	z	
Environmental factors													
Drought experience	0.677	0.88	-1.015	1.18	1.938**	2.03	1.610	1.58	0.059	0.07	0.508	0.55	
Perception of droughts	-0.239	1.64	0.112	0.78	-0.522***	2.94	0.191	1.04	0.229	1.58	-0.114	0.77	
Institutional factors													
Extension services	0.705	1.63	0.493	1.15	0.556	1.17	0.408	1.06	0.663	1.53	-0.406	1.04	
Access to credit	0.162	1.22	-0.135	1.03	0.128	0.80	-0.367**	2.29	0.069	0.52	-0.268**	2.01	
Market access	0.378**	2.21	-0.078	0.46	0.090	0.44	-0.223	1.02	-0.181	1.04	-0.211	1.22	
Constant	-4.752***	3.61	-1.448	1.08	-0.858	0.56	-3.578**	2.34	-1.559	1.20	-0.587	0.43	
Interrelationships among WCPs													
Correlations				Coefficient								 z-value 	
rho21	(Conservation tillage and MEPIDs)				0.095								1.26
rho31	(Cover cropping and MEPIDs)				0.208**								2.35
rho41	(Intercropping and MEPIDs)				0.254***								2.74
rho51	(Mulching and MEPIDs)				0.158**								2.06
rho61	(Drought-tolerant crops and MEPIDs)				0.038								0.49
rho32	(Cover cropping and conservation tillage)				0.035								0.38
rho42	(Intercropping and conservation tillage)				0.673***								8.62
rho52	(Mulching and conservation tillage)				-0.073								0.97
rho62	(Drought-tolerant crops and conservation tillage)				0.038								0.51
rho43	(Intercropping and cover cropping)				0.311 ***								3.34
rho53	(Mulching and cover cropping)				0.055								0.61
rho63	(Drought-tolerant crops and cover cropping)				0.013								0.15
rho54	(Mulching and intercropping)				-0.032								0.36
rho64	(Drought-tolerant crops and intercropping)				0.165 **								2.02
rho65	(Drought-tolerant crops and mulching)				-0.012								0.15
Log likelihood											-1510.31		
Wald chi ² (180)											647.62		
Prob > chi ²											0.0000		
Number of observations											555		

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0
chi²(15) = 77.1373 Prob > chi² = 0.0000

Note: ***, **, and * denote 1%, 5%, and 10% significance levels respectively

2.5.1.1 Interrelationships among WCPs

The pair-wise correlation coefficients across the residuals of the MVP model that indicate interdependence among the six WCPs show significant and positive associations among combinations, such as cover cropping and MEPIDs, intercropping and MEPIDs, mulching and MEPIDs, intercropping and conservation tillage, intercropping and cover cropping, and growing drought-tolerant crops and intercropping. This suggests that farmers adopt and use these practices together, confirming a significant bundling of these WCPs. This outcome is further confirmed by the summary statistics of the intensity of adoption in Table 2.3, where cumulatively 95% of farmers are bundling 2, 3, 4, 5, and 6 WCPs on their farms. However, the other pair-wise correlations are insignificant, even though most of them have the expected positive *a priori* signs.

2.5.1.2 Determinants of the Adoption of Multiple WCPs

The results show that gender influences the adoption of mulching negatively. That is, female farmers are less likely to adopt mulching than their male counterparts. Gender is, however, insignificant for the other WCPs. This result is anticipated, as gender inequality due to income, asset ownership (land title and tenure tend to be vested in men, either by legal conditions or by sociocultural norms), and the right to productive resources are linked to lower adoption rates by females (Ndiritu et al., 2014). These results are in accordance with Fisher et al. (2018), who found female-headed households to be low adopters of mulching. However, Mango et al. (2017) did not find gender to significantly influence the adoption of land and SWC technologies, including mulching, in their study.

Age is quadratic and statistically significant for conservation tillage, cover cropping, and intercropping. However, it is insignificant for the other WCPs. This result indicates, first, that the adoption of conservation tillage and intercropping increases with age at a decreasing rate until a turning point is reached at age $-\frac{0.054}{2(-0.0005)} = 54$ years for conservation tillage and at age $-\frac{0.084}{2(-0.0008)} = 53$ years for intercropping. This implies that the adoption of conservation tillage and intercropping increases among younger farmers until ages 54 and 53, respectively, after which (having become older farmers), their adoption decreases, all else being constant. This outcome, according to Mauceri et al. (2007), implies that as farmers grow older, there is an increase in risk aversion and a decreased interest in long-term investment in the farm, which,

therefore, decreases their adoption rates. Younger farmers, on the other hand, are typically less risk-averse and more willing to try new technologies.

Second, the adoption of cover cropping decreases with age at an increasing rate until a turning point is reached at $-\frac{-0.075}{2(0.0007)} = 54$ years. This indicates that the adoption of cover crops decreases with younger farmers until age 54, when its adoption increases with older farmers, all else constant. This is consistent with the literature's assertion that as farmers age, they gain knowledge and experience, making them better able to evaluate information and the benefits of technology than younger farmers (Kariyasa and Dewi, 2013; Mignouna et al., 2011). These results show the importance of modelling age as non-linear, as it signals that there is an age threshold for the adoption of these WCPs, which failing to acknowledge can bias the estimates of a study.

Literate farmers are more likely to adopt MEPIDs. However, this variable has no effect on the adoption of the other WCPs. This finding is consistent with the literature, which shows that literate farmers are better informed and more likely to adopt modern technologies (Abdulai et al., 2011; Zhang et al., 2019). On spousal education, farmers with literate spouses and those without spouses are less likely to adopt MEPIDs, mulching, and conservation tillage, all else being constant. This outcome is unexpected, as literate spouses are expected to help their partners make sound farm decisions and assist with resources to increase adoption. However, during the survey, it was observed that the decision to adopt WCPs was an isolated one and not part of the overall household decision-making process.

More experienced farmers are less likely to adopt drought-tolerant crops, all else being constant. However, the variable is insignificant for the other WCPs. This outcome is intriguing but not surprising. According to Kumar et al. (2020), the low adoption of drought-tolerant crops is because the technique has only recently been introduced and experienced farmers—compared to relatively less experienced farmers—are less likely to quickly switch to their adoption. In addition, during the survey, one reason adduced for the low adoption of drought-tolerant crops was that farmers wanted to avoid the seasonal financial obligations associated with having to buy drought-tolerant seeds every farming season. Even though drought-tolerant crops produce seeds, the seeds lose some of their drought-protection capabilities. Therefore, farmers are required not to save seeds from their harvest but to buy new seeds at the start of

every farming season. This, together with other factors such as high seed prices, suitable soil conditions, inadequate information, and the perceived attributes of different varieties of drought-tolerant crops, are the major barriers to the adoption of this practice (Fisher and Snapp, 2014).

In line with the literature's assertion that ownership of farms increases the assurance of future access to the return on investments (Kassie et al., 2009), farmers who cultivate their own farmlands are more likely to adopt MEPIDs and conservation tillage but are less likely to adopt cover cropping, all else being constant. This outcome underscores the important role that farm ownership plays in the adoption of WCPs in the LRB.

Consistent with the findings of Abegunde, Sibanda, and Obi (2019), farmers with an annual farm income greater than USD 733 are more likely to adopt MEPIDs, all else being constant. However, fluctuations in farm income can affect farm decisions and the ability to sustain operations, including the adoption of innovations (Mishra and Sandretto, 2002). An additional source of income from off-farm work may enable farmers to overcome credit constraints or fluctuations in farm income. It is, therefore, not surprising that farmers with off-farm activities are more likely to adopt MEPIDs but are less likely to adopt conservation tillage, all else being constant. These findings demonstrate the importance of farm and off-farm incomes in providing farmers with greater incentives to invest in WCPs.

Farmers with membership in a cooperative are less likely to adopt cover cropping and mulching, all else being constant. This result is not unexpected as explained earlier, social effects can be negative when networks are very large (Dong and Saha, 1998), and cover cropping and mulching are mostly feasible on small farms. Therefore, the low adoption of these practices suggests that most farmers have large farms, making these practices unsuitable.

Household size increases the probability of adopting drought-tolerant crops but does not influence the adoption of the other WCPs, all else being constant. The finding supports the notion that the likelihood of adopting some WCPs (especially drought-tolerant crops) rises as household labor becomes more abundant. For this practice, some amounts of labor are required for some management practices, including mulching and the removal of weeds and alien species that compete with drought-tolerant crops for water. It is, therefore, not surprising that household size increases the probability of adopting drought-tolerant crops.

Farm size increases the probability of adopting mulching but is negatively associated with the adoption of drought-tolerant crops. Farm size is insignificant for the other WCPs. This result is in line with Mugonola et al. (2013), who found farm size to increase the likelihood of adopting SWC technologies, including mulching, but contradicts Martey and Kuwornu (2021), who found farm size to be negatively associated with the use of mulching. On the other hand, farmers' reluctance to adopt drought-tolerant crops is a result of some of the reasons adduced above for the challenges that farmers face with respect to the adoption of this practice.

In accordance with expectations, farmers with diversified farms (growing multiple crops) are more likely to adopt cover cropping and intercropping compared to those with specialized farms (growing one crop). However, this variable is insignificant for the other WCPs. These results agree with Jensen, Johnston, and Olsen (2019) and He et al. (2007). This finding is consistent in practice, as farmers who grow different crops (diversified) can intercrop and/or grow cover crops to meet the different needs of the different crops, including complementing and compensating each other.

Distance to market influences the adoption of MEPIDs and mulching positively, but it does not influence the adoption of the other WCPs. This result indicates that most farmers are not constrained by distance to market, hence the greater adoption of MEPIDs and mulching. This finding is in line with Ersado, Amacher, and Alwang (2004), who report that distance to the market increases the adoption of SWCs. The results point to the importance of markets in promoting the adoption of WCPs.

With respect to the location of the farm, downstream farmers are less likely to adopt conservation tillage. This is not expected given that downstream farmers suffer water problems more than upstream farmers (Chuchird et al., 2017). This practice is expected to be an attractive option for downstream farmers to conserve water. However, a study by Mandiringana, Mabi, and Simalenga (2006) on the acceptance of conservation tillage in South Africa reported that the method's high labor requirements generally made it less attractive. Also, the special equipment required for the successful implementation of the method is generally not available to all farmers. These factors account for the low adoption of this method.

As reported by Alam (2015) and Caswell and Zilberman (1985), farmers who exclusively use groundwater are more likely to adopt MEPIDs but are less likely to adopt cover crops. The low

adoption of cover crops by groundwater users is surprising. However, it was observed that the types of cover crops grown in the study area (sweet potatoes, beans, pumpkin, and watermelons, among others) were not popular among groundwater users (10% of the sample). These groundwater users were mainly into fruits (largely bananas and grapes) and a few vegetable productions.

On proximity to a water source, farmers who are more than a kilometer away are more likely to adopt conservation tillage, all else being constant. Water poverty is more prevalent on farms more than a kilometer from the source compared to farms less than a kilometer away. A study of smallholder farmers by Maponya and Mpandeli (2012) in the Tshiombo Irrigation Scheme in Limpopo Province emphasized that farmers whose plots are far from the canal system suffer serious water access challenges and low crop yields. It is, therefore, not surprising that conservation tillage is a more attractive option for this category of farmers.

Farmers with secured rights to their farmlands are more likely to adopt MEPIDs, intercropping, and drought-tolerant crops, all else being constant. This result suggests that a sense of exclusive rights to their property motivates farmers to improve the land and adopt water management practices in both irrigated and rain-fed systems (Alam, 2015). Additionally, it encourages farmers to take up adaptation strategies that pertain to long-term investment—capital and maintenance (Deressa et al., 2009). This finding underscores the importance of secured land rights in motivating farmers' adoption of WCPs on their own farmlands rather than more so on rented (or borrowed) farmlands, possibly reflecting tenure insecurity and Marshallian inefficiency (Kassie et al., 2013; Teklewold et al., 2013a).

Consistent with expectations, farmers who produce vegetables are more likely to adopt intercropping and mulching, all else constant. Vegetable cultivation requires adequate cooling at the roots of the plants. This is mostly achieved through mulching. Additionally, intercropping was a common practice among these farmers. Evidence of pure vegetable intercropping systems such as spinach-garlic, tomatoes-lettuce, and eggplant-okra, among others, were observed during the survey. Studies such as Yildirim and Guvenç (2005) highlight intercropping in vegetables as an important sustainable farming practice that increases the productivity of vegetables and net income.

Maize farmers are less likely to adopt intercropping but more likely to adopt drought-tolerant crops. Generally, most maize farmers in the study area do not intercrop their fields. Also, given that maize and cowpea are the dominant drought-tolerant crops grown in South Africa, this finding is expected.

Fruit farming is positively associated with the adoption of intercropping but negatively associated with the adoption of drought-tolerant crops. Significant evidence of intercropping among fruit farmers was also observed during the survey exercise. The findings of Mossie et al. (2020) corroborate these results. However, the adoption of drought-tolerant crops was not evident among fruit farmers in the study area.

Spice farmers are less likely to adopt MEPIDs and mulching but are more likely to adopt intercropping. According to these farmers, they would prefer MEPIDs for their operations, but first, the cost of the drip irrigation method is currently a major constraint. Second, sprinklers—which behave like rain—beat down the flowers of their crops, especially tomatoes, chillies/peppers, and thus reduce or prevent yield. So, the cost of the drip method and the seemingly unsuitable sprinklers are the causes of this aversion. The low adoption of mulching is, however, surprising, as this is a major practice among spice farmers in the study area. During the survey, some farmers, especially those with farms over a hectare, expressed concerns about the method. They complained that it is not only expensive to apply but also very difficult to execute, as it requires a large amount of labor and mulch to be successful. Junge et al. (2009) confirmed that cover cropping and mulching were performed only on areas that were smaller than one hectare.

The probability of adopting cover crops increases with bean farmers. Given that one of the cover crops cultivated in the study area is beans, this finding is anticipated.

In accordance with the literature, if farmers perceive the incremental net benefits of an innovation to exceed its cost, then adoption would occur (Foster and Rosenzweig, 1995). Farmers who perceive the cost of implementing WCPs to be high are less likely to adopt conservation tillage, intercropping, and drought-tolerant crops but more likely to adopt cover cropping, all else being constant. The low adoption of conservation tillage, intercropping, and drought-tolerant crops with respect to the cost variable is expected. Various arguments have

been advanced for this effect. In addition, Wekesa et al. (2003) report the high cost of technology as a hindrance to adoption.

Farmers who, in the last seven years, have experienced one or more droughts are more likely to adopt cover cropping but not any other WCPs. This finding corroborates those of Anyokwu and Olabisi (2019), who report that the potential to increase the adoption of SWCs, including cover crops, increased with drought experience. With regards to perceived future droughts, farmers who expect future droughts to get worse are less likely to adopt cover cropping, all else being constant. This outcome is not surprising because, during the survey, farmers alluded to the fact that some previous droughts were severe and prolonged, killing off most crops, including cover crops. Therefore, if future droughts would get worse, the adoption of cover crops might not be an attractive option for conserving water or adapting to climate change, as demonstrated by Cai and Rosegrant (2004) and Caswell and Zilberman (1986).

Access to extension services does not significantly influence the adoption of any of the WCPs. This is unanticipated, as most studies report a positive relationship between extension services and agricultural technology adoptions (Mignouna et al., 2011). This result, however, is not unique, as Gebru et al. (2020) also found access to extension services to have no effect on farmers' adoption of SWCs. Such findings indicate that, first, extension officers in the study area are inactive in providing effective services, particularly in relation to the adoption of WCPs. That is, they are more focused on crops and livestock production than on WCPs (Amsalu and De Graaff, 2007). Second, extension officers may be using outmoded extension service methods.

Farmers with access to credit are less likely to adopt intercropping and drought-tolerant crops, all else being constant. This outcome is not unexpected, as interactions with farmers during the survey show that those with access to credit are more likely to adopt other WCPs, such as MEPIDs. Even though the results do not reflect this, this is the reality that was observed on the ground during the survey. Ahmed (2015) did not find access to credit to be significant in explaining the adoption decisions of farmers in the Central Rift Valley of Ethiopia.

Finally, access to markets is positively associated with the adoption of MEPIDs but is insignificant for the other WCPs. This finding suggests that farmers with access to markets are more likely to adopt MEPIDs, all else being constant. Farmers in the study area are not

constrained by access to markets. They mostly have contractual agreements with Tiger Brands Limited and/or some of the major supermarkets to which they supply their harvested farm products. Additionally, some farmers sell their produce at mini markets that exist by the wayside along the highways closer to their farms. Accordingly, it is not surprising that farmers are exhibiting a higher probability of adopting MEPIDs. This finding is in accordance with Ersado et al. (2004), who observed that better market access increased the adoption of SWC practices.

2.5.2 Determinants of the Intensity of Adoption of WCPs

In Table 2.5, the results of the OPM and the marginal effects of each outcome is reported. The OPM's chi-squared statistic is highly significant [$\chi^2(30) = 166.03$; $\text{prob} > \chi^2 = 0.0000$], suggesting that the null hypothesis that all slope coefficients are jointly equal to zero is rejected. The results here show that several factors influence the intensity of adoption of WCPs, however as noted earlier, the direct interpretation of the estimated coefficients of the OPM are less informative, thus the focus is rather on the marginal effects for each outcome. These marginal effects show that farmers with literate spouses and those without spouses are 5.9% more likely to adopt up to three WCPs, all else being constant. Farmers who own their farms are 3.1% more likely to adopt more than four WCPs. While those with an annual farm income greater than USD 733 are 2.1% more likely to implement all six WCPs. Also, farmers who are members of a cooperative are 2.4% more likely to implement up to three WCPs. Those with diversified farms are 5.1% more likely to implement all six WCPs, all else being constant. This outcome confirms the importance of diversified farming in the bundling of WCPs in the MVP model.

Furthermore, the intensity of adopting WCPs increases with distance to market by 0.09% for full implementation of all six WCPs, all else being constant. This outcome is not surprising given that distance to the market can influence the availability of information on new technologies and enhance adoption (Kassie et al., 2013). Furthermore, the results of the MVP model show that farmers are not constrained by distance to market. Accordingly, the closer the farmer is to the market, the more enhanced he or she is in implementing all six WCPs, since proximity lowers the transaction cost of purchasing inputs and transporting farm produce to the market.

Table 2. 5: Results of the Ordered Probit Model and the Marginal Effects of each Outcome

Intensity of WCP adoption	Ordered probit model and marginal effects of each outcome															
	Ordered probit		Pr(Y=0 X)		Pr(Y=1 X)		Pr(Y=2 X)		Pr(Y=3 X)		Pr(Y=4 X)		Pr(Y=5 X)		Pr(Y=6 X)	
	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z
<i>Farmer's characteristics</i>																
Gender of farmer	-0.013	0.13	0.0002	0.13	0.001	0.13	0.002	0.14	0.001	0.13	-0.001	0.14	-0.002	0.13	-0.001	0.13
Age	0.011	0.57	-0.0002	0.55	-0.001	0.56	-0.002	0.56	-0.001	0.56	0.001	0.56	0.002	0.56	0.001	0.56
Age squared	-0.0001	0.55	1.5e-06	0.53	7.2e-06	0.54	0.00001	0.55	8.3e-06	0.55	-8.6e-06	0.55	-0.00002	0.55	-7.2e-06	0.55
Education	0.312	1.44	-0.005	1.21	-0.023	1.40	-0.052	1.44	-0.027	1.42	0.027	1.44	0.056	1.44	0.023	1.40
Spousal education																
<i>Literate spouse</i>	-0.526***	2.58	0.005*	1.88	0.029***	3.07	0.078***	2.90	0.059**	2.17	-0.023***	3.69	-0.097***	2.59	-0.054**	1.90
<i>Without spouse</i>	-0.516**	2.01	0.005	1.39	0.028**	1.90	0.077**	2.06	0.059**	1.93	-0.022	1.42	-0.095**	2.04	-0.053*	1.74
Farm experience	-0.003	0.46	0.00005	0.45	0.0002	0.46	0.0005	0.46	0.0003	0.46	-0.0003	0.46	-0.0006	0.46	-0.0002	0.46
Farm ownership	0.349*	1.87	-0.005	1.43	-0.026*	1.79	-0.058*	1.86	-0.029*	1.84	0.031*	1.83	0.063*	1.87	0.026*	1.80
Farm income	0.289**	2.22	-0.004	1.56	-0.021**	2.07	-0.048**	2.22	-0.025**	2.18	0.025**	2.17	0.052**	2.21	0.021**	2.08
Off-farm income	0.035	0.33	-0.0005	0.33	-0.003	0.33	-0.006	0.33	-0.003	0.33	0.003	0.33	0.006	0.33	0.003	0.33
Member cooper.	-0.285**	2.48	0.004*	1.65	0.021**	2.29	0.047**	2.46	0.024**	2.40	-0.025**	2.38	-0.051**	2.47	-0.021**	2.30
Household size	0.016	0.85	-0.0002	0.79	-0.001	0.84	-0.003	0.85	-0.001	0.85	0.001	0.85	0.003	0.85	0.001	0.84
<i>Farm characteristics</i>																
Farm size	0.022	1.60	-0.0003	1.29	-0.002	1.55	-0.004	1.59	-0.002	1.58	0.002	1.56	0.004	1.60	0.003	1.55
Diversified farming	0.700***	3.65	-0.011*	1.84	-0.052***	3.30	-0.116***	3.61	-0.059***	3.23	0.061***	3.44	0.125***	3.54	0.051***	3.13
Distance to market	0.013***	4.87	-0.0002**	1.99	-0.0009***	3.83	-0.002***	4.73	-0.001***	4.41	0.001***	4.22	0.002***	4.79	0.001***	3.87
Location of farm	-0.134	1.31	0.002	1.13	0.009	1.28	0.022	1.30	0.011	1.30	-0.012	1.29	-0.024	1.31	-0.009	1.28
Source of water	0.142	0.91	-0.002	0.85	-0.010	0.91	-0.023	0.91	-0.012	0.91	0.012	0.91	0.025	0.91	0.010	0.90
Proximity to water	0.175	1.47	-0.003	1.20	-0.013	1.44	-0.029	1.47	-0.015	1.45	0.015	1.45	0.031	1.46	0.013	1.44
Secured land rights	0.415***	2.91	-0.006*	1.76	-0.031***	2.66	-0.069***	2.89	-0.035***	2.78	0.036***	2.84	0.074***	2.89	0.031***	2.60

Table 2.5: (Continued)

Intensity of WCP adoption	Ordered probit model and marginal effects of each outcome															
	Ordered probit		Pr(Y=0 X)		Pr(Y=1 X)		Pr(Y=2 X)		Pr(Y=3 X)		Pr(Y=4 X)		Pr(Y=5 X)		Pr(Y=6 X)	
	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z
<i>Crop choice characteristics</i>																
Vegetables	0.364***	2.64	-0.006*	1.68	-0.027**	2.47	-0.060***	2.64	-0.031**	2.50	0.032***	2.59	0.065***	2.61	0.027**	2.42
Maize	0.409***	3.91	-0.006*	1.89	-0.030***	3.32	-0.068***	3.84	-0.035***	3.65	0.036***	3.59	0.073***	3.81	0.030***	3.38
Fruits	0.092	0.55	-0.001	0.54	-0.007	0.55	-0.015	0.55	-0.008	0.55	0.008	0.55	0.017	0.55	0.007	0.55
Spices	-0.568***	4.38	0.009**	1.95	0.042***	3.59	0.094***	4.28	0.049***	4.02	-0.049***	3.88	-0.102***	4.34	-0.042***	3.58
Beans	0.078	0.66	-0.001	0.63	-0.006	0.66	-0.013	0.66	-0.007	0.66	0.007	0.66	0.014	0.66	0.006	0.66
<i>Cost characteristics</i>																
Perceived cost	-0.112	1.09	0.002	0.98	0.008	1.07	0.019	1.08	0.009	1.08	-0.009	1.08	-0.020	1.09	-0.008	1.07
<i>Environmental characteristics</i>																
Drought experience	0.733	1.16	-0.011	1.03	-0.054	1.14	-0.121	1.16	-0.063	1.16	0.064	1.15	0.131	1.16	0.054	1.14
Perception drought	-0.062	0.58	0.001	0.56	0.005	0.58	0.010	0.58	0.005	0.58	-0.005	0.58	-0.011	0.58	-0.005	0.58
<i>Institutional characteristics</i>																
Extension services	0.526*	1.93	-0.008	1.45	-0.039*	1.84	-0.087**	1.93	-0.045**	1.90	0.046*	1.91	0.094**	1.92	0.039*	1.84
Access to credit	-0.099	1.01	0.002	0.92	0.007	1.00	0.016	1.01	0.008	1.01	-0.009	1.01	-0.017	1.01	-0.007	0.99
Market access	-0.036	0.28	0.001	0.28	0.003	0.28	0.006	0.28	0.003	0.28	-0.003	0.28	-0.006	0.28	-0.003	0.28
/cut1_cons	0.957	0.97														
/cut2_cons	1.973**	2.04														
/cut3_cons	3.004***	3.10														
/cut4_cons	3.865***	3.98														
/cut5_cons	4.798***	4.92														
/cut6_cons	5.940***	6.04														
Log likelihood	-818.42															
Pseudo R ²	0.1000															
chi ² (30)	166.03															
Prob > chi ²	0.0000															
Number of obs.	555		555		555		555		555		555		555		555	

Note: ***, **, and * denote 1%, 5% and 10% significance levels respectively.

Consistent with the MVP model's result on secured land rights and the Marshallian inefficiency hypothesis. Farmers with secured land rights are 3.1% more likely to adopt all six WCPs. Farmers predominantly involved in vegetable and maize production are 2.7% and 3.0%, respectively, more likely to implement all six WCPs, all else being constant. Spice farmers are 4.9% more likely to adopt up to three WCPs. Farmers with access to extension services are 3.9% more likely to implement all six WCPs, all else being constant. This finding shows that a factor can have a varying influence on both the probability and the intensity of adoption. In the MVP model, access to extension services was insignificant for all WCPs, but with the intensity of adoption, it increased the number of WCPs adopted. This set of outcomes additionally confirms the bundling of WCPs by farmers.

2.6 Conclusion and Policy Implications

This chapter investigated the factors that drive farmers' simultaneous adoption of six WCPs (bundling) and the intensity of their adoption in the LRB of South Africa. Multivariate probit and ordered probit models were used to estimate the relationships from the survey data. The results show, first, that key farm, farmer, institutional, and environmental factors, like gender, age, education, off-farm and farm incomes, and access to markets, among others, trigger the probability and extent of adoption of the WCPs differently. While some determinants influence the adoption of the various WCPs positively, others do so negatively, and yet others are statistically insignificant. Second, the interrelationships among the six WCPs show strong evidence of the bundling of WCPs in the LRB. Finally, in the intensity of adoption model, the results show that a minimum of two practices to a maximum of six were being adopted or bundled. These findings are relevant not only for farmers, decision-makers, and other stakeholders in the Limpopo Province of South Africa for the promotion and adoption of WCPs but also for their counterparts in other water-risk hotspots where climate-change effects have become rampant on water resources and in the agricultural sector.

This chapter, like many previous studies, especially those on SWCs and climate-smart agricultural (CSA) practices, both fits established patterns of farmers' adoption behaviour of these practices and is unique for agricultural practitioners and policymakers. The findings of this chapter suggest that under conditions of extreme climate change and droughts, farmers in South Africa exhibit similar characteristics of farmers' adaptation behaviour and adopt strategies to mitigate the effects of intensified climate change and farm-level water scarcity.

This chapter is, however, unique in that, first, unlike many previous studies on WCPs, it underscores the important need for farmers to consider combining several WCPs or bundling them to mitigate farm-level water scarcity or, in response to climate change intensification, consider the adoption of the best bundle mix and/or the supporting technologies that are appropriate for tackling the different levels of DWSs encountered. Second, the six unique WCPs provide farmers and policymakers with a mixed toolset that is effective at helping farmers counter climate change effects and DWSs in water-stressed areas.

The framework in this chapter is not only critical for long-term planning under likely changes in climate but also provides farmers with more flexibility, better resilience, and a wide range of toolsets to adapt to increased climate volatility. This way, farmers have more control over climate change effects and their related impacts over time.

The results offer some important implications for policy. First, WCPs are interdependent; therefore, the design of any effective strategy(ies) aimed at increasing their uptake rate must take this interdependence into consideration. Second, it was found that being female reduces the probability of adopting mulching. Policies aimed at fostering and making the adoption of MEPIDs more appealing to females are necessary. Training and sensitization of female farmers on mulching are advocated. Third, education increases the adoption of MEPIDs, implying that improving farmers' knowledge will positively impact adoption decisions. Therefore, policies that encourage onsite demonstration and sensitization on the potentials of irrigation among the farmers and the education of farmers on the likely effects of climate change on water resources and agricultural productivity are recommended. In addition, education and training of extension service officers on modern best agricultural practices that incorporate the adoption of WCPs into farming in response to DWSs are recommended. Fourth, the government should strive to create a conducive atmosphere for farmers to secure tenure rights to their farmlands, as tenure rights significantly influence the adoption of MEPIDs. Also, the significant and positive impacts of access to and distance to markets indicate that policies aimed at improving access to and distance to markets will help promote the adoption of WCPs, especially MEPIDs.

Finally, these suggestions would go a long way towards increasing the adoption rate of WCPs, enable farmers build resilience against intensified climate change and DWSs and engender water use efficiency. This is important to enable farmers acclimatize to intensified climate change, DWSs, and to alleviate the pressures associated water shortages in water-stressed

South Africa, especially in the arid Limpopo Province. By doing so, farmers would not only be conserving water under drought circumstances but would also be ensuring the sustainability of water resources for increased agricultural production, food security, improved incomes, poverty alleviation, rural employment, and, above all, sustained and continuous contributions to economic and social development.

This chapter is not without limitations. First, it is limited by its scope, which focused only on the determinants and number of WCPs adopted but not the effects or challenges of the adoption of WCPs. Second, due to time and financial constraints, only two farming communities in the Limpopo Water Management Area (WMA) were covered. Not including the entire Limpopo WMA or even the entire portion of the Limpopo River in South Africa means the findings are entirely of those two farming communities. A study that covers these areas could have a higher power of generalizability and further advance this research. Such studies could be done by including other variables like temperature and rainfall changes, weather forecast figures, and soil types, among others, or the same variables as this chapter. In addition, future studies could examine the impact of the adoption of WCPs on farm output and profits.

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Chapter 3: Farmers' Willingness to Accept Compensation to Control Agricultural Nonpoint Source Pollution: the Limpopo River Basin of South Africa

Abstract

Farmers differ regarding their farm management practices and the costs that arise from changes in those practices. Therefore, they require different compensation payments to participate in water quality improvement-related agri-environmental schemes, but these heterogeneities are not characterized in the design and implementation of these programmes. This chapter thus investigates, through a choice experiment, farmers' willingness to accept compensation to control agricultural nonpoint source pollution in the Limpopo River Basin of South Africa. Conditional logit and restricted latent class models are used to estimate the data from 552 farmers. The results identified three preference choice classes of farmers—low, moderate, and high resistance with dissimilar compensation requirements to improve water quality—and one random choice class, where farmers were classified as making random choices. For instance, high-resistance farmers required 1,331 and 1,793 United States dollars (USD) hectare⁻¹ year⁻¹ to reduce fertilizer by 25 and 50%, respectively. While moderate resistance farmers required 151 and 319 USD hectare⁻¹ year⁻¹ for the same reductions in fertilizer, respectively.

Keywords: agricultural nonpoint source pollution control, choice experiment, latent class model, willingness to accept (WTA), South Africa.

JEL classification: Q15, Q25, Q52, Q53

3.1 Introduction

Agricultural nonpoint source (agNPS) pollution¹⁶, a type of nonpoint source pollution¹⁷ is the chief cause of water quality deterioration and an issue of major concern to policymakers and water resource managers. This problem is exacerbating as agriculture is being expanded and intensified in response to population growth, increased food demand, and changes in dietary patterns (FAO, 2017b). This has resulted in undesirable agricultural land-use practices and the intensive application of inorganic fertilizers and pesticides, which all contribute to intensifying agNPS pollution. This pollution degrades water quality at the farm level and causes serious eutrophication in water bodies, precluding water use for other key sectors in an economy, including industry, fishery, and recreation services (Halliday et al. 2014). It also exacerbates water scarcity and endangers water security goals. The salinization of water resources by this pollution decreases agricultural yield, farm profits, and efficiency in irrigation systems. Therefore, reduced agNPS pollution is expected to contribute to alleviating water scarcity, improve water resource management and sustainability, to enable farmers to make meaningful and continuous contributions to economic growth.

However, given the difficult-to-control nature of agNPS pollution, different efforts and policies are needed to regulate it differently from point-source pollution. The policies that are often applied include mandatory and voluntary measures. Mandatory measures include instruments that force and constrain farmers to use pollution control practices—higher taxes on inputs that cause pollution (Feather and Cooper, 1995), tax subsidy schemes (Segerson, 1988; Xepapadeas, 1997), and direct regulations (Feather and Cooper, 1995). But due to the

¹⁶ The runoff and leaching into water bodies of nutrients (nitrogen and phosphorus), pesticides, agricultural waste (film and animal), and soil sediments from farms (Ribaud, Horan, and Smith, 1999)

¹⁷ Nonpoint source pollution refers to all contaminants of [air, and] surface and subsurface soil and water resources that are diffuse in nature and cannot be traced to a point location or a single source (Corwin and Wagenet, 1996; USEPA, 2023). Hence, it is difficult to identify the origin and take actions to minimize or prevent it. Examples of this pollution include excess herbicides, pesticides, and fertilizers from residential neighbourhoods and agricultural areas; sediment caused by erosion from land development and failing stream banks; salt from irrigation practices and acid mine drainage from abandoned coal mines; bacteria and nutrients from livestock, pet wastes, and faulty septic systems; and oil, grease, and toxic chemicals from urban runoff and energy production (Hardy and Koontz, 2008; USEPA, 1994). However, agriculture is generally recognized as the largest contributor to this pollution in surface and subsurface water sources (USEPA, 1998a). On the other hand, point-source pollution occurs at a single identifiable source. This pollution remains localized to the point of pollution and can be traced back to the source. Compared to nonpoint source pollution, this pollution is characteristically (i) easy to identify the source, (ii) easier to control, (iii) more readily identifiable and measurable, and (iv) generally more toxic. Hence, actions can be taken to prevent it (Loague and Corwin, 2006; USEPA, 2023). Some examples of point-source pollution include hazardous spills, underground storage tanks, storage piles of chemicals, mine-waste ponds, deep-well waste disposal, industrial or municipal waste outfalls, runoff and leachate from municipal and hazardous waste dumpsites, and septic tanks (Loague and Corwin, 2006; USEPA, 2023).

characteristics¹⁸ of agNPS pollution, a moral hazard problem and incomplete knowledge of the relationship between production and nonpoint loadings occur (Han and Zhao, 2010). Thus, efforts to identify the origin or specific loads can be prohibitively costly, making mandatory instruments ineffective and administratively costly to apply. Instead, voluntary incentives that provide farmers with the motivation to voluntarily change their inherent behaviour and adopt practices that lead to improved water quality are perceived as the preferred approach to dealing with agNPS pollution (Feather and Cooper, 1995). Voluntary incentives include cost-sharing, incentive payments, and technical assistance (Feather and Cooper, 1995). These are mostly implemented through agri-environmental schemes (AESs)¹⁹, where farmers are incentivized or paid to reduce the damage agriculture has on water quality and to promote the positive environmental effects of agriculture. These programmes, thus, incentivize farmers to provide environmentally non-market goods in greater quantities than would otherwise be the case (McGurk, Hynes, and Thorne, 2020). But, due to the voluntary nature of these programmes their acceptance and uptake, as well as their effectiveness in providing the targeted environment quality, is still low, with alignment between payments and outcomes requiring fine-tuning (European Court of Auditors, 2011; Matzdorf and Lorenz, 2010). To overcome these challenges, the European Court of Auditors (2011) recommended providing sufficient financial support to encourage farmer participation and tailoring programmes (relevant targeting approach) to local and regional circumstances. Though 'relevant targeting' at the local or regional level is necessary, it is not sufficient to offer widespread acceptance and uptake.

Farmers are heterogeneous by nature, with different farm management strategies, cost structures, farming styles, and subcultures (Brodt, Klonsky, and Tourte, 2006; Howden et al., 1998; Jaeck and Lifran, 2014). Despite these differences being key to the success of these programmes, they are not characterized in the design of AES contracts, especially agNPS pollution control schemes. Additionally, the current approach of 'lumping farmers together' and making payments based on the average loss of income is dated. This flat rate ignores the heterogeneity of compliance costs among eligible farmers. This results in farmers with lower-than-average costs being overcompensated, while it deters farmers whose compliance costs are above average (Latacz-Lohmann and Breustedt, 2019). Understanding these key factors that

¹⁸ Agricultural nonpoint emissions are essentially unobservable and highly stochastic due to natural variation in weather and other environmental processes (Han and Zhao, 2010; Horan, Shortle, and Abler, 1999).

¹⁹ AESs are voluntary incentive-based payments to farmers and land managers to operate in environmentally friendly ways that support biodiversity, conserve and enhance landscapes (beach, forest, mountains, etc.), and improve the quality of water, air, and soil.

differentiate farmers and how these differences drive their compensation requirements is fundamental in designing appropriate and more acceptable water AESs in South Africa and elsewhere to successfully regulate agNPS pollution. This chapter, therefore, aims to provide new insights to enrich the efficient design of tailored water quality improvement-related AESs for maximum participation and more persistent environmental benefits that would ultimately result in positive externalities beyond benefits to farmers and the environment. Accordingly, the purpose of this chapter is to investigate, through a discrete choice experiment, farmers' willingness to accept (WTA)²⁰ compensation to adopt more sustainable farming practices²¹ that might contribute to reducing agNPS pollution in the Limpopo River Basin (LRB) of South Africa. To this end, this chapter first determines the appropriate compensation that encourages greater acceptance and participation in an agNPS pollution control programme in South Africa. Second, it determines the socio-economic and attitudinal factors that drive farmers' WTA compensation to control agNPS pollution. Finally, it explores unobserved heterogeneity among farmers in the sample.

This chapter focuses on the LRB for various reasons. First, the LRB is one of the most polluted river systems in South Africa (Marr, Mohlala, and Swemmer 2017; Nel and Driver 2015). Yet, the basin is important for agriculture, eco-tourism, mining, and industry, which contribute to promoting employment, income generation, and poverty alleviation. Second, remedying this pollution is part of plans for restoring and protecting the basin (National Water Resource Strategy 2 [NWRS 2], 2013). Third, in South Africa, empirical studies on how monetary incentives are used to motivate farmers to control agNPS pollution are lacking. This lack of studies creates a gap in our understanding of how best to control this pollution and hinders the crafting of cost-effective and proactive water quality improvement policies in the agricultural sector to properly regulate agNPS pollution. Finally, experiences from South Africa permits the investigation water quality regulation in an emerging economy's context, where increased growth in food production and water use is expected to influence the efficiency of the agricultural system in the coming decades. This chapter contributes to the literature on agNPS pollution, first by enhancing the understanding of the factors that influence farmers WTA

²⁰ WTA is the minimum monetary amount required for an individual to forgo some good (Dupraz et al., 2003; Martín-Fernández et al., 2010). Therefore, WTA is defined as the minimum payment that a farmer requires to forgo some undesirable agricultural practices (i.e., fertilizer and pesticide reduction, among others) to reduce agriculture's impact on water quality.

²¹ Reduced use of fertilizers and pesticides, to the construction of ecological ditches and agricultural-waste recovery initiatives, all of which contribute to reducing the release of harmful pollutants.

compensation to control agNPS pollution. Second, beyond its academic contributions, the chapter offers some policy guidance to decision-makers on the importance of integrating behavioural traits and preference heterogeneity into the design and implementation of AES contracts.

The rest of this chapter is structured as follows: Section 3.2 provides a review of the related literature, and Section 3.3 provides a brief description of the study area. Section 3.4 comprises the methodology. The results and discussion appear in Section 3.5, and Section 3.6 concludes, provides policy implications, and discusses the limitations of the chapter and directions for future research.

3.2 Related Literature Review

There is a growing number of empirical studies that have used discrete choice experiments (DCEs)²² to elicit farmers' preferences for and WTA requirements to participate in AESs and PESs for quality improvements in environmental goods (Broch and Vedel, 2012; Ducos et al., 2009; Espinosa-Goded et al., 2010; Li et al., 2019; Ruto and Garrod, 2009).

Given the expanse of this literature, this chapter focused on empirical studies that used DCEs to investigate how financial incentives are used to encourage desirable farming practices that prevent or curb agNPS pollution. Specifically, Beharry-Borg et al. (2013) examined payment incentives for farmers to adjust their agricultural land management practices to protect water quality in the United Kingdom. Using a DCE with five attributes—inorganic fertilizer application, farmyard manure application, blocking of drainage 'grips', duration of the agreement, and compensation payment—the results from their conditional logit model (CLM) and latent class logit model (LCM) showed that even though the transaction cost of changing from the status quo was substantial, farmers were willing to modify their land management practices if compensation payments were sufficient. Their study, however, did not explicitly deal with unobserved heterogeneity. It also did not include pesticide reduction as an attribute,

²² DCEs are quantitative tools for evaluating many non-market phenomena for which data does not exist. They are increasingly being used to elicit preferences from participants (patients, payers, commissioners, farmers, etc.). In a DCE, participants are typically presented with a series of alternative hypothetical scenarios containing a number of 'attributes', each of which may have a number of variations or 'levels'. Participants are then asked to state their preferred choice between 2 or 3 competing scenarios, each of which consists of a combination of these attributes or levels (Mangham, Hanson, and McPake, 2009).

which is very important for reducing agNPS pollution. Therefore, a study that examines unobserved heterogeneity and includes pesticide reduction, such as the current chapter, is needed to augment the literature on agNPS pollution control.

Li et al. (2019) used four attributes—fertilizer reduction, pesticide reduction, agricultural waste recovery rate, and compensation standards—to analyze 632 farmers' WTA compensation to control agNPS pollution in Northwest China. The results from their random parameter logit (RPL) model showed that compensation increased farmers' willingness to control agNPS pollution. In addition, households with younger residents, higher family income, and a perception of the ecological benefits, among others, were more willing to participate in the scheme. Despite such interesting findings, their study did not include the duration of the programme as an attribute. Moreover, the study's focus on rice farmers only fails to produce a conclusion for all farmers since different farming practices may be required for different crops. Thus, using farmers who grow multiple crops introduces more flexibility to the set of options that individual farmers face compared to farmers who grow only single crops. Therefore, a study that includes the duration of the programme with diverse farmers is important to augment the discourse on agNPS pollution control, hence the current chapter.

As their contribution to the literature, Wu and Ge (2019) used a multinomial logit model (MNL) to analyze data from 516 farmers in Heyang County, China. They constructed three policy environments—technological guidance for planting, subsidies for organic fertilizer application, and agricultural tailwater discharge standards. They found that farmers had different preferences for these three policy settings. However, the MNL's assumption that preferences are homogenous across respondents and its concomitant independence of irrelevant alternatives (IIA) assumption (Hausman and McFadden, 1984) make other models (like the LCM) that relax these assumptions preferable. Thus, this chapter uses the LCM to account for preference heterogeneity and to overcome the challenges of the MNL.

Additionally, recent contributions to the literature show that age, education, gender, occupation (farming and non-farming), and other socioeconomic, as well as attitudinal factors, influence participation in water quality improvement-related AESs. For instance, Lin et al. (2021), with a MNL model, analyzed the key factors determining farmers' WTA compensation to control agNPS pollution in the Xin'an River Reservoir. They concluded that farmers' participation in controlling agNPS pollution in the area mainly depended on social and economic factors

(gender, age, family size, etc.), farmland management behaviours (agNPS pollution and environmental protection awareness, pesticide and fertilizer application reduction actions), different scheme attributes (fertilizer and pesticide use management, technical support, etc.), and satisfactory compensation that covered the losses of farmers.

In Table 3.1, an overview of key-related empirical studies and their findings from around the world is presented to augment this review.

Table 3. 1: An Overview of Key Related Studies from Around the World

Authors	Study area/sample size (N)	Attributes	Empirical models	Findings
Bourceret et al. (2023)	France N = 80	Financial compensation, training and information, duration of the programme and the parameters	Extended agent-based model of a social-ecological system (SES)	<ol style="list-style-type: none"> 1. Targeting farmers who have higher environmental preferences is more effective than no targeting. 2. The heterogeneity in farmers' environmental preferences impacts their involvement in the programme depending on their average environmental preferences. 3. The higher the initial pollution, the more farmers are involved in the protection programme. When two different measures are combined, once a certain threshold of public awareness is reached, there is a synergy between them.
Lu et al. (2021)	China N = 238	Chemical fertilizer application reduction, pesticide application reduction, agricultural waste recovery rate, compensation	Multinomial logit	<ol style="list-style-type: none"> 1. The results showed that financial compensation can effectively stimulate farmers' willingness to control agNPS pollution. 2. The willingness of farmers to participate in the ecological compensation is greater when there is a higher level of risk preferences and a higher understanding of farmland nonpoint source pollution control policy. 3. Additionally, willingness is higher in younger, highly educated, and highly involved in a part-time family business with a higher recognition degree in the ecological function of farmland nonpoint source pollution control.
Lee et al. (2018)	The Soyang Watershed in South Korea N = 240	Agricultural profits, water quality, and biodiversity level	Conditional logit model	<ol style="list-style-type: none"> 1. The results showed that water quality is the most important attribute that is preferred by both downstream water users and upstream farmers. 2. Both water users place substantial value on the protection of water bodies in the Soyang watershed and are concerned about the consequences of water usage on the environment and human health. 3. Income groups in different local communities seemed to have different implicit costs for water quality improvement in the Soyang watershed.
Aguilar et al. (2018),	U.S.A	Water quality, flood control, landscape beauty, habitat for	Mixed logit model	<ol style="list-style-type: none"> 1. Results showed limited knowledge of payment for ecosystem service (PES) programmes and antagonistic opinions regarding initial WTP for watershed conservation and corresponding PES financial charges.

	N = 1200	plant and animal species and PES management fees		<ol style="list-style-type: none"> 2. Water quality (30.4%) dominated importance among selected PES attributes used in the study, followed by provisioning of habitat for threatened plant and animal species (23.4%), flood control (21.4%), and landscape aesthetics (14.0%). 3. Environmental attitudes significantly influenced WTP results, even more than annual household income. Results show WTP levels for improvements in water quality were homogeneous across the nation but heterogeneous for the enhancement of habitat, landscape, and flood control.
Lin and Pan (2020)	China N = 218	Socio-economic and some attitudinal factors	Improved double-bounded dichotomous choice (DBDC) model and ordinal regression	<ol style="list-style-type: none"> 1. Voluntary fertilizer reduction ratio and family size were positively correlated with compensation attitude. While total family income, farmer's evaluation of the impact of fertilizers on the environment, whether the farmers had other jobs, and education level were negatively correlated with compensation attitude. 2. In contrast to fertilizers, pesticides are a stronger output-related factor for farmers, and any reduction in pesticides would cause greater output fluctuations. 3. For farmers, compared with pesticides, the risk of fertilizer reduction is lower, and their attitudes are quite different, but as long as the compensation is sufficient, they are willing to take more stringent measures.
Wang et al. (2013)	China N = 444	Socio-economic and some attitudinal factors	Multiple-bounded discrete choice (MBDC) approach	<ol style="list-style-type: none"> 1. Respondents were willing to pay 74 CNY (or USD12.33 in 2012 prices) per household per month (or 5% of household income) continuously for five years to achieve an improvement of water quality in the two major local rivers from the current Grade IV to Grade III, which denotes a level suitable for swimming and fishing and matches the water quality level from 10 years ago. 2. Although the presentation order of the polychotomous likelihood choices may not have a significant impact on the WTP estimation, the presentation order of bid levels may have a significant impact. 3. Respondents who had better knowledge of past environmental quality changes or who had previously heard of the project were generally willing to pay more for the water quality improvement project.
Gachango et al. (2015)	Denmark N = 267	Exogenous water quality variables/physical factors,	Ordered probit models	<ol style="list-style-type: none"> 1. Adoption of voluntary nutrient reduction technologies is significantly explained by farm slope, farmers' age, farmers' attitude to subsidies, farm size, and farmers' awareness of the existence of the constructed wetland funds. 2. The majority of the farmers perceive the quality of water in the fjords and lakes draining from their farms to be above average. This perception, may, however, be

		personal and attitudinal factors, economic factors and institutional factors			misinformed, since the majority of the farmers have not had access to full information on the underlying stipulations and requirements of “good ecological status” under the Water Framework Directive.
Villanueva et al. (2015)	Southern Spain N = 295	Cover crop area, cover crop management ecological focus area, collective participation, monitoring and payment.	Latent class model	<ol style="list-style-type: none"> 1. High heterogeneity among farmers with different classes was identified, including potential participants and non-participants. 2. With ecological focus area (EFA), almost half of the farmers were willing to accept it up 2% for low monetary incentives (€8–9/ha per additional 1% of the farmland devoted to EFA), while the rest did it for moderate-to-high monetary incentives (€41–151/ha per additional 1% of EFA). 3. However, for a high share of EFA (e.g., 5–7%), higher incentives were presumably required due to the intrinsic spatial restrictions of farmers. For collective participation, it is unlikely that farmers would participate collectively with the incentive of up to 30% EU-wide bonus. 	
Broch and Vedel (2012)	Denmark N = 853	Purpose of afforestation, option of cancelling the contract, monitoring, and compensation level	Random parameter logit and latent class models	<ol style="list-style-type: none"> 1. Their results showed that having the option to cancel the contract decreased farmers’ required compensation level, and monitoring increased it. 2. Furthermore, farmers were willing to accept lower compensation when the aim was to protect biodiversity and groundwater relative to recreation. 	
Christensen et al. (2011)	Denmark N = 444	Contract length, release option, buffer zone width, changed agricultural practice, application method, and size of subsidy	Random parameter logit model	<ol style="list-style-type: none"> 1. Payments above and beyond direct costs are a necessary condition for showing interest in the subsidy scheme. 2. The majority of farmers are willing to trade off the size of the subsidy for less restrictive scheme requirements. 3. The amount of the subsidy they were willing to trade off varies with specific scheme requirements. Additionally, farmers value flexible contract terms more than reduced administrative burdens. 	
Pan et al. (2016)	China	Technical support, pollution fees, technical standards, biogas subsidies,	Random parameter logit	<ol style="list-style-type: none"> 1. The biogas subsidy, technical support, pollution fees, and manure market are significant factors of preference over alternative policy designs in terms of incremental changes in environmentally friendly manure handling. 	

	N = 754	and the manure market		<ol style="list-style-type: none"> 2. Heterogeneity was observed in farmers' preferences for livestock pollution control policies. Farmers' choices of improved pollution policy options were significantly influenced by their education, the size of their farms, and their willingness to treat pollution. 3. Farmers showed the highest preferences for a biogas subsidy policy, followed by a high technical support policy, a pollution fee policy, a medium technical support policy, a manure market policy, and finally a technical standard policy.
Liu et al. (2013)	China	Changes in land use, fertilizer management and tillage measures	Soil and Water Assessment Tool (SWAT)	<ol style="list-style-type: none"> 1. Results revealed that when farmland was returned to forests, both runoff and agNPS pollution loads showed a clear downward trend, and the agNPS pollution loads in the Xiangxi River watershed decreased by 20% or more when compared with the status of 2007. 2. Conservation tillage and contour farming can help reduce runoff by 16% and 9%, total nitrogen (TN) by 9% and 8%, and total phosphorus (TP) by 7%, and 5%, respectively. 3. Based on the fertilizer conditions of 2007, changing the fertilizer application resulted in little change in local runoff; however, for agNPS pollution loads, various forms of nitrogen (N) and phosphorus (P) pollution loads were directly proportional to the amount of chemical fertilizer applied.
	N = monthly flow and water quality data observed from 2002 to 2007			
Franzén et al. (2016)	Himmerfjärden coastal catchment, South of Stockholm, Sweden	Annual economic subsidy per hectare, time frame for subsidy, practical support, economic compensation for construction and cost ceiling per compensation	Generalized linear mixed model with binomial error distribution	<ol style="list-style-type: none"> 1. Approximately 30% of the farmers were interested in wetland creation. A common reason for not wanting to create wetlands was the cost incurred by the farmer. 2. Males were significantly more willing than females to create wetlands. 3. Prior knowledge of the Water Framework Directive (WFD) increased willingness almost threefold, and landowners were significantly more willing than leaseholders. 4. Higher cost ceiling for compensation, compensation percentage and annual subsidies can significantly increase the willingness to create wetlands.
	N = 135			

The general observation from the review of the literature shows that farmers' participation in water quality improvement-related AESs is highly heterogeneous. While some farmers are willing to accept monetary compensation to participate in these programmes (McGurk et al., 2020; Li et al., 2019; Lu et al., 2021), others are hesitant, indicating strong preferences for the status quo (Beharry-Borg et al., 2013; Christensen et al., 2011). Yet others placed higher importance on the regulatory agency that would implement and monitor the programme and the amount of land that would be committed to it (Kreye et al., 2017). Still, some required greater financial incentives to join schemes that had longer contract durations or that offered less flexibility and/or higher levels of paperwork (Ruto and Garrod, 2009). Furthermore, for some farmers, having the option to cancel the contract, and if the contract was aimed at protecting biodiversity or groundwater quality relative to recreation, decreased the compensation amount they required, while monitoring increased it (Broch and Vedel, 2012). Finally, fixed transaction costs are perceived as significant barriers to farmers' interest in scheme contracts, particularly for small farms. Therefore, lump sum payments that are yearly are perceived to increase participation rates (Ducos, Dupraz, and Bonnioux, 2009).

These reviewed studies have contributed to the literature, but first, none of the studies reviewed have explicitly dealt with the issue that farmers are different, with different farm management practices and costs, and therefore have different preferences for the different agNPS pollution control scheme attributes. Ultimately, this results in the requirement of different levels of compensation payments to attract full participation. Accordingly, using the LCM to account for unobserved heterogeneity instead of the mixed logit model (MXL), which is the model of choice for almost all the DCE studies found on agNPS pollution control, except Beharry-Borg et al. (2013), makes the current chapter stand out in terms of methodology.

Second, none of these studies are from South Africa, despite the country being the largest agricultural and food exporter on the continent. To the best of my knowledge, this chapter is the first attempt at using DCE to gauge farmers' WTA compensation to control agNPS pollution in South Africa. South Africa—and especially the LRB—adds an important angle to the study of policy regulations for agNPS pollution under extreme water-scarcity conditions.

Third, the omission of some attributes by Beharry-Borg et al. (2013) and Li et al. (2019), among others, justifies the current chapter, which includes these attributes that are relevant to the policy discourse on agNPS pollution control. In addition, the inclusion of the construction of

ecological ditches and monitoring for compliance is especially novel, as none of the agNPS pollution control studies have used these attributes, even though their use in other AESs studies (forest, coastal, wetlands, mangrove conservation, etc.) and the non-DCE literature is popular. For monitoring, see Broch and Vedel (2012) and Greiner (2016), and for ecological ditches, see Blankenberg, Haarstad, and Braskerud (2007) and Hernandez and Mitsch (2007). The inclusion of these attributes differentiates this chapter from previous studies and provides policymakers and AES implementers with a wider range of practices to control agNPS pollution at the farm level.

Lastly, the choice of farmers who grow diverse crops, including vegetables (tomatoes, green beans, green pepper, chillies, onions, and garlic), sweet potatoes, and maize (corn), instead of farmers who grow only single crops, such as rice, olives, wheat, etc., makes this chapter wide and unique. The crops these farmers grow are particularly prone to fertilizer and pesticide leaches and run-off due to frequent cultivation, relatively shorter growing cycles, and low nutrient uptake efficiency (Di and Cameron, 2002). In addition, using farmers that grow multiple crops introduces diversity and flexibility to the set of options that face individual farmers compared to farmers who grow only single crops.

Accordingly, to fill these gaps, this chapter constructed a hypothetical market scenario where farmers stated their WTA compensation for different agNPS pollution control policy interventions. In these interventions, farmers agree to adopt or alter their farming practices—reducing fertilizer and pesticide usage, recovering agricultural waste, among other initiatives for compensation.

3.3 An Overview of the Study Area

The LRB, which covers an area of 416,296 square kilometers (160,200 square miles), is the second longest river (approximately 1,750 kilometers or 1,087 miles) and most significant river in southern Africa (Nakayama, 2003). Average runoff measured over a year is 170 m³ (6,000 cu ft; 170,000 L; 44,900 US gal) per second at its mouth (Nakayama, 2003). The basin has a population of about 14 million people, distributed between rural (52%) and urban (48%). It is shared by four countries—Botswana (19%), Zimbabwe (15%), Mozambique (21%), and South Africa (45%) (Limpopo Basin Permanent Technical Committee [LBPTC], 2010). South Africa's largest share (an area of about 184,150 square kilometers) lies predominantly in the

Limpopo Province. Agricultural activities constitute a large portion of land use in this part of the basin (LBPTC, 2010). The Limpopo River has several economic and ecological importance. First, the river plays a crucial role in supporting agriculture and livestock farming in the region. Many communities rely on the river for irrigation, and the fertile soils around the river support the cultivation of many crops, including cotton, maize, citrus fruits, etc. The province has 180 of the 302 small irrigation schemes in the country (Van Koppen et al., 2017; Van Averbeke et al., 2011). Second, the river is also significant for wildlife conservation. Kruger National Park, which sits on the river's banks, is one of the largest game reserves in Africa and is home to the iconic African Big Five (lion, leopard, elephant, rhinoceros, and Cape buffalo). While the river is vital to the province's people, wildlife, and economy, it also faces several threats and challenges—climate change and water pollution are major concerns. Changing rainfall patterns and rising temperatures have impacted the river's flow and reduced water availability for agriculture, wildlife populations, and livestock farming. While anthropogenic activities have led to increased levels of pollution in the river, consequently impacting water quality, aquatic life, and the loss of natural habitats and biodiversity,

Accordingly, given the river's importance to the province's people, wildlife, and economy, significant efforts, including research, are required to look for solutions to save the river from the current threats and challenges it faces. In this regard, two farming communities in the basin, namely, Folovhodwe and Tshiombo in the Musina and Thulamela local municipalities, respectively, of the Vhembe District Municipality²³ of the Limpopo Province, are selected for the research, as shown in Figure 3.1. Much of the agricultural activities in Limpopo Province occur in this district, especially in the two farming communities. Folovhodwe and Tshiombo are located on important tributaries of the Limpopo River. The Nwanedi River, which houses the Nwanedi Irrigation Scheme, passes through Folovhodwe, while the Tshiombo Irrigation Scheme, one of the largest in Limpopo Province, is in Tshiombo at the western end of the Tshiombo Valley on the south bank of the Mutale River (Lahiff, 1997). Agricultural activities predominantly consist of growing vegetables, bananas, citrus fruits, maize, melons, and peanuts (groundnuts), as well as poultry and livestock production, among others.

²³ South Africa has a three-tier local government system—provinces (or regions), which consist of district municipalities (or districts). The district municipalities also consist of local municipalities.

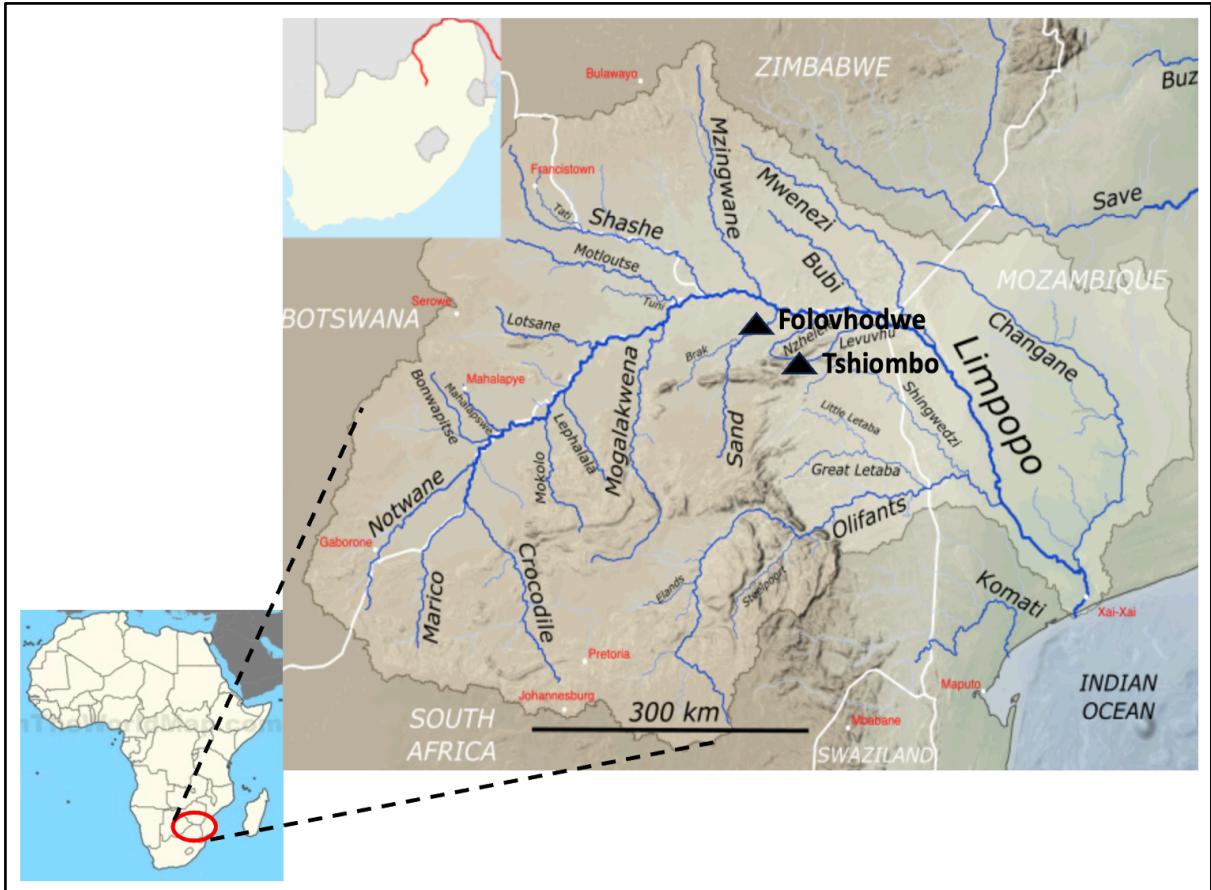


Figure 3. 1: Limpopo River Basin with the Study Area
 (Adapted and modified from Google Maps, 2022).

3.4 Methodology

3.4.1 Model Specification

The choice experiment (CE) methodology has its theoretical foundation in Lancaster’s model of consumer choice (Lancaster, 1966) and its econometric basis in Random Utility Theory (RUT) (Luce, 1959; McFadden, 1974). Based on RUT, farmers choose the alternative that provides them with the highest expected utility associated with the choice attributes. The i th farmer’s utility of the j th alternative associated with choosing an agNPS pollution control intervention is given in Equation 3.1:

$$U_{ij} = \beta_i x_{ij} + \varepsilon_{ij} = V_{ij} + \varepsilon_{ij} \quad (3.1)$$

where β_i is a vector of individual-specific coefficients and x_{ij} is a vector of observed agNPS pollution control attributes related to the i th farmer and the j th alternative. The utility (U_{ij}) of a choice set, thus, comprises a deterministic part (V_{ij}) and a random component (ε_{ij}).

Assuming the random components in Equation 3.1 are independent and identically distributed (IID), with a Gumbel (0,1) distribution (Greene, 1997), then the conditional logit model (CLM) of the probability of the i th farmer choosing the j th alternative, is given by Equation 3.2:

$$P_{ij} = \frac{\exp(\lambda V_{ij})}{\sum_{l=1}^J \exp(\lambda V_{il})} \quad (3.2)$$

where J is the set of available agNPS pollution control alternatives and $\lambda = 1$.

Following Hole (2007b), the log-likelihood function of the CLM is given by Equation 3.3:

$$\log \mathcal{L} = \sum_{i=1}^N \sum_{j=1}^M y_{ij} \ln \left[\frac{\exp(V_{ij})}{\sum_{l=1}^M \exp(V_{il})} \right] \quad (3.3)$$

where y_{ij} is an indicator variable that is equal to 1 if the j th alternative is chosen by farmer i and zero otherwise, N is the total number of farmers ($i = 1, 2, \dots, N$), and M indicates the j th alternative in a choice set of the farmer ($j = 1, 2, \dots, M$). However, the CLM's strict assumption of the independence of irrelevant alternatives (IIA)²⁴ makes other models like the mixed logit model (MXL) and the latent class logit model (LCM) that relax this assumption more desirable. Furthermore, under the CLM's assumption that preferences are homogenous across respondents (Mariel et al., 2021), while farmers are heterogeneous because of socio-economic, attitudinal, and other factors such as farm size, cost structure, crop management practices, and awareness of the dangers of agNPS pollution, among others, farmers' preferences for the agNPS pollution control attributes are expected to be heterogeneous. This chapter, therefore, proceeded to estimate the LCM to account for the presence of heterogeneity.

The LCM is chosen over models of choice experiment, such as the MXL, because it is more informative and allows decision-makers to explicitly account for unobserved heterogeneity. The LCM does this by implicitly grouping individuals that exhibit similar (unobservable to the analyst) preferences into specific classes or sub-groups (Lagerkvist et al., 2012) based on some probabilities (Boxall and Adamowicz, 2002; Dietz and Atkinson, 2010). Such sub-groupings then make it possible for the different concerns of the different groups of farmers in the sample to be addressed with policies that are tailored to each group. In the context of policy, accounting

²⁴ The relative probabilities of two options being chosen are unaffected by the introduction or removal of other alternatives (Hausman and McFadden, 1984; Pan et al., 2016).

for heterogeneity provides a broader picture of distributional consequences and other impacts of policy actions, enables the prescription of policies that take equity concerns and divergent behaviour into account, and provides better insights into policy outcomes (Garrod et al., 2012; Greene, 2011).

Following Swait (1994), the functional form of the utility function for the LCM of the i th farmer's choice among J alternatives, given that the farmer belongs to class $c = 1, \dots, C$ is expressed as:

$$U_{ij/c} = \beta_c x_{ij} + \varepsilon_{ij/c} \quad (3.4)$$

where x_{ij} is a vector of attributes associated with alternative j , β_c is a class-specific parameter vector associated with the vector x_{ij} , and $\varepsilon_{ij/c}$ represents the random variations for the i th farmer. Assuming that the error terms are IID and follow a Type 1 extreme value distribution across classes and individuals, the probability that the i th farmer belongs to class c and selects alternative j is given by:

$$P_{ij/c} = \frac{\exp(\beta_c x_{ij})}{\sum_J \exp(\beta_c x_{ij})} \quad (3.5)$$

The joint probability of farmer i belonging to class c and selecting alternative j is $P_{ijc} = P_{ij/c} * P_{ic}$, where $P_{ic} = \frac{\exp(\delta Z_i)}{\sum_C \exp(\delta Z_i)}$ with Z_i being a vector of the class-specific parameters and δ being a scale factor = 1. Accordingly, the marginal probability of observing the i th farmer in class c choosing alternative j is expressed as:

$$P_{ij} = \sum_{c=1}^C \left[\frac{\exp(\beta_c x_{ij})}{\sum_J \exp(\beta_c x_{ij})} \right] \left[\frac{\exp(\delta Z_i)}{\sum_C \exp(\delta Z_i)} \right] \quad (3.6)$$

Equation 3.6 implies that the probability of selecting the j th alternative is equal to the sum over all latent classes c of the class-specific membership model, conditional on $(P_{ij/c})$ multiplied by the probability of belonging to that class (P_{ic}). The log-likelihood function to obtain the parameters δ and β_c is given as:

$$\log \mathcal{L} = \sum_{n=1}^N \sum_{j=1}^J y_{ij} \ln \left(\sum_{c=1}^C P_{ij/c} * P_{ic} \right) \quad (3.7)$$

where J is the total number of alternatives, y_{ij} is the observed frequency of choice of alternative j by the i th farmer. All other indicators have their usual meaning.

Following Beharry-Borg et al. (2013), the marginal willingness to accept (mWTA)—the maximum amount of compensation a farmer is willing to accept to forgo some farm management practices—is derived as follows:

$$WTA_{i,k,l} = \sum_{c=1}^C P_{ic} \left(\frac{-\beta_{c,attributes,asc}}{\beta_{c,compay}} \right) \quad (3.8)$$

where P_{ic} is the estimated matrix of individual n -specific probabilities of segment membership, and $\left(\frac{-\beta_{c,attributes,asc}}{\beta_{c,compay}} \right)$ is the ratio of implicit price for the attribute change being valued, relative to the probability of the status quo option. In addition to the mWTA estimates, the compensating surplus (CS) are estimated. Following Hanemann (1984), the CS is calculated as follows:

$$CS = -\frac{1}{\beta_{compay}} \left[\ln \left(\sum_i \exp(V_i^1) \right) - \ln \left(\sum_i \exp(V_i^0) \right) \right] \quad (3.9)$$

where β_{compay} is the coefficient of the compensation attribute. It captures the marginal utility of income. V_i^0 and V_i^1 represent the i th farmer's indirect utility functions before and after the change under consideration.

Following the specification of the LCM, an important aspect in its estimation is the determination of the suitable number of latent classes that not only provide numerical measures of fit but also an interpretable depiction of heterogeneity, simplicity, and theoretical consistency (Boxall and Adamowicz, 2002; Swait, 1994). To accomplish the latter, the same LCM is estimated repeatedly with a different number of classes, and inspecting which number leads to the best model using the minimum values of the following information criteria—Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Consistent Akaike Information Criterion (CAIC) (Killian et al., 2019; Vermunt, 2002).

In addition, given that this chapter is interested in estimating ‘random responses’, a recent addition to latent class modelling, it assumes some respondents sometimes make/give inattentive responses in choice experiment surveys (Malone and Lusk, 2018; Meade and Craig, 2012). Therefore, this chapter follows Lagerkvist et al. (2020) and Malone and Lusk (2018) to estimate a restricted LCM, allowing for a random response share. Here, the probability of class membership for one class is determined completely by the random utility term (Lagerkvist et al., 2020; Malone and Lusk, 2018), and systematic utility is restricted to zero for all attribute parameters in this given class (Lagerkvist et al., 2020). Accordingly, just as in the above, the same LCM is estimated repeatedly with a different number of classes, including one class with a random choice in each model (Lagerkvist et al., 2020), and inspecting which number leads to the best model.

3.4.2 Design of the Choice Experiment

3.4.2.1 Attributes, Levels and Validation

Based on the literature, interviews with experts in the region, and focus group discussions (FGDs), the chapter identified and used seven attributes²⁵ and their respective levels in the experiment. In addition to the CE variables, socio-demographic and attitudinal data of representative farmers like age, education, farm and off-income, and farming experience, among others, were collected. In the next few paragraphs, a description of the attributes, their justifications, and their respective levels is provided.

First, **fertilizers** promote plant growth and enhance crop yield, compensating for scarce water. But their excessive application aggravates the water-quality deterioration when they enter water sources through run-off, run-in, and leaching (Ribaudó et al., 1999). Fertilizer reduction is important in reducing agNPS pollution. This attribute is thus assigned three levels: apply current levels, apply 25% less, and apply 50% less. Beharry-Borg et al. (2013) and Li et al. (2019) used this attribute in their respective studies.

Second, **pesticides** are important in controlling crop pests and diseases. However, their excessive application is known to deteriorate water quality (Ribaudó et al., 1999) when they

²⁵ These are: (1) fertilizer reduction, (2) pesticide reduction, (3) agricultural waste recovery, (4) construction of an ecological ditch (vegetative strips), (5) duration of the program (in years), (6) monitoring for compliance, and (7) the compensation payment in USD per hectare per year.

enter water sources. Pesticide reduction is important in curbing agNPS pollution. Thus, it assigned three levels: apply current levels, apply 25% less, and apply 50% less. Christensen et al. (2011) and Li et al. (2019) used this attribute in their respective studies.

Third, **agricultural waste** includes mainly waste crop straw, empty fertilizer and pesticide packaging, plastic film, and animal waste—livestock and poultry dung and urine, etc. (Briassoulis et al., 2012). These enter the soil and water sources to impair water quality (Sims, Goggin, and McDermott, 1999; Li et al., 2019). Recovering agricultural waste is important in mitigating agNPS pollution. However, some crop straw, livestock, and poultry dung may not be considered waste in the study area as they are used for manure. Accordingly, this attribute is assigned three levels: use current recovery levels, recover 50% waste, and recover 100% waste. Li et al. (2019) and Lu et al. (2021) employed this attribute in their respective studies.

Fourth, **ecological ditches**, such as constructed wetlands and vegetative buffer strips (vegetative filter strips), are effective for controlling agNPS pollution and run-off. They are known to stabilize banks, trap sediments, and filter out pollutants, thereby sustaining water quality and protecting aquatic habitats and associated biota (Dabney, Moore, and Locke, 2006). They are increasingly being incorporated into farming systems to improve downstream water quality (Brodie et al., 2011) due to their ease of construction and low maintenance cost (Krutz et al., 2005). The length of the strip matters, as nitrate reduction was found to significantly increase as the length increased from 0 to 25 meters. But increasing the length from 25 to 50 meters did not significantly increase nitrate removal (Borin et al., 2005). This attribute is given three levels: no construction of an ecological ditch, construction of a 25-meter ecological ditch, and construction of a 50-meter ecological ditch. This attribute is one of the chapter's contributions to the agNPS pollution literature.

Fifth, **the duration of the programme** is the number of years that the agNPS pollution control programme will remain active. Remedying agNPS pollution through altering farming practices takes a while for the needed results to be realized. Therefore, this attribute is assigned 0, 5, and 10 years. Beharry-Borg et al. (2013) and Ruto and Garrod (2009) used this attribute in their respective studies.

Sixth, **monitoring** is widely applied in agri-environmental contracts to secure compliance and to prevent the problem of moral hazards (Broch and Vedel, 2012). Three levels are assigned

this attribute: *no* monitoring, partial monitoring (intra-monitoring—farmers monitoring each other), and external monitoring (random inspection visits from local authorities). Broch and Vedel (2012) and Greiner (2016) used this attribute in their respective studies.

Finally, **compensation payment** is the actual monetary transfer made to farmers to compensate them for their losses and the uncertainty associated with enrolling in the programme. Broch and Vedel (2012) cite Wilson (1997), who states that there exists a strong relationship between the participation decision and payment. While low payment was among the reasons for non-participation, finance was the main motivation to participate (Broch and Vedel, 2012). Four levels are assigned this attribute after consultations with farmers and industry experts: 0 ZAR²⁶ (USD 0), 9,000 ZAR (USD 600), 15,000 ZAR (USD 1,000), and 29,000 ZAR (USD 1,933) hectare⁻¹ year⁻¹. Hereafter, all compensation payments are specified in USD for ease of understanding and international readership. In addition, there are two farming cycles (major and minor farming seasons) in a year in the study area. However, since the programme is in years, per-annual payments are used, which are more acceptable (Ducos et al., 2009). Accordingly, all annual payments must be divided by 2 to get a cycle's payment. This attribute is common with WTA compensation studies (see Beharry-Borg et al., 2013; Li et al., 2019; Ruto and Garrod, 2009, etc.).

To ascertain the validity of the questionnaire and choice sets, two focus group discussions (FGDs) were conducted—one with farmers and extension service officers, and the other with stakeholders and industry experts from the Department of Agriculture, Forestry, and Fisheries (DAFF) and the De Beers Group (the world's largest producer and distributor of diamonds, but with a special interest in water quality in the LRB). The discussions centered on several issues, including the purpose of the research, input prices, and farmers' revenues, and sought expert opinions on how best to make the questionnaire more relevant, concise, and understandable to farmers. The discussions resulted in an upward revision of all the levels of compensation, from their initial levels of USD 0, USD 200, USD 600, and USD 1,400 hectare⁻¹ year⁻¹ to their current levels. Overall, the participants validated the other choice attributes and their levels.

²⁶ ZAR is the South African Rand, and USD is the United States Dollar. The exchange rate during the survey was 1 USD = 15 ZAR (in April 2021).

The questionnaire had four sections. Section A sought information on the farmers' socio-economic and demographic characteristics, including gender, age, educational level, farm income, farm size, and off-farm income. Section B had the DCE survey of the nine (9) choice tasks, farmers' perceptions of the ecological benefits of improved water quality, agNPS pollution awareness, and the debrief questions, among others. Sections C and D sought information on farmers' water conservation behaviour.

3.4.3 Experiment and Survey Design

Having determined the relevant attributes and levels, a fractional factorial design was generated, resulting in seventy-two (72) choice sets in total, which were "blocked" into eight (8) blocks of nine (9) choice sets. This means that there were eight (8) versions of the questionnaire, and each version included nine (9) choice sets with no dominant or redundant choice task. The experimental design was generated using Ngene 1.2.1 software (ChoiceMetrics, 2018). Each version of the questionnaire was randomly given to a farmer, and the farmer chose nine times to complete the questionnaire. Each choice set consisted of three alternatives—two agNPS pollution control alternatives (Option 1 and Option 2) and one opt-out alternative, or the status quo alternative (Option 3). Farmers who chose Option 1 or Option 2 desired improvements in water quality, whereas those who chose Option 3 were unwilling to undertake actions to improve water quality. These choices allowed us to assess the impact of remedying agNPS pollution in monetary terms.

The DCE question that preceded the nine (9) choice sets was as follows: Assuming you are being encouraged to control agNPS pollution by using less fertilizers, less pesticides, recover agricultural waste, construct ecological ditches that trap sediments and filter out nitrates/pollutants within your farm for a period of time to receive financial payments or compensations. Now, considering the benefits of improved water quality on your health, farm output, and the benefits of monetary payments, which of the following options will you choose?







You are now presented with nine choice sets consisting of two agNPS pollution control options and one status quo (neither) option. These choice sets describe different agNPS pollution control interventions for farmers, and you are required to choose the "option" that you would prefer in each case. The options differ in terms of specific attributes of agNPS pollution control. These choices will allow us to explore farmers' preferences on different aspects of agNPS

pollution control in this area. Specifically, in each question, two imaginary “options” are provided. Please think of a choice for each option as if you were making a real-world decision and tell us whether you most prefer “Option 1” or “Option 2”. If you do not like either option, please choose “Neither” (I prefer my current farming practices). Please, before making a choice on which of the following **options to choose**, please remember that sincerity, honesty, integrity, and truthfulness are very important.

For the survey, face-to-face interviews were employed. With this method the enumerators were able to explain the purpose of the research, background, difficult concepts, and choice tasks objectively to farmers in their own language. Before commencing the interviews, the enumerators were taken through a thorough two-day training exercise to master the questionnaires and interview techniques. A detailed album with colored pictures of all the attributes and their respective levels was given to the enumerators to help explain the attributes in both words and pictures to facilitate the understanding of respondents (Brown, Ajzen, and Hrubes, 2003).

An example of one of the choice sets used in the discrete choice experiment survey is presented in Table 3.2.

Table 3. 2: An Example of One of the Choice Sets Used in the DCE

Attribute	Picture	Option 1	Option 2	Neither
Fertilizer application		Reduce by 50%	Reduce by 50%	
Pesticide application		Reduce by 25%	Reduce by 50%	
Agricultural waste recovery		100% recovery	50% recovery	
Construction of ecological ditches		Not required	25 meters	
Duration of the program	0 5 10	5 years	10 years	
Monitoring for compliance		Partial monitoring	No monitoring	
Compensation payment		USD 1,933	USD 1,000	
Which OPTION do you prefer?		<input type="radio"/>	<input type="radio"/>	

3.4.4 Sampling and Data

A two-stage sampling approach involving purposive and random sampling procedures were used in selecting the study area and the farmers. In the first stage, Folovhodwe and Tshiombo farming communities in the Musina and Thulamela local municipalities, respectively, were purposively selected not only because these are agrarian hubs in the Vhembe District of the Limpopo Province, but also because the two farming communities are located near important tributaries of the Limpopo River and house major Irrigation Schemes (the Nwanedi and Tshiombo Irrigation schemes). In addition, the frequent droughts in the area, the imposition of water use restrictions, how farmers are responding to water scarcity in the area as well as the area having a large number of documented and undocumented farmers with well-organized farmer associations that are readily accessible also informed the choice of these two farming communities. The Vhembe District has a total agricultural household population of 74,073 (Statistics South Africa, 2022). In the second stage, a simple random sampling technique was applied to select farmers from a population of both documented and undocumented farmers on the farming blocks in the study area. Each farmer on one of the eight blocks, whether documented or undocumented, had an equal chance of being selected into the sample. In coordination with the farmers' leaders and extension services officers, farmers were informed of the impending interviews for the research. Enumerators then went to farmers on their farms and conducted one-on-one interviews with farmers using structured questionnaires. If a farmer was not present, the enumerators had to return twice, but if a farmer expressed unwillingness to participate, the enumerators moved on to the next farmer on the block on the irrigation site.

Before commencing the interviews, the 11 enumerators, who had varying levels of completed education—first degree, college, or Matric (high school or secondary school)—were taken through a rigorous two-day training exercise to master the questionnaires and interview techniques. Data collection lasted one month, between March and April 2021. A total of 559 questionnaires were used in the interviews. However, at the data entry phase, seven (7) questionnaires were rejected because of incomplete, blank-choice tasks and inconsistent information. This high success rate of questionnaires completed was a result of the training the enumerators received, and the thorough checks put in place to scrutinize each questionnaire before accepting it. In these checks, if any errors or incomplete fields were detected, the enumerators were requested to go back to the respective farmer(s) to complete the questionnaire before it was accepted.

3.5 Results and Discussions

3.5.1 Descriptive Statistics

The descriptive statistics of the socio-demographic and attitudinal characteristics in Table 3.3 show that females constitute 55.25% of the sample. This is not surprising, as the 2011 South Africa Population Census shows that females constitute 54.35% of the population in Folovhodwe and 53.71% in Tshiombo (Census 2011).

Table 3.3: Descriptive Statistics of the Covariates

Covariates and description	% of sample (N = 552)	Mean	Std. dev.	Min	Max
Gender (= 1, if farmer is female, 0 otherwise)		1.55	0.49	1	2
<i>Male</i>	45				
<i>Female</i>	55				
Age (continuous, age of the farmer)		50.95	15.11	20	95
Education (= 1, if farmer is literate farmer, 0 otherwise)		0.94	0.24	0	1
<i>Non literate</i>	6				
<i>Literate</i>	94				
Farming experience (continuous, years of farming)		16.22	9.88	1	55
Farm ownership (= 1, if farm is owned by the farmer, 0 otherwise)		0.93	0.26	0	1
<i>Leased, rented, or government</i>	7				
<i>Owned by the farm</i>	93				
Diversified farming (= 1, if farm is diversified, 0 otherwise)		0.92	0.26	0	1
<i>Specialized farming</i>	7				
<i>Diversified farming</i>	93				
Source of water (= 1, if surface water is used, 0 otherwise)		0.11	0.31	1	2
<i>Surface</i>	89				
<i>Underground</i>	11				
Farm income (= 1, if income is more than USD 733 ²⁷ , 0 otherwise)		0.800	0.400	0	1
<i>Annual farm income less than USD 733</i>	20				
<i>Annual farm income greater than USD 733</i>	80				
Off-farm income (= 1, if farmer has off-farm income, 0 otherwise)		0.31	0.46	0	1
<i>No off-farm income</i>	69				
<i>Has off-farm income</i>	31				

²⁷ This USD 733 [11, 000 South African Rands (ZAR) converted to United States Dollars (USD) 733.33 using the exchange rate 1 USD = 15 ZAR, prevailing during the survey in April 2021] annual farm income in the study area is in accordance with Statistics South Africa (2022) and De Cock et al. (2013), who report that total farm income per month of smallholder farmers in the Limpopo Province may range from USD 14 (minimum) to about USD 2,334 (maximum). The data for the income variable was initially solicited based on income groups. However, these income groups did not behave as expected in the estimations. The variable was thus converted into a dummy variable, where the lower bound of the modal class became the basis for sectionalizing the data. The USD 733 was the lower bound of the modal class. Accordingly, farmers earning annual farm incomes less than this threshold (USD 733) were labelled '0' (farmers with annual farm income less than USD 733), whereas those earning annual farm incomes greater than this threshold were labelled '1' (farmers with annual farm income more than USD 733). This was done because, in statistical theory, the mean (average) and the median are mostly located in the modal class for data that follows a normal distribution.

Table 3.3: (continued)

Covariates and description	% of sample (N = 552)	Mean	Std. dev.	Min	Max
Farm size (= 1, if size is more than 3.27 hectares, 0 otherwise)		0.30	0.46	0	1
<i>Cultivates less than or equal to 3.27</i>	70				
Cultivates greater than 3.27 hectares	30				
Member of a cooperative (= 1, if farmer is a member, 0 otherwise)		0.62	0.49	0	1
<i>No</i>	38				
Yes	62				
Secured land rights (= 1, if farmer has secured rights, 0 otherwise)		0.76	0.43	0	1
<i>No</i>	24				
Yes	76				
Awareness of agNPS pollution (= 1, if farmer is aware, 0 otherwise)		0.44	0.49	0	1
<i>No</i>	55				
Yes	45				
Perceived benefits of the programme (= 1, if benefits are perceived, 0 otherwise)		0.98	0.13	0	1
<i>No</i>	2				
Yes	98				

Source: Survey data (April 2021).

The average age is 51. With regards to education, 94% are literate. The average farming experience is 14 years. Ninety-three percent of farmers own the farms they work on, while the rest rent or work on leased lands. Ninety-three percent of the farmers have diversified farms, where they rear several animals and grow multiple crops at the same time. Further, 89% of the sample used surface water, while 11% used groundwater. Farmers with an annual farm income greater than USD 733 (in April 2021) constituted 80% of the sample, while 69% had no off-farm income. The average farm size is 3.27 hectares. However, only 30% of farmers have farm sizes greater than 3.27 hectares. Sixty-two percent are members of a cooperative, while 76% have secured land rights. Fifty-five percent have no awareness of agNPS pollution, while 98% believe that they stand to benefit if water quality is improved.

To ascertain the representativeness of the sample, the descriptive statistics from this chapter were compared to those of the Vhembe District Municipality in the 2011 Population Census. These statistics, in most cases, matched well and proved that the sample is fairly representative. For instance, the chapter's descriptive statistics show that females constituted 55% of the sample. While the 2011 Population Census puts the figure of women at 54% each in both Folvhodwe and Tshiombo (Statistics South Africa, 2011), at the provincial level, 53% were

females in the Limpopo Province (Statistics South Africa, 2011). While at the national level, females were 51% (Statistics South Africa, 2011).

The response rate was also compared to the minimum sample size requirements following Cochran (1963) and Yamane (1967). In Equation 3.10, Cochran (1963) assumes there is a large population, but the variability in the proportion that will adopt a practice is unknown, just as in the case of this chapter. Therefore, assuming a $p = 0.5$ (maximum variability), a 95% confidence level and $\pm 5\%$ precision, the resulting sample size required is given as

$$n_0 = \frac{Z^2 pq}{e^2} = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 385 \text{ farmers} \quad (3.10)$$

where n_0 is the sample size, Z^2 is the abscissa of the normal curve that cuts off an area α at the tails ($1 - \alpha$ equals the desired confidence level, e.g., 95%), e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population and q is $1 - p$. The value for Z is found in the statistical table which contains the area under the normal curve.

Similarly, in Equation 3.11, the sample size is calculated following Yamane (1967) and using the population of 74,073, which is number of agricultural households in the Vhembe District Municipality.

$$n = \frac{N}{1 + N(e)^2} = \frac{74073}{1 + 74073(0.05)^2} = 398 \text{ farmers} \quad (3.11)$$

where n is the sample size, N is the population size and e is the level of precision.

Furthermore, if it is even assumed that both documented and undocumented farmers total about 90,000, which is unlikely because it is estimated that in the entire Limpopo Province there were about 273,000 smallholder farmers (Statistics South Africa, 2002), Accordingly, this estimation yields a representative sample of 398 farmers.

$$n = \frac{N}{1 + N(e)^2} = \frac{90000}{1 + 90000(0.05)^2} = 398 \text{ farmers} \quad (3.12)$$

Consequently, based on these estimations, financial and time constraints, a sample of 552 farmers was chosen. This sample passed the minimum sample size requirements for adequate

power analysis of Cochran (1963) and Yamane (1967). Chaikaew, Hodges, and Grunwald (2017) used these approaches to determine the sample size of their DCE study. Similarly, Nylund-Gibson and Choi (2018) emphasized that for DCE studies involving the LCM, a sample of 300 or more cases is desirable. Accordingly, this sample of 552 farmers is adequate for power analysis.

3.5.2 Conditional Logit Model (CLM)

In Table 3.4, the results of the CLM are reported. The CLM is estimated such that the probability of selecting any alternative is a function of the agNPS pollution control attributes and the alternative-specific constant (*ASCsq*). The *ASCsq* is a dummy variable representing the non-control alternative. That is, it is 1 for the status quo option and 0 otherwise (Li et al., 2019). A positive parameter estimate of the *ASCsq* indicates that farmers prefer their current situation and are unwilling to alter their current farming practices to improve water quality. Whereas a negative parameter estimate of the *ASCsq* means that farmers prefer the agNPS pollution control alternatives and are willing to alter some farm management practices to improve water quality (Li et al., 2019; Train, 2009).

Table 3. 4: Results of the CLM

Indicators	Coefficients	z-values
Reduce fertilizer use by 25%	-0.3298***	6.11
Reduce fertilizer use by 50%	-0.4326***	8.01
Reduce pesticide use by 25%	-0.2231***	4.29
Reduce pesticide use by 50%	-0.3932***	7.56
50% agricultural waste recovery rate	-0.0719	1.33
100% agricultural waste recovery rate	-0.0282	0.53
Construct 25-meter ecological ditch	-0.2610***	4.71
Construct 50-meter ecological ditch	-0.3974***	7.15
5-year duration programme	-0.3788***	6.84
10-year duration programme	-0.8773***	16.02
Partial monitoring	-0.3281***	6.31
External monitoring	-0.4279***	7.83
Compensation payment	0.00006***	20.35
<i>ASCsq</i>	-2.2249***	21.26
Log-likelihood	-4014.04	
Prob > chi ²	0.0000	
AIC	8056.09	
BIC	8162.62	
N	552	

Note: ***, **, and * represent the levels of significance at 1%, 5% and 10% respectively.

^a The base categories are the reference point for the indicators.

The results show that the coefficient of ASCsq is negative and highly significant. This indicates that the farmers are willing to alter their current undesirable farming practices. Similarly, the coefficient of compensation payment is positive and highly significant. This suggests that farmers are willing to accept compensation payments to change their inherent behaviours to control agNPS pollution, all else being constant. These results further show that the coefficients of all the other agNPS pollution control attributes have the expected negative *a priori* signs and are highly significant, except that the different levels of agricultural waste recovery are insignificant but have the right signs. These results suggest that, in comparison with the status quo alternative, fertilizer and pesticide reductions, the construction of ecological ditches, monitoring, and the duration of the programme reduce farmers' likelihood of participating in the scheme to control agNPS pollution, all else being constant. The aversion (depicted by negative signs of the coefficients) by farmers is not a rejection of the programme, but an indication that the current compensation levels are not sufficient to motivate them to change their status quo farm management practices. The reason is that the status quo option often offers farmers the highest level of utility. Therefore, accepting to participate in the programme with its current compensation levels is a decrease in their utility (disutility). Thus, to be incentivized to shift from the status quo alternative or join the scheme, the current compensation levels must be increased or at least be adequate enough to induce such a shift. These findings are in line with Beharry-Borg *et al.* (2013).

3.5.3 The Latent Class Logit Model (LCM)

The information criteria presented in Table 3.5 suggest both BIC and CAIC favour the five classes (4 preference classes and one random choice class), while AIC favours the seven classes (6 preference classes and one random choice class).

Table 3. 5: Information Criteria for Selecting the Number Classes for the LCM.

Number of classes	Log likelihood	AIC	BIC	CAIC
1 preference class + 1 random choice class	-3987.15	8004.30	8069.01	8084.01
2 preference classes + 1 random choice class	-3777.22	7614.44	7743.85	7773.85
3 preference classes + 1 random choice class	-3668.21	7426.42	7620.53	7665.53
4 preference classes + 1 random choice class	-3530.97	7211.93	7535.45*	7610.45*
5 preference classes + 1 random choice class	-3494.98	7169.96	7558.18	7648.18
6 preference classes + 1 random choice class	-3461.78	7131.55*	7580.16	7684.16

Source: Survey data (April 2021).

According to Boxall and Adamowicz (2002) and Swait (1994), lower BIC and CAIC are the most reliable and preferred for selecting the number of classes for LCMs. Based on the BIC and CAIC statistics, the five-class latent model (4 preference classes and one random choice class) was selected. However, after estimating this model, it was immediately realized that some of the model's estimates did not make sense theoretically. For instance, some estimated coefficients of ASCsq as well as compensation payments were zero in some classes. In this regard, Muthén and Muthén (2000), Nylund, Asparouhov, and Muthén (2007), and Weller, Bowen, and Faubert (2020) advised that the information criteria should always be evaluated in conjunction with theoretical interpretability. In view of this, the four-class latent model (3 preference classes and 1 random choice class) was rather estimated. This model had no such theoretically interpretable flaws. Consequently, the rest of the analyses in this chapter are based on this four-class latent model (FCLM). A similar approach was adopted by Lagerkvist et al. (2020) when their information criteria-selected model failed to yield results that were theoretically interpretable.

The results of the FCLM in Table 3.6 show an uneven distribution of farmers' preferences across the classes. The percentage of farmers associated with classes 1, 2, 3, and 4 is 49%, 22%, 26%, and 3%, respectively. The parameter estimates differed not only in terms of magnitude but also in terms of signs. In addition, not all the parameter estimates are statistically significant in these classes. The FCLM's results are an improvement in the predictiveness of the sample over the CLM. This is shown by the FCLM's decreased log-likelihood, AIC, and BIC statistics. However, the general aversion of farmers to reduce fertilizer and pesticide use, construct ecological ditches, and be monitored for a period of time to control agNPS pollution in the CLM is also evident in the FCLM, especially for classes 2 and 3.

3.5.3.1 The ASCsq and the Compensation Payment Across the Classes

The results show that the coefficients of the ASCsq for classes 1, 2, and 3 are negative and highly significant, as expected. This indicates that farmers in classes 1, 2, and 3, relative to the status quo option, are willing to change some of their farm management practices to improve water quality, just as in the CLM. In addition, the coefficients of compensation payment for these classes are positive and highly significant, suggesting that farmers in these classes are willing to accept financial compensation to alter their undesirable farming practices to control agNPS pollution.

Table 3. 6: Results of the Four-Class Latent Logit Model with Covariates

Label	Class 1		Class 2		Class 3		Random choice	
	Low resistance farmers		High-resistance farmers		Moderate -resistance farmers		—	
Class share (in %)	49		22		26		3	
	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
Reduce fertilizer use by 25%	0.073	0.86	-1.702***	9.58	-0.274*	1.70	0	—
Reduce fertilizer use by 50%	0.055	0.62	-2.294***	10.61	-0.579***	3.38	0	—
Reduce pesticide use by 25%	-0.064	0.85	-1.316***	7.85	-0.149	0.94	0	—
Reduce pesticide use by 50%	-0.138*	1.76	-1.339***	8.31	-0.630***	3.68	0	—
50% agricultural waste recovery	0.077	0.98	-0.768***	4.48	-0.110	0.65	0	—
100% agricultural waste recovery	0.013	0.17	-0.457***	3.12	0.318**	1.92	0	—
Construct 25-meter ecological ditch	-0.146*	1.82	-0.865***	5.12	-0.014	0.08	0	—
Construct 50-meter ecological ditch	-0.231***	2.82	-1.038***	6.09	-0.397**	1.98	0	—
5-year duration programme	0.027	0.33	-0.336**	1.93	-2.193***	9.80	0	—
10-year duration programme	-0.005	0.07	-1.092***	6.45	-4.325***	13.84	0	—
Partial monitoring	-0.255***	3.34	-0.801***	5.03	-0.295**	2.03	0	—
External monitoring	-0.529***	6.56	-0.775***	4.49	-0.128	0.81	0	—
Compensation payment	0.00005***	10.70	0.00009***	7.97	0.00012***	11.71	0	—
ASCsq	-4.033***	9.14	-3.341***	9.56	-2.710***	8.42	0	—

Table 3.6: (Continued)

	Class 1		Class 2		Class 3		Random choice		
Label	Low-resistance farmers		High-resistance farmers		Moderate -resistance farmers		—		
Class share (in %)	49		22		26		3		
Class membership function									
	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	
Gender (1 = Female)	0	—	0.292	0.77	-0.426	1.29	0.954	0.84	
Age in years	0	—	0.052***	3.09	0.006	0.35	-0.087	1.36	
Education (1 = Literate)	0	—	-1.522**	2.44	-0.586	0.81	11.156	0.07	
Farming experience in years	0	—	-0.050**	2.11	-0.019	0.74	0.061	0.86	
Farm ownership (1 = Owned by farmer)	0	—	-0.827	1.09	-0.773	1.15	13.794	0.10	
Diversified farming (1 = Diversified)	0	—	-0.489	0.46	-2.074***	3.30	12.015	0.09	
Source of water (1 = Surface)	0	—	1.173**	2.24	0.075	0.14	-0.123	0.06	
Farm income (1 = Greater than USD 733)	0	—	-1.892***	5.19	-1.319***	3.37	-0.597	0.43	
Off-farm income in USD (1 = Yes)	0	—	0.852**	2.15	-0.152	0.39	1.165	0.94	
Farm size (1 = Greater than 3.27 hectares)	0	—	0.511	0.88	3.014***	7.38	3.825**	2.47	
Membership of a cooperative (1 = Yes)	0	—	-0.401	1.13	0.975**	2.52	-0.924	0.86	
Security of tenure to farmland (1 = Yes)	0	—	2.357***	2.80	1.469***	3.30	-3.217**	2.00	
Awareness of agNPS pollution (1 = Yes)	0	—	1.595***	4.21	1.146***	2.98	1.916	1.22	
Perceived benefits from the scheme (1 = Yes)	0	—	-3.146**	2.28	-1.352	0.85	12.997	0.09	
Constant	0	—	-0.683	0.33	1.849	0.92	-49.349	0.37	
Model statistics									
Log-likelihood								-3546.72	
AIC								7267.45	
BIC								7642.73	
N								552	

Note: ***, **, and * represent the levels of significance at 1%, 5%, and 10% respectively

This result shows the importance of financial compensation in incentivizing farmers and increasing their willingness to adopt sustainable farming practices that lessen agriculture's negative impact on water quality. At present, farmers do not receive compensation or any other incentive to alter their farming practices to control agNPS pollution in South Africa. Thus, introducing compensations as a new instrument may lead to greater interest and maximum participation for greater water quality improvements.

3.5.3.2 The Non-monetary Scheme Attributes for Class 1—Low-Resistance Farmers

The results for the non-monetary attributes for class 1 show that pesticide reduction by 50%, the different levels of ecological ditches, and monitoring are negative and significant. This result suggests that, relative to their status quo levels, pesticide reduction by 50%, the different levels of ecological ditches and monitoring reduce the likelihood of class 1 farmers participating in the scheme to control agNPS pollution, all else being constant. These farmers are, however, indifferent to the rest of the choice attributes.

The descriptive statistics across the classes presented in Table 3.7 show that the average age of this class is 50 years. Females constitute 60% of the class, while 96% are literate. The average farming experience is 14 years. Some 95% are owners of the farms they work on. Further, 95% of the farmers in this class have diversified their farms. Ninety-two percent use surface water. In terms of farm income, 73% have an annual farm income greater than USD 733, while only 29% have an off-farm income. On farm size, only 14% of the class cultivate farm sizes larger than 3.27 hectares. Also, 61% belong to a cooperative association, while some 67% have secured rights to their lands. Only 28% of farmers in this class are aware of agNPS pollution. However, 99% perceive that they will benefit from the improved quality of water through the programme. The marginal WTA (mWTA) estimates across the classes (Table 3.8) show that even though this class has the highest compensation requirement to change from the status quo option, its compensation requirements for the choice attributes are low relative to the other classes. Therefore, the class is labeled as **low-resistance farmers**.

Table 3. 7: Descriptive Statistics Across the Classes

Label	Class 1	Class 2	Class 3	Random choice	Test of significant differences	
	Low-resistance farmers	High-resistance farmers	Moderate-resistance farmers	—		
Class share (in %)	49	22	26	3		
Covariates					χ^2	P-value
Gender ^b (1 = Female)	60	59	44	67	305.75	0.000
Age ^a	50	54	50	43	246.72	0.000
Education ^b (1 = Literate)	96	87	95	100	357.40	0.000
Farming experience ^a	14	15	14	10	6.570	0.087
Farm ownership ^b (1 = Owned by farmer)	95	91	90	100	129.36	0.000
Farm type ^b (1 = Diversified)	95	97	85	100	541.35	0.000
Source of water ^b (1 = Surface)	92	83	89	88	201.30	0.000
Farm income ^b (1 = Greater than USD 733)	73	30	66	77	18.000	0.000
Off-farm income ^b (1 = Yes)	29	39	29	22	135.67	0.000
Farm size ^b (1 = Greater than 3.27 hectares)	14	12	71	78	4.800	0.000
Membership of a cooperative ^b (1 = Yes)	61	37	83	56	15.000	0.000
Security of tenure to the farmland ^b (1 = Yes)	67	92	82	44	971.25	0.000
Awareness of agNPS pollution ^b (1 = Yes)	37	52	52	44	333.46	0.000
Perceived benefits from the program ^b (1 = Yes)	99	94	98	100	255.12	0.000

Note: ^aKruskal-Wallis test,

^bChi-square test.

3.5.3.3 The Non-monetary Scheme Attributes for Class 2—High-Resistance Farmers

All the utility coefficients for class 2 are negative and highly significant. This result implies that, relative to the status quo preference, the different levels of fertilizer and pesticide reduction, agricultural waste recovery, construction of ecological ditches, programme durations, and monitoring reduce the likelihood of class 2 farmers participating in the scheme to control agNPS pollution, all else being constant. The waste recovery attribute that was insignificant in the CLM is significant in this class, suggesting that the LCM provides more information on farmers' preferences than the CLM.

The class's descriptive statistics show that farmers in the class are relatively older (54 years) compared to the other classes. Females constitute 59%, while 87% are literate. The class has the highest average farming experience (15 years). Some 91% are owners of their farms. Ninety-seven percent have diversified their farms, with some 87% using surface water. Only 30% (least among the classes) have an annual farm income greater than USD 733, while only 39% have an off-farm income. Further, only 12% of the class cultivate farm sizes greater than 3.27 hectares. Thirty-seven percent are members of a cooperative. Some 92% (the largest) have secured rights to their lands. Fifty-two percent of the class is aware of agNPS pollution, while 94% perceive to benefit if water quality is improved. Though the mWTA compensation requirement of this class to change from the status quo option is moderate relative to the other classes, its compensation requirements for the choice attributes are very high compared to the other classes. Class 2 farmers are thus classified as **high-resistance farmers**.

3.5.3.4 The Non-monetary Scheme Attributes for Class 3—Moderate-Resistance Farmers

The utility coefficients in class 3 show that the different levels of fertilizer reduction, pesticide reduction by 50%, construction of the 50-meter ecological ditch, the different durations of the programme and partial monitoring are negative and highly significant. This suggests that the different levels of fertilizer reduction, pesticide reduction by 50%, construction of the 50-meter ecological ditch, the different durations of the programme and partial monitoring reduce the likelihood of the farmers in class 3 participating in the scheme to control agNPS pollution, all else being constant. Conversely, agricultural waste recovery by 100% increases the likelihood of class 3 farmers accepting the scheme to control agNPS pollution, all else being constant. However, pesticide reduction by 25%, agricultural waste recovery by 50%, construction of the 25-meter ecological ditch, and external monitoring are insignificant in this class.

The average age of the farmers in the class is 50, just like in class 1. Females constitute 44% (least compared to the other classes) of the class, while 95% are literate. The average farming experience, just like in class 1, is 14 years, while 90% own the farms they operate on. Some 85% (least compared to the other classes) have diversified their farms. Eighty-nine percent use surface water. Only 66% of the farmers in the class have an annual farm income greater than USD 733, while some 29% have an off-farm income. For farm size, 71% (highest relative to the other classes) of the class cultivate farm sizes greater than 3.27 hectares. Eighty-three percent are members of a cooperative, whereas 82% have secured rights to their lands. Some 52% are aware of agNPS pollution, while 98% perceive to benefit if the quality of water is improved. This class's mWTA compensation requirements to shift from the status quo option is the least relative to the other classes, but its compensation requirements for the choice attributes are moderate compared to the other classes. Therefore, the class is characterized as **moderate-resistance farmers**.

3.5.3.5 The Random Choice Class

Regarding class 4, the random choice class, the results show that a relatively smaller proportion (3%) of farmers were classified as making random choices or providing inattentive responses. This is in line with the findings of the two debrief questions in the choice survey: (1) the level of difficulty answering the choice questions, and (2) the extent of the farmer's understanding of the choice questions. This result shows that, for question (1), 15% of farmers found the choice task to be 'fairly difficult'. Another 17% found the choice task as 'neither difficult nor easy', while 68% found the choice task to be 'fairly easy'. With question (2), 87% 'fully understood' the choice task, 13% 'partially understood' it, while no farmer stated that they 'did not understand' the choice task. These statistics attest that the majority of farmers understood the choice experiment task. In addition, farmers were not cognitively burdened, nor did they plainly neglect the choice tasks, nor was there a disinterest for the choice attributes of the chapter, all leading to inattentive responses.

This low rate (3%) of inattentive choice responses is attributed to the stringent measures put in place to ensure the quality of the data collected. These included the quality training given to the enumerators, the use of a detailed album with colored pictures of attributes and their levels to aid understanding of the choice sets, communicating and explaining the choice tasks in farmers own language, and the thorough checks put in place to scrutinize questionnaires before

accepting them. The descriptive statistics of this class show that the farmers are the youngest (43 years) and most inexperienced (10 years) relative to the other classes. This might have resulted in their random choices. Nevertheless, their responses contribute to the validity of the preferences of farmers in the other classes, for which attribute choices were not random.

3.5.3.6 The Covariates of the LCM

Finally, regarding the covariates of the LCM, the membership coefficients for class 1 are normalized to zero to allow the remaining coefficients of the model to be identified and interpreted relative to the normalized class (Boxall and Adamowicz, 2002). Thus, the direction of significant coefficients (+ / -) of the covariates are interpreted as a farmer is more (or less) likely to belong to the respective class than to class 1. Older farmers with surface water sources who have off-farm income activities, secured land rights to their farmlands, and are aware of the dangers of agNPS pollution are more likely to have their preferences aligned with class 2. Whereas experienced, literate farmers with an annual farm income greater than USD 733 who perceive benefit if the quality of water is improved are less likely to be associated with class 2, all else being constant. Furthermore, farmers who are members of a cooperative with secured land rights to their farms with a farm size greater than 3.27 hectares are more likely to have their preferences aligned with class 3. However, diversified farmers with an annual farm income greater than USD 733 are less likely to have preferences aligned with this class, all else being constant. For the random choice class, farmers with farm sizes greater than 3.27 hectares are more likely to have their preferences aligned with this class, whereas farmers with secured land rights are less likely to be associated with this class.

Overall, the FCLM provided a good fit to the choice data, and the classes appeared to be an interpretable depiction of farmers' preferences for the agNPS pollution programme proposed. In essence, the results fit established patterns of farmers' behaviour in their acceptance of these programmes and are consistent with previous findings on water quality improvement-related AESs studies such as Beharry-Borg et al. (2013), Christensen et al. (2011), and Li et al. (2019).

3.5.4 Marginal Willingness to Accept (mWTA) Compensation

The results for the mWTA estimates by class are reported in Table 3.8. The weighted average across the classes is also estimated to gain further insight into farmers' preference patterns. A

comparison of the mWTA compensation requirements across the classes shows that the aversions expressed by farmers in the various classes for some of the choice attributes are now reflected in monetary terms. Where the aversions were strongest, farmers required very high compensation payments to be induced to alter or adopt those sustainable farming practices to deliver improvements in water quality. For instance, low-resistance farmers (class 1) have the strongest aversion to monitoring relative to the other classes. This aversion is, however, strongest with external monitoring. Therefore, to compensate these farmers adequately, they require USD 784 to be motivated to accept external monitoring, all else being constant. This is not surprising, because according to Broch and Vedel (2012), monitoring generally has a negative impact on farmers' utility.

Furthermore, high-resistance farmers (class 2) have the strongest aversion to fertilizer and pesticide reductions relative to the other classes. The aversion, however, is strongest with a fertilizer reduction of 50%. To compensate these farmers sufficiently to reduce fertilizer and pesticides, they require USD 1,331 and USD 1,793 hectare⁻¹ year⁻¹ for the 25 and 50% reductions in fertilizer, respectively, and USD 1,028 and USD 1,047 hectare⁻¹ year⁻¹ for the 25 and 50% reductions in pesticides, respectively.

Also, relative to the other classes, moderate-resistance farmers (class 3) have the strongest aversion to the duration of the programme, with the aversion being strongest toward the 10-year duration of the programme. To adequately induce these farmers to accept the duration of the programme, they require USD 1,208 and USD 2,382 hectare⁻¹ year⁻¹ for the 5- and 10-year durations of the programme, respectively. Conversely, however, farmers of this class relative to the other classes are willing to pay USD 175 hectare⁻¹ year⁻¹ for 100% agricultural waste recovery, all else being constant.

However, it should be noted that some of the compensation requirements of some sub-farmer groups in this chapter on hectare⁻¹ year⁻¹ basis may be high compared to the European or global averages for such AESs. A few reasons may account for these figures. First, land ownership issues are very sensitive in South Africa because of some historical antecedents (for more details, see Daniels, 1989; Moyo, 2014; Ntsebeza and Hall, 2007). This and the current debates that were ongoing on land expropriation created some misinformation and pushed some farmers to even shy away from the survey, saying the survey was a ploy to source information to take their lands.

Table 3. 8: Marginal WTA Compensation in USD Per Hectare Per Year by Class

Label	Class 1	Class 2	Class 3	Random choice	Weighted average
	Low-resistance farmers	High resistance farmers	Moderate-resistance farmers	—	
Class share (in %)	49	22	26	3	
Reduce fertilizer use by 25%	-109 (-356/139)	1,331*** (978/1,683)	151* (-24/326)	—	282*** (138/426)
Reduce fertilizer use by 50%	-81 (-335/173)	1,793*** (1,323/2,263)	319*** (129/508)	—	442*** (285/601)
Reduce pesticide use by 25%	95 (-126/316)	1,028*** (709/1,348)	82 (-88/250)	—	278*** (166/429)
Reduce pesticide use by 50%	205* (-27/437)	1,047*** (708/1,387)	347*** (154/539)	—	427*** (292/561)
50% agricultural waste recovery	-115 (-344/115)	600*** (303/897)	61 (-124/245)	—	93 (-39/224)
100% agricultural waste recovery	-20 (-250/211)	357*** (109/605)	-175** (-350/0.24)	—	23 (-106/151)
Construct 25-meter ecological ditch	216 (-18/451)	678*** (395/958)	8 (-174/166)	—	260*** (125/394)
Construct 50-meter ecological ditch	342*** (98/586)	810*** (485/1,137)	219** (-5/443)	—	408*** (270/547)
5-year duration programme	-40 (-273/194)	262** (10/515)	1,208*** (951/1,465)	—	361*** (222/500)
10-year duration programme	8* (-234/250)	854*** (548/1,159)	2,382*** (2,010/2,754)	—	829*** (665/994)
Partial monitoring	378*** (144/611)	626*** (345/608)	163*** (4/321)	—	370*** (240/500)
External monitoring	784*** (510/1,057)	606*** (278/933)	70 (-101/241)	—	542*** (394/691)
ASCsq	5,973*** (4,262/7,685)	2,811*** (1,613/3,610)	1,492*** (1,010/1,975)	—	—

Note: ***, **, and * represent the levels of significance at 1%, 5%, and 10% respectively.

^b 95% confidence intervals in brackets

^c The exchange rate during the survey was 1 USD = 15 ZAR (in April 2021).

^c All payments are to be divided by 2 since there are two (2) farming cycles in the study area.

If some farmers thought this way, then it is possible that some of them also might have inflated their WTA requirements to prove that their farmlands were not cheap, in case the research was actually a ploy to source information to take over or buy their farmlands. This might have impacted the WTA requirements if some farmers made choices based on this misinformation, hence the high compensation requirements.

Second, the farmers in this chapter, just like farmers anywhere else, perceive fertilizer reductions as reductions in yield/output and profits. If this is the perception, then the farmers in this chapter suffer a double jeopardy. This is because these farmers do not only suffer reductions in yield/output and profits when they reduce their fertilizers, but they also miss their production targets and contracts with the big companies like Tiger Brands Limited (a major distributor of food products in 22 African countries and one of the top 40 companies on the Johannesburg Stock Exchange), a major buyer of the produce of farmers in the area. Upon signing these contracts with farmers, farmers secure a market for their produce, input finance support, offtake agreements, and agrarian and technical support (Tiger Brands, 2022). This way, Tiger Brands Limited hopes to help the farmers develop into commercial farmers. Therefore, it is in the interest of farmers to meet their production targets, which are a prerequisite for Tiger Brands Limited and the other big companies to continue to buy their produce. A fall in production targets simply results in Tiger Brands Limited or the big companies canceling their contracts with the farmers. If this happens, farmers will not have a ready market for their produce and will also not enjoy the other benefits these big companies offer. Therefore, for the farmers in this chapter, all these contractual agreements, production targets, and benefits are factored into compensation requirement considerations and the decision to participate in the programme. Whatever these considerations are, they are surely reflected in the high compensation requirements that can offset the effects of contract cancellation in the event that production targets fall.

Third, in DCEs, especially those that solicit farmers' WTA compensation to provide environmental quality goods, like the current study, the implicit prices that express the mWTA for a discrete change in an attribute level allow for some understanding of the relative importance that respondents give to attributes within the design (Bennett and Blamey, 2001; Mashayekhi et al., 2016). Therefore, if farmers attach so much utility (value) to an attribute, asking them to sacrifice or reduce this utility by being in the scheme means they are more likely to suffer greater disutility, hence they would require higher financial incentives as

compensation (Ruto and Garrod, 2009). In addition, according to Horne (2006), when such higher compensations are required, like in the current chapter, the implication is often that the scheme's attributes are less restrictive. Therefore, increased restrictions result in increased compensation requirements (Broch and Vedel, 2012). The strong aversion demonstrated by farmers to some of the scheme's attributes is an indication of the increasing restrictions they perceive. Hence, it is only proper and right that farmers ask for higher compensations for scheme attributes they perceive as less restrictive. Accordingly, these higher compensation requirements simply reflect the higher utilities that are being sacrificed and the seemingly less restrictive nature of the scheme's attributes. That is, the high mWTA requirements from some of the sub-groups depict farmers sacrificing higher utilities (or some aspects of them) and/or accepting the scheme's seemingly less restrictive attributes to join the scheme. Therefore, demanding higher compensation payments for these attributes is somewhat fair.

Fourth, unlike many DCE studies conducted with farmers in single-growing cycle areas, who grow only single crops, the DCE of this chapter is conducted in an area where there are two growing cycles and farmers grow a diversity of crops with different farm management practices. Therefore, the two growing cycles in the study area imply that the farmers of this chapter would require a double of the compensation payments their counterparts in single growing cycle areas require hectare⁻¹ year⁻¹. Further, the crops the farmers in this chapter grow are particularly prone to fertilizer and pesticide leaches and run-off due to frequent cultivation, relatively shorter growing cycles, and low nutrient uptake efficiency (Di and Cameron, 2002). These facts presuppose that the farmers in this chapter may inadvertently be using more fertilizers and pesticides than their counterparts in single-growing cycle areas. This is particularly true if the single crop(s) grown (like rice, wheat, olives, etc.) are not susceptible to fertilizer and pesticide leaches and run-off like the crops the farmers in this chapter grow. Consequently, the farmers in this chapter may inadvertently be using more fertilizer and pesticides compared to their counterparts in Europe and beyond, who mostly operate in single-growing cycle areas and grow only single crops. It should, therefore, not be surprising if the farmers in this chapter are requesting higher compensation payments than European averages.

Finally, the compensation requirements might have been influenced by how compensation payment levels were calibrated in the DCE, which were based on suggestions from the FGDs. The discussants suggested USD 0, 600, 1000, and 1,933 hectare⁻¹ year⁻¹, instead of the initially calibrated compensation levels of USD 0, 200, 600, and 1,400 hectare⁻¹ year⁻¹, which were

based on the initial literature reviewed and some prior research inquiries made with farmers in the region. It would thus seem that the initially calibrated compensation levels rightly reflected the actual costs and incomes forgone to implement the programme/scheme in the area. But the high compensation levels suggested by the discussants in the focus groups are not surprising. It would seem some discussants perceived the agNPS pollution control scheme as an impending social intervention programme (South Africa has many of such social interventions, but not in agriculture) or an income distribution one, and therefore stating higher compensation requirements, meant that the benefits to them would be higher when the programme is implemented.

However, it should be noted that stringent measures were put in place before, during, and after the data collection phase to minimize strategic bias (a phenomenon that occurs when an individual “deliberately misrepresents their preferences in order to influence the decision-making process” (Bennett and Blamey, 2001)) and ensure that the issues raised above, like the historical antecedents and the pieces of misinformation that were ongoing on land expropriation, did not bias the responses of farmers. First, before the data collection exercise, the FGDs conducted, especially the one with the farmers, was aimed at explaining these issues to farmers while assuring them of the confidentiality of their responses and that the research was purely for academic purposes. It had nothing to do with land expropriation or anything. In addition, the enumerators with varying levels of education completed (first degree, college, and Matric (or high school or secondary school)) were taken through a two-day rigorous training exercise to master the questionnaire and interview techniques. Also, face-to-face interviews were adopted to enable the enumerators to describe the background and choice sets objectively to farmers without ambiguity in farmers’ own language. Second, during the data collection exercise, in order to reduce cognitive burden, farmers were to answer only 9-choice tasks instead of the mostly 12-, 16-, and 18-choice tasks, among others common with most CE studies.

Additionally, enumerators wore University of Cape Town-branded T-shirts to show association and allay the fears of farmers about the entity undertaking the research. Also, a detailed album with colored pictures of all the attributes and their respective levels was made available to enumerators. As explained earlier, this was to help the enumerators explain the choice sets in both words and pictures in the farmers’ own language. This facilitates understanding (Brown et al. 2003) and reduces biases. Third, after the data collection exercise, the estimation strategy

used was the restricted LCM. This was for the purposes of accounting for or allowing for random responses or inattention bias. A situation in DCE where participants are assumed to not always attentively respond to choice experiment surveys (Malone and Lusk, 2018). The result showed that only 3% of the sample provided random responses. All these were done to ensure that the findings are free of the biases of farmers' responses.

Finally, as explained above, a number of factors may be accounting for the high compensation requirements of this chapter. Notwithstanding, the mWTA requirements are in accordance with farmers' income figures for the Limpopo Province. For instance, De Cock et al. (2013) reported that the minimum total farm income per month of smallholder farmers in the Limpopo Province was about USD 14, while the maximum was about USD 2,334. Similarly, Statistics South Africa (2022) reports that the monthly farm income in the Vhembe District Municipality is about USD 2,560. This puts the yearly farm income in the Vhembe District Municipality around USD 30,720 (the upper limit). These income figures, coupled with the reasons adduced above, offer enough proof that even though the current compensation requirements on a hectare⁻¹ year⁻¹ basis may be high compared to the European averages, they are within the acceptable limits for farmers in the Vhembe District Municipality and therefore, the two farming communities, and reflect the income forgone to implement this AES programme in the study area. Furthermore, the compensation results of this chapter offer proof that the South Africa case may be a peculiar one that would enrich the discourse on agNPS pollution control/regulation in Sub-Saharan Africa and beyond.

3.5.5 Welfare Measures of Different Policy Scenarios

The non-marginal welfare or compensating surplus (CS) measures the change in required compensation between the initial situation of agNPS pollution (lower water quality) and subsequent situations (improved water quality) needed to render the farmer indifferent to a change. CS allows policymakers to choose not only the alternatives that provide farmers with the highest utility but also those that provide the needed high water-quality improvement. Using equation 3.9 and the status quo option as the base category, which contains the possibility of applying current levels of fertilizers and pesticides, no agricultural waste recovery, no construction of ecological ditches, zero duration of the programme, no monitoring, and no compensation payments.

In Table 3.9, three water-quality improvement policy scenarios—high-, medium-, and low-impact water-quality improvement scenarios—are presented. The result showed that farmers in the sample are willing to accept USD 6,391 hectare⁻¹ year⁻¹ to implement the high-impact water-quality improvement scenario rather than accept the status quo alternative, all else being constant. Similarly, for the medium- and low-impact water-quality improvement scenarios, farmers are willing to accept USD 3,797 and USD 3,392 hectare⁻¹ year⁻¹, respectively, to implement these policy options rather than accept the status quo alternative in both cases, all else being constant. The choice of any of these water-quality improvement policy scenarios is, however, subject to the budget available to the authorities.

Table 3. 9: Welfare Measure for Different Water Quality Improvement Policies

Indicators	Scenario I	Scenario II	Scenario III
	High-impact water-quality improvement	Medium-impact water-quality improvement	Low-impact water-quality improvement
Fertilizer reduction	Reduce by 50%	Reduce by 50%	Reduce by 25%
Pesticide reduction	Reduce by 50%	Reduce by 25%	Reduce by 25%
Agricultural waste recovery	100% recovery	50% recovery	50% recovery
Construct ecological ditch	50 meters	25 meters	25 meters
Duration of programme	10 years	5 years	5 years
Monitoring for compliance	Partial	External	Partial
Compensating surplus	6,391*** (4,303 / 8,479)	3,797*** (1,893 / 5,702)	3,392*** (1,131 / 5,474)

Note: ***, **, and * represent the levels of significance at 1%, 5%, and 10% respectively.

^a95% confidence intervals in brackets.

^bCompensating surplus is in USD.

^cAll payments are to be divided by 2 since there are two (2) farming cycles in the study area.

3.6 Conclusion and Policy Implications

This chapter reports the results of a CE that investigated farmers' WTA compensation to alter their undesirable farming practices to control agNPS pollution in the Limpopo River Basin (LRB) of South Africa. Two estimation strategies—conditional logit (CLM) and restricted latent class (LCM) models—are used to estimate the relationships from the survey data of 552 farmers in the basin. The results of the restricted LCM identified three sub-groups of farmers (in total, representing 97%) with different compensation requirements to alter their status quo

farming practices to improve water quality. In addition, one random choice class where farmers made random choices or provided inattentive responses was identified (3%). This random choice class is important in addressing the issue of whether farmers are indeed making trade-offs between all the agNPS pollution control attributes in a choice task or whether choice responses are determined only by the random utility term. The results generally show that compensation payments positively increased farmers willingness to alter their undesirable farming practices to control agNPS pollution. This suggests that the cost of using monetary incentives to incentivize farmers to control agNPS pollution in South Africa may not be prohibitive. However, sufficient and appropriate financial inducements specifically targeted at the different sub-groups of farmers identified may be required to overcome their distaste.

This chapter, like many previous studies on AESs, both fits established patterns of farmers' behaviour and is unique for water resource managers and AES implementers. First, unlike many previous studies on agNPS pollution in wet regions, this chapter suggests that even under extremely scarce water conditions, farmers show similar preferences regarding compensation payments. Second, it underscores the importance of farmers being different with different farm management practices and cost structures. These differences, therefore, lead to differences in preferences and, therefore, different levels of compensation requirements and acceptance of these programmes. Therefore, farmers should not be lumped together, as is the case now with most AESs. Finally, the inclusion of the construction of ecological ditches provides AES implementers with a cheaper, easier-to-construct technology that is easy to maintain and effective at controlling agNPS pollution at the farm level.

The findings of this chapter are relevant for policymakers and AES implementers. They provide a cost-effective framework and a robust basis for the formulation of water-quality improvement policies in the agricultural sector to regulate/control agNPS pollution. Since public expenditure decisions may be required if financial compensation is incorporated into agricultural policy for controlling agNPS pollution, these results could be of great interest to policymakers. Within this framework, policymakers and AESs implementers may consider several water-quality improvement policies and estimate the costs of each to identify their preferred optimal option for managing water quality while enhancing farmers' utility and social welfare in general.

This chapter has some important implications for policy. First, the results suggest that farmers are willing to accept monetary compensation to control agNPS pollution. Therefore, this chapter recommends the promotion and use of monetary incentives in the agricultural sector to induce farmers to lessen agriculture's impact on water quality. Second, the divergent behaviour noted is driven by differences in age, farming experience, secured land rights, awareness of agNPS pollution, farm size, and farm ownership, among others. Thus, any effective strategy(ies) aimed at increasing farmers' participation in future AESs must, of necessity, factor in these differences. Tailoring AESs contracts specific to farmers' needs with the option of scaling up is important for maximum participation and successful environmental outcomes. Third, AES contracts with extensive requirements such as external monitoring and a long contract duration may be effective in ensuring high-quality outcomes but are likely to deter farmers from maximum acceptance of the programme. Therefore, the chapter recommends low-to-moderate requirements initially and then scaling up later. Finally, awareness through public education and campaigns of the dangers of agNPS pollution is essential. However, all these would require further investment in research and development toward the promotion and advancement of agNPS pollution control programmes.

Despite the robustness of these findings, this chapter is not without limitations. First, due to budget and time constraints, the survey data was collected from only two farming communities in the LRB. Not including farmers in the entire Limpopo Water Management Area (WMA) or even those of the entire LRB in South Africa means that the monetary estimates may not entirely reflect the preferences of farmers located far from the two farming communities. It is, however, certain that the farmers included in this chapter represent the population that would most likely be targeted for such a programme in the Limpopo Province. Second, as is common with all stated preference techniques, the monetary estimates of this chapter are entirely limited to the design in the chapter and the data collected. Finally, land ownership issues are very sensitive in South Africa because of some historical antecedents. This factor and the debates that were ongoing on land expropriation created some misinformation and even pushed some farmers to shy away from the survey exercise, saying that it was a ploy to source information to take away their lands. This misinformation might have resulted in an overestimation of the amount of compensation required.

This chapter can be further advanced with similar research in other parts of the Limpopo WMA or the entire LRB in South Africa. Furthermore, there is a need to establish the actual costs and

benefits of the WTA compensation to control agNPS pollution under different policy situations. Understanding how the cost of the mitigation actions will change if the monetary values of the agNPS pollution control attributes and the CS of future alternative policy scenarios are taken into consideration in decision-making is necessary. Such a cost-benefit analysis would provide policymakers with more information to design effective agNPS pollution control programmes in the future.

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Chapter 4: A Meta-Analysis of Water Institutions and their Performance: Implications for Water Resource Management

Abstract

This chapter employed meta-regression analysis to investigate the empirical literature on the performance of water institutions. It synthesized and quantified the overall water institution-performance effect using data extracted from 23 original studies that reported the impact of water institutions on the performance of the water sector. The bivariate and multivariate meta-regressions suggest the presence of a publication selection bias that favours a positive impact of water institutions on performance. Once this bias is corrected, evidence of a genuine empirical effect of water institutions on the performance of the water sector is evident. In addition, the variations in the primary studies are attributable to differences in the way the primary studies capture water institutions, the dependent variables used to capture performance, and the estimation strategy/methodology, among others. Specifically, primary studies that use the water law, water policy, and/or some aspects of these to capture the performance of water institutions tend to report a greater impact of water institutions on performance. This chapter contributes to improving the quality of research, reporting, review, and publication in the water space on institutional performance.

Keywords: Meta regression analysis; formal water institutions; water sector performance; water resource management; policy and water sector

JEL Classification: D02; E02; Q25

4.1 Introduction

Water institutions are a set of nested and linked rules (formal and informal, as well as macro and micro) that guide individual and collective decisions in the development, allocation, use, and management of water resources (Saleth and Dinar, 1999b; 2004). They are important in facilitating water resource management, equitable allocation, and sustainability for a better life for mankind, ecosystems, production, and economic growth. But the growing challenges of issues of water access, security of supply, efficiency of use, deteriorating quality, as well as poor management and under-sustainability of water resources, bring to the forefront the role and performance of water institutions. The quest for effective water institutions that improve water resource management has generated substantial research and discourse on their performance, reforms, and efficacy (Bandaragoda, 2000; Saleth and Dinar, 1999b; 2004; 2008). This set of literature provides evidence that the effective performance of water institutions is important in remedying these challenges termed ‘the water crisis’ (Chopra and Ramachandran, 2021; Ingram et al., 1984; UN-Water, 2009; World Water Council, 2003).

Urbanization, population growth, climate change, increasing demand for food, industrialization, and economic development make the water crisis a major challenge for many countries (Chopra and Ramachandran, 2021). However, evidence of what works, where, and why it works in some places but not others in terms of these institutions is difficult to realize. Some institutional arrangements have been presented as performance indicators for gauging the performance of water institutions. These include the water law, water policy, strong government agencies, enhanced participation, improved decentralization, user organizations, water markets, and conflict-resolution mechanisms (Balint et al., 2002; Merrey et al., 2007; Nhundu et al., 2015; Saleth and Dinar, 1999b; 2004; 2008). However, much of the literature on this subject is qualitative in nature (Balint et al., 2002; Bandaragoda, 2000, among others), with a few also providing systematic reviews of the relationship between water institutions and performance (Araral, 2010; Hepworth et al., 2013; Özerol et al., 2018). The challenge, however, with this set of studies is that they cannot quantify the water institution-performance effect. In addition, they are subjective and have no objective standard for how to weight alternative estimates. Consequently, they cannot be relied upon to provide clear guidance to policymakers and researchers (Alinaghi, 2017).

The studies that provide quantitative analysis of the water institution-performance relationship are scant but growing. The challenge with this set of literature, however, is that water institutions are diverse/multidimensional, complex, and evaluated with different methodologies and contrasting variables (dependent and independent) of various dimensions. These differences may then explain why robust evidence of the performance of water institutions is difficult to find. In particular, difficulties are realized in what variables are used to capture water institutions, how the water institution-performance relationship is measured, and what control variables were included in the estimation strategies, among others. This lack of a uniform analytical framework can make the empirical findings of the water institution-performance relationship somewhat ambiguous. This then makes it challenging for economists and practitioners to accurately identify what works, why, and how.

Consequently, this chapter employs a meta-regression analysis (MRA) to evaluate this quantitative literature on water institutions and their performance. MRA is a quantitative method for identifying, reviewing, and aggregating empirical findings from an existing body of literature on a given research question (Hunter and Schmidt, 1990; Stanley, 2001; Wolf, 1986). This methodology has several advantages. First, it allows researchers to unravel various factors and discrepancies responsible for conflicting results among studies (Stanley, 2001). Second, combining the results from individual studies gives more insight and greater explanatory power (Stanley, 2001). Third, the methodology is useful in overcoming the small sample sizes of individual studies and helps to detect the precise effects of an intervention, especially once a larger sample size is required (Stanley, 2001). Given these advantages, this chapter seeks to: (i) synthesize and quantify the water institution-performance effect evidenced in the literature; (ii) provide a statistical integration of existing studies on this important relationship; and (iii) explore the heterogeneities responsible for the variations of the water institution-performance effect in existing primary studies.

Accordingly, this chapter aims to answer the following research questions: (i) Is there publication selection bias in the water institution-performance literature? (ii) What is the overall effect of water institutions on performance? and (iii) what factors account for the heterogeneity in the observed water institution-performance literature? To the best of the author's knowledge, no study has previously used MRA to synthesize and quantify the effects of water institutions on performance. This chapter thus seeks to close this gap in the literature.

To this purpose, the respective meta-data is extracted from 23 original studies following established procedures for meta-analysis by Lipsey and Wilson (2001) and Stanley (2013). Four weighted least squares (WLS) estimators and a restricted maximum likelihood (REML) estimator are estimated to answer these questions.

The main novelty of this chapter is, thus, the use of meta-analysis to increase the statistical power of results from a growing literature on the performance of water institutions that covers different methodologies, water institutions, geographic and environmental conditions compared to studies specifically focused on one location or a given narrow set of conditions. Beyond the academic contributions to the literature, this chapter provides further insights for additional development, facilitation, and strengthening of the water laws, policies, and administration in the water space. This is critical not only for efforts to engender reforms in the water sector but also for the effective allocation and utilization of the resource in all sectors of the economy.

The next section presents the conceptual and analytical framework for water institutions and their performance. This is followed in Section 4.3 with a review of the related literature and a presentation of the materials and methods of meta-regression analysis in Section 4.4. The results and discussion appear in Section 4.5. Section 4.6 concludes, provides policy implications, and the directions for future research.

4.2 Conceptual and Analytical Framework

4.2.1 Water Institutions and Water Sector Performance

Institutions are the humanly devised rules of behaviour that shape human interactions (North, 1990). The institutions set the ground rules for resources use and establish the incentives, information, and compulsions that guide economic outcomes (Bandaragoda, 2001). Saleth and Dinar (2004) add further perspectives to this definition by noting that institutions are a pervasive phenomenon with diverse definitions and interpretations that reflect different disciplinary perspectives and theoretical traditions. But beneath this diversity lies an undercurrent of convergence on the generic meaning and purpose of institutions (Saleth and Dinar, 2004). They affect various dimensions of human relationships and interactions. Specifically, in Figure 4.1, Saleth and Dinar (2004) conceptualize water institutions as

comprised of water law, water policy, and water administration (termed formal water institutions).

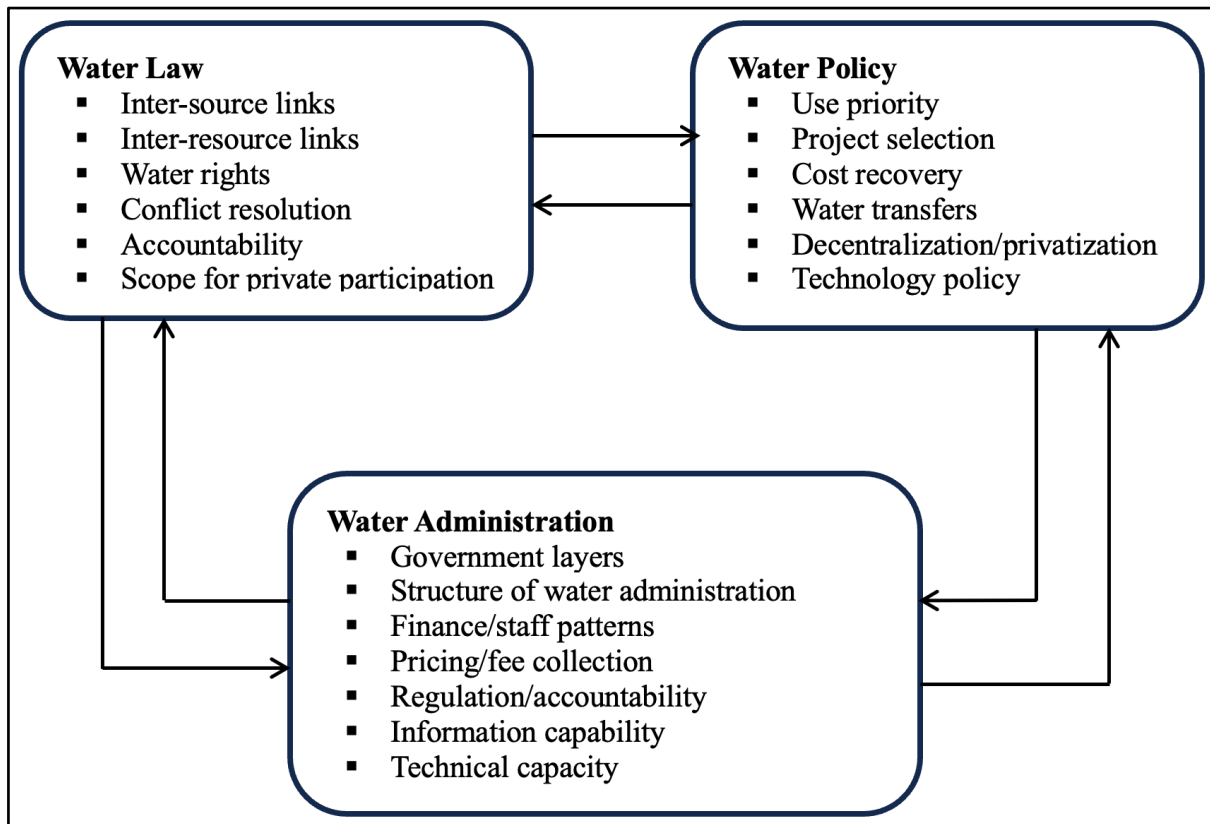


Figure 4. 1: Decomposition of Water Institutions and Linkages Within a Water Institution

(Adapted and modified from Saleth and Dinar, 2004, pp 102)

In addition to formal water institutions, informally established procedures, norms, practices, cultures, and patterns of behaviour also form part of the framework of water institutions. As informal practices become accepted in society, they also become rules in their own right (Bruns et al., 2002). According to Nhundu et al. (2015), the difference between formal and informal institutions lies in their degree, not in their type. In many cases, some informal institutions gradually become part of their formal counterparts, and some formal institutions take on informal forms (Nhundu et al., 2015). Similarly, Balint et al. (2002) acknowledge that combining formal institutions with their informal ones will increase efficiency and lower the costs related to monitoring and enforcement.

In most parts of Africa, access to and use of water, especially in irrigation, involves both formal and informal institutions (Meinzen-Dick & Nkonya, 2007). Informal institutions are largely dominant at the local and grassroots level of agricultural water management. There is evidence

from several studies in the literature that acknowledges the importance of informal institutions in water management (Bruns & Meinzen-Dick, 2000; Maganga, 2003; Meinzen-Dick & Bruns, 2003; Mwakaje & Sokoni, 2003; Sokile et al., 2003; Van Koppen, 2003). The evidence also shows that some of these studies that favour informal institutions advocate for a sound mix of formal and informal institutional arrangements and recommend that the elements of existing local institutions, in particular informal traditional arrangements, should be incorporated into new management systems (Sokile et al., 2003). Water institutions, whether formal or informal, aim to steer individual and collective behaviours toward lowering the transaction costs associated with the development, allocation, and management of water resources.

North (1990) provides an analogy of how lowering transaction costs impacts the performance of institutions. North asserts that in a comparative evaluation of two different sets of institutions, performance can be expected to be better in the institutional framework in which transaction costs are lower. When transaction costs are high or not accounted for, the performance of institutions generally suffers. Therefore, the challenge is to design institutions that lower transaction costs and create incentives favouring cooperative arrangements (North, 1997). In view of this, Saleth and Dinar (2004) highlight the importance of the water law, policy, and administration in managing (or lowering transaction costs of) the water sector and/or its related sectors through possible intra- and inter-institutional linkages. For instance, well-defined water rights can facilitate water transfers, pricing, and cost recovery, which may facilitate private sector participation. Private sector participation/decentralization in turn may help enhance water administration and, therefore, the performance of water institutions.

In addition, conflict resolution mechanisms, trans-boundary water transfers, and the functional capacities of water organizations, among others, can influence the performance of water institutions. In Figure 4.2, Saleth and Dinar (2004) extended the water institution framework by showing the linkages between water institutions and the performance of the water sector, as well as exogenous factors that may affect both. The Institutional Decomposition and Analysis (IDA) framework of Saleth and Dinar (1999b; 2004) that is used to measure the overall effectiveness of water institutions is a two-stage comprehensive analytical decomposition process. In the first stage, water institutions are decomposed into three main components: water law, water policy, and water administration. In the second stage, the three institutional components and water sector performance are further decomposed to identify their major subcomponents (Saleth and Dinar, 2004).

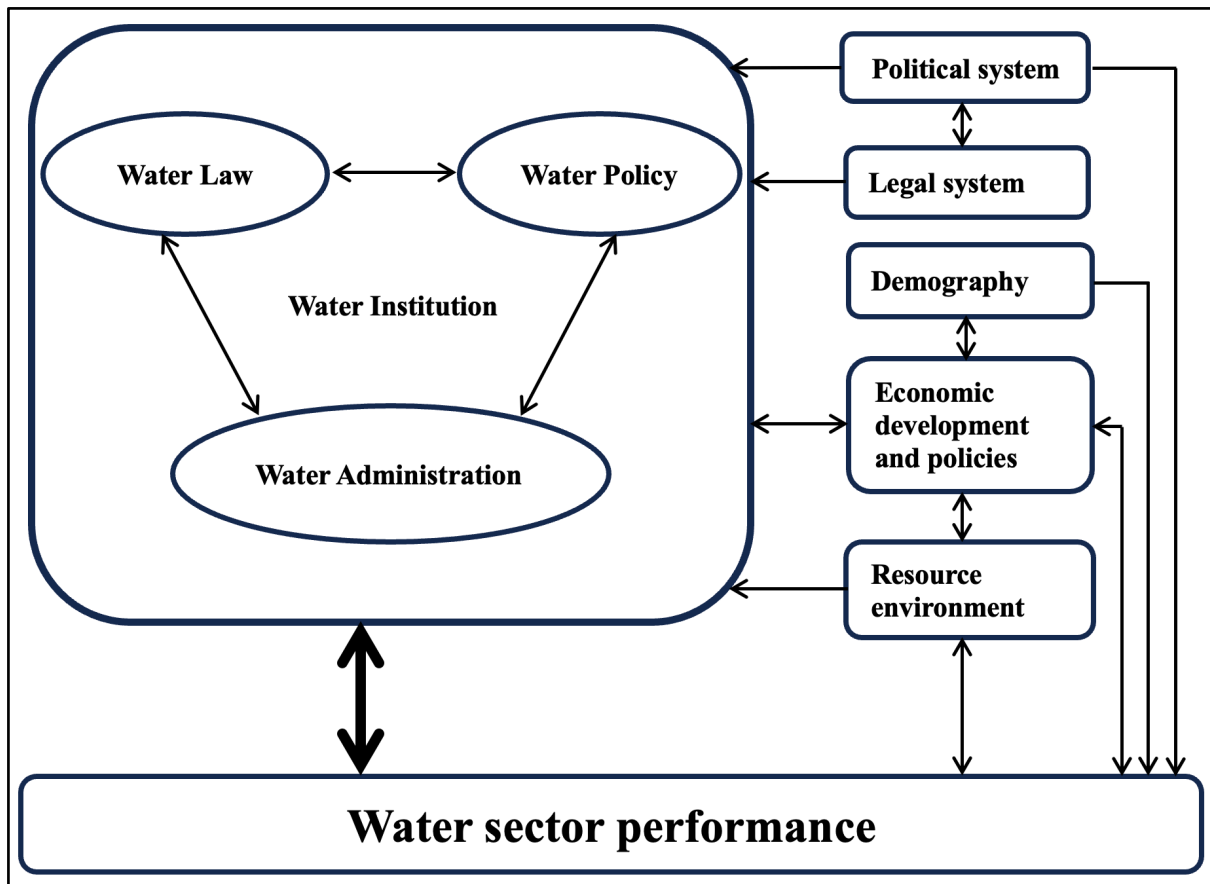


Figure 4. 2: Influence of Exogenous Economic Factors on the Institution–Performance Interaction

(Adapted and modified from Saleth and Dinar, 2004, pp 104)

Within this methodology, the overall effectiveness of each of the three institutional components depends not only on the effectiveness of their constituent institutional aspects but also on the strength of their linkages with other institutional components (Saleth and Dinar, 2004). So that, the overall effectiveness of a water institution depends on both the individual and interactive effects of the performance levels of the three institutional components (Saleth and Dinar, 2004). In this way, the overall performance of a water institution is ultimately linked to both the individual and joint effects of the institutional aspects underlying all three institutional components (Saleth and Dinar, 2004). In addition to the direct impact of the institutional components and their underlying institutional aspects, the performance of water institutions is also influenced by the general socio-economic, political, and resource-related environment within which they operate (Saleth and Dinar, 2004). Broadly, given the decomposition of water institutions and their performance outlined above, it is possible to link—both analytically and functionally—the performance of each institutional component with its constituent institutional aspects (Saleth and Dinar, 2004). Similarly, the overall performance of water institutions can also be linked not only with the performance of the institutional components but also with the

institutional aspects themselves. In this way, the analytical decomposition exercise provides a framework for evaluating both the institutional inter-linkages as well as the institution-performance linkages within the water sector (Saleth and Dinar, 1999b), which minimize transaction costs and maximize performance.

Additionally, Saleth and Dinar (2004) note further that attempts to fix isolated parts of the water sector will influence other aspects. Thus, an integrated approach is best, and at the heart of this approach should be institutional changes aimed at modernizing and strengthening the entire water sector's legal, policy, and administrative arrangements. Therefore, in this MRA, the focus is on water institutions covered by Saleth and Dinar (1999b; 2004). Consequently, this chapter is interested in studies that use the overall performance of water institutions and studies that construct composite indexes for the performance of water institutions.

4.3 Related Literature

Effective water institutions remain critical to water resource management and governance at the local, national, and/or international level. The important literature in this area includes Saleth and Dinar (1999a; 1999b; 2004 and 2008), who used the IDA framework with cross-country data from water experts. They make a comprehensive analytical decomposition of both water institutions and water sector performance at the formal level. They identified various layers of institutional inter-linkages and institution-performance linkages in the water sector. Their studies show the important role that various institutional aspects play in determining the performance of both water institutions and the water sector, as well as how these institutional aspects minimize transaction costs and maximize the performance impact.

Chopra and Ramachandran (2021) evaluated water institutions and their impact on the performance of the water sector in India. Using factor analysis and multiple linear regression methods, they determined the important factors of water institutions (including water law, policy, and administration) and their effect on the different aspects of water sector performance in India. Their analysis showed that the most important factors for improving the water sector's performance are (i) legal accountability provisions, (ii) water transfer policies, and (iii) the use of science and technology applications along with reliable data. The level of importance of these institutional variables also varied across various performance aspects.

Similarly, Nhundu et al. (2015) used both the formal institutional indicators of Saleth and Dinar (1999b) and some informal indicators of agricultural water management (clearly defined boundaries to use common pool resources (CPRs), local appropriation rules related to local conditions, local management mechanisms, local monitoring of CPRs, and local regulatory sanctions, among others) and concluded that some institutional aspects of the water law, water policy, and water administration positively and significantly strengthen the effectiveness of the performance of water institutions.

Araral and Wang (2015) employed a similar methodology with 17 indicators of water laws, policies, and administration to analyze the effects of water institutions on different aspects of water sector performance in ten provinces in China. The authors concluded that the interpretation and implementation of guidelines for water laws, policies, and administration vary considerably amongst the ten provinces in China. This is an indication that differences may exist in how water institutions are interpreted and implemented in different countries or regions, which in turn lead to variations in their performance.

A recent study by Ahmed and Araral (2019) used the IDA framework and survey data from two periods (before and after the announcement of the United Nations Sustainable Development Goals (SDGs)) from 152 respondents. The aim of this study was to determine whether water resources management and governance have improved since the announcement of the SDGs. This is because good water governance is key to sustainable management of water resources, which is important for the realization of SDG 6. They calculated 17 nominal and weighted water governance indices (WGIs) of the water law, policy, and administration for eight Indian states. A comparison of the before and after SDGs announcement of these indices showed that water governance in these states had improved after the announcement, confirming the important role water governance plays in the sustainable management of water resources.

Another study by Dinar and Saleth (2005) argued that, once we agree that appropriate institutional arrangements play a key role in explaining the level of performance of the water sector, we still have the daunting task of defining, measuring, and comparing institutional performance across countries. It is, however, their view that water institutions in many countries are dated and weak. Despite the importance of evaluating water institutions in order to identify gaps between needed and actual arrangements, which would lead to reform strategies, major methodological and data problems make such comparisons challenging. To

overcome these challenges, the authors constructed a water institution health index for 43 countries based on a set of legal, policy, and administrative variables identified from the institutional decomposition approach using an international sample of 127 water experts. As an indicator of institutional health, the index enables comparisons between countries and their components and shows how the index is linked to economic, social, and governance indicators.

In the context of meta-analysis, no study has used meta-regression analysis to the best of the author's knowledge to analyze the effect of water institutions on the performance of the water sector. However, studies such as Hepworth et al. (2013) and Özerol et al. (2018) used systematic reviews to evaluate the water institution-performance relationships. Specifically, Hepworth et al. (2013) used a systematic mapping approach to systematically review the literature on the factors that determine the performance of institutional mechanisms for water resources management (WRM) in developing countries. The conclusion from their comprehensive systematic mapping of the relevant literature showed that the pool of reliable knowledge from which to draw is minimal or limited. Nevertheless, their findings suggest the need for radical improvements across the research cycle, including commissioning, design, delivery, reporting, review, and publishing. It is not surprising that Hepworth et al. (2013) could not offer a definitive conclusion on the performance of the institutional mechanisms for WRM. This challenge is purely a problem of systematic reviews. They cannot quantify or determine the genuine empirical effect of the variables of interest. Accordingly, Alinaghi (2017) asserts that systematic reviews suffer from several shortcomings: (i) they reflect the reviewers' points of view and can certainly vary from one reviewer to another; (ii) bias might be an inherent part of these kinds of reviews; (iii) they have no objective standard for how to weight alternative estimates; and (iv) as a result, they cannot be relied upon to provide clear and concrete guidance to policymakers and other researchers. Such shortcomings provide additional justification for this chapter, which uses meta-regression to estimate the genuine empirical effect of water institutions on performance and largely to overcome the shortcomings of systematic reviews.

Similarly, Özerol et al. (2018) conducted a systematic review of studies on comparative water governance to critically reflect on how water governance is defined, conceptualized, and assessed in different contexts. In doing so, they sought to identify trends, gaps, and ongoing issues that must be resolved as the field progresses. Based on their resultant insights, four areas for future research in this area are identified: (i) improving the balance between small-, medium-, and large-*N* studies that are used in comparative studies of water governance; (ii)

conducting longitudinal comparisons of water governance to identify temporal governance trends and patterns; (iii) expanding the geographical coverage of the comparisons to include underrepresented countries and regions, focusing more broadly on the global South; and (iv) addressing the issues of justice, equity, and power, which are becoming increasingly important in tackling the water governance challenges that are exacerbated by the effects of climate change, industrialization, and urbanization. However, the weaknesses of systematic reviews alluded to also implicate Özerol et al. (2018).

This literature review would be incomplete without a review of some informal institutional water management literature. Accordingly, in the next few paragraphs, a brief review of some of these works is provided to augment the literature on formal water institutions. In this regard, Bastidas (1999) examined gender issues and women's participation in irrigated agriculture in two private irrigation canals in Ecuador to fully understand the importance of informal rules. Using a combination of qualitative and quantitative methods, the author concluded that women's participation in water user associations is low, and that culture plays a strong role in terms of their decision-making power. The author added that women tried to solve their irrigation-related problems through informal ways where they had more decision-making power.

Contributing to the informal water institution literature, Malzbender et al. (2005) discussed the rationale for the recognition of traditional water management structures in the light of the realities of water management and supply in South Africa's rural areas. They argued that customary arrangements form part of the social adaptive capacity of communities and can aid integrated water resource management. The relationship between traditional water governance structures and the National Water Act explored indicated that South Africa's water law and policy framework supported the recognition of traditional water governance structures as part of the overall water management strategy.

Furthermore, Kapfudzaruwa and Sowman (2009) examined the extent to which traditional governance systems have been acknowledged and incorporated into new water management institutions and approaches. They concluded that both state governance systems and traditional governance systems are relevant to water resource management. However, management is predominantly guided by state-driven strategies that are based on statutory legal systems. Yet, traditional governance systems, including customary laws and cultural and religious practices,

have an important role to play in achieving the purposes of the water user associations. Failure to acknowledge and incorporate aspects of these traditional governance systems may undermine the ability of the government to achieve the objectives of the National Water Act.

Sokile, Mwaruvanda, and Van Koppen (2005) focused on the interfaces and linkages between formal and informal institutional frameworks for water management in Tanzania with a case study of the Mkoji sub catchment in the Rufiji Basin. They opined that formal and informal institutions are closely linked and greatly depend on each other. The authors identified four major areas of interfaces, namely, centralized and local institutions; modern water rights and customary rights; water user associations and informal associations of water users; and formal and informal power relations. They argued that although there are some positive linkages between formal and informal institutions, there are also struggles and bickering between the two. The study further highlighted the complexities of institutional interfacing and finally identified potential ways in which the ongoing reforms could consider customary arrangements and provide a better framework for sound management of water.

Finally, however, this chapter did not find any literature on informal water institutions that met the chapter's selection and inclusion criteria. As such, the MRA did not include any informal water institutions.

The review of the literature shows that, although there is a growing literature of both qualitative and quantitative studies on the role of water institutions and performance, none used meta-analysis to quantify the effects of water institutions on performance. The few studies that used systematic reviews have also not been able to provide a definitive conclusion about the effects of this relationship. In addition, they have failed to account for the presence of publication selection bias in this set of literature. According to Begg and Berlin (1988) and Stanley (2001), when publication selection bias is ignored, it can distort any literature review, whether it is a conventional narrative review or a meta-analysis. It is thus important to investigate this set of literature for publication selection bias. It is in this regard that, this chapter uses MRA to investigate the presence of publication selection bias in the targeted literature and to determine the magnitude and direction of the genuine empirical effect of water institutions on performance.

4.4 Materials and Methods

4.4.1 Selection of Studies

For meaningful conclusions to be drawn from the representative literature, the primary studies must meet some quality and inclusion criteria. This chapter follows the Meta-Analysis of Economics Research-Network (MAER-Net) meta-analytical protocols (Stanley et al., 2013) in the search and coding procedures. These protocols start with a systematic and comprehensive search of the relevant databases (Scopus, Science Direct, JSTOR, Web of Science, Working Paper Series, Google Scholar, among others) to identify and collect data from empirical studies that estimate the effect of water institutions on performance. This is done using a three-stage approach. First, with the help of keywords using the Boolean operators, searches were made, especially in Scopus and the Web of Science. The use of Boolean operators is important in facilitating access to the most comprehensive and yet relevant set of targeted studies. The following keywords were searched in the databases: (i) water institutions; (ii) performance; (iii) administration; (iv) legislation; (v) policy; (vi) governance; (vii) management; and (viii) combinations of these keywords. All searches resulted in a number of studies (both relevant and irrelevant). For instance, in Scopus, the search resulted in more than 1,440 articles. These searches were complemented with a backward search approach, where the references to the relevant literature were searched.

Secondly, titles, keywords, and abstracts were screened and examined in detail for relevance, and the inclusion criteria were applied to the remaining full texts. To be included, studies should: (i) quantitatively evaluate the performance of water institutions; (ii) report regression coefficients, sample size, standard errors, and/or t-statistics that allow for calculating partial correlations between the variables of interest; (iii) be journal articles in English from peer-reviewed journals or World Bank working papers and reports; (iv) be books, and (v) should have been published between 1999 and 2022. The justification for this period is the resurgence of institutional analysis in the 1990s. Before this period, little attention was given to the institutional and managerial aspects relating to the operations, functions, and performance of water institutions. The first known quantitative water institution-performance study around the period, to the best of my knowledge, is Saleth and Dinar (1999a). Thus, Saleth and Dinar (1999a) marked the beginning of a new era in water institution-performance analysis, while 2022 is the termination period because the latest study included in the MRA is from this period (Li et al., 2022).

In the final stage, a total of 23 studies were eligible and were included in the final list for data extraction. The search period spanned from January to April 2023. The coding of the data was done by me, and a research assistant double-checked the data entries to ensure that the data was of the highest quality possible.

In Figure 4.3, a systematic and comprehensive search flow diagram showing how this section was accomplished is presented. The final sample of 23 studies is listed in Table A4.1 of Appendix A4.1.

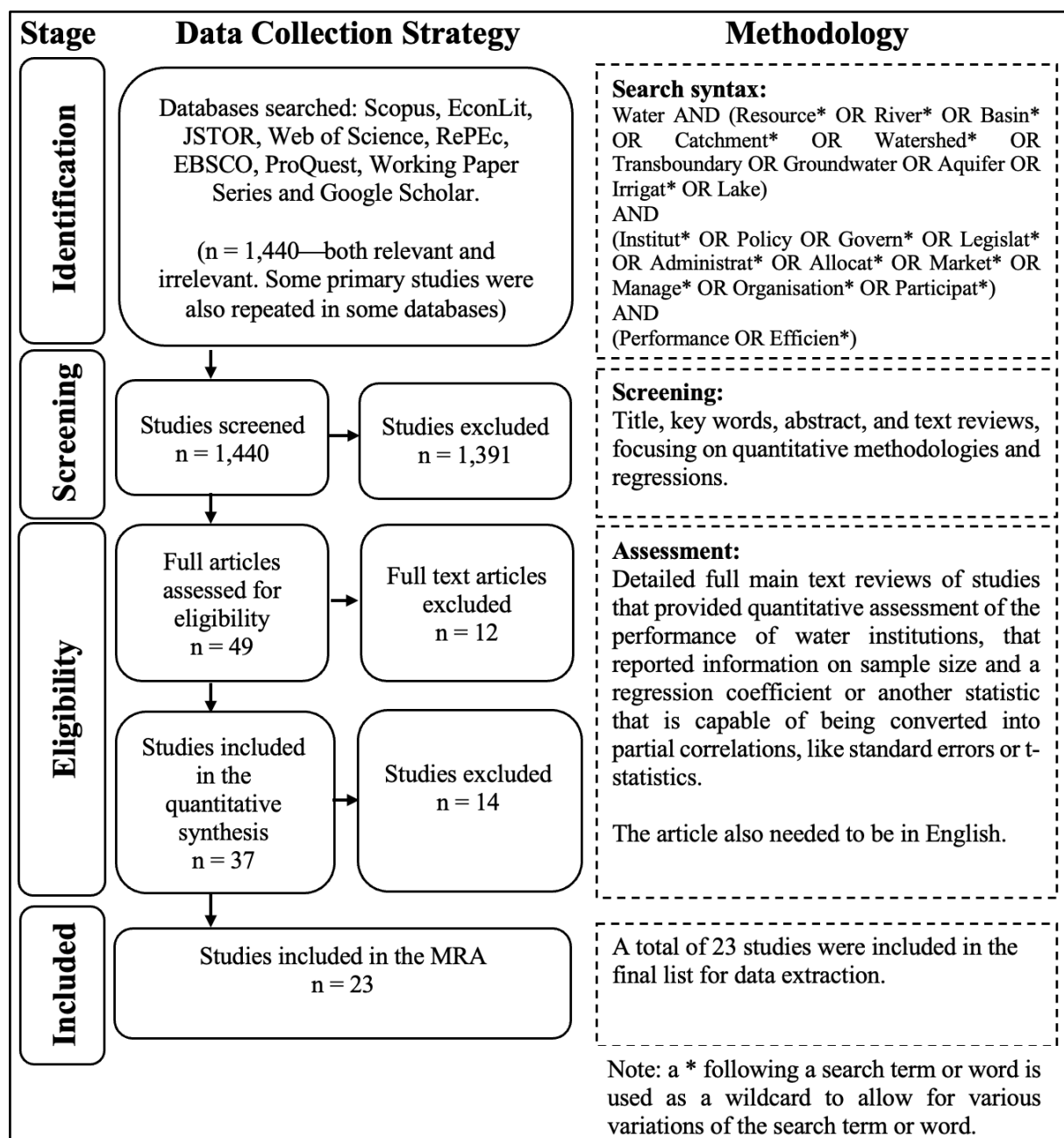


Figure 4. 3: A Systematic and Comprehensive Search Flow Diagram

In each of the regressions under investigation in the original studies, the dependent variable is related to some measure of the performance of water institutions. In the IDA framework, researchers mainly specify the dependent variables as the overall performance of water institutions—the water law, water policy, water administration, and/or some aspects of these. Therefore, this meta-regression analysis will also test whether the choice of methodology and the dependent variable influence the water institutions-performance effect or not. In Table A4.2 of Appendix A4.2, a list of the primary studies and how they captured water institutions as well as performance is presented.

4.4.2 Empirical Strategy

Having successfully determined the meta-dataset for this chapter, the next important step in the meta-regression analysis is the specification of the empirical methodology. To do this, a standardized measure of the estimated effect of water institutions on performance is needed. This measure should be dimensionless (Stanley and Jarrell, 1989). Therefore, for each primary study, a partial correlation coefficient (PCC) between the dependent variable (performance) and the water institution variable of interest is calculated. Partial correlation is a standardized measure of the degree of association, controlling for the influences of other factors (Greene, 2008) and for application in meta-regression (see Doucouliagos and Laroche, 2009). This standardization enables direct comparison between different studies in the sample as well as between different meta-regression subsamples.

Following Stanley and Doucouliagos (2012), the simplest form of the meta-regression model is specified as follows:

$$P_{k,j} = \beta_0 + \beta_1 * SEp_{k,j} + \varepsilon_{k,j} \quad (4.1)$$

where $P_{k,j}$ is the effect size or the PCC between water institutions and performance, $SEp_{k,j}$ is the standard error of the PCC, and a measure of precision, $k = 1, \dots, 23$ statistically independent²⁸ studies in the dataset, $j = 1, \dots, 23$ estimates of the individual regressions reported by the primary studies, β_0 and β_1 are estimates of the meta-regression coefficients, and $\varepsilon_{k,j}$ is the meta-regression error term. However, according to Stanley et al. (2008),

²⁸ Studies are regarded as statistically independent if they are produced by different authors, or by the same author(s), but using different samples (Doucouliagos and Laroche, 2003; Klomp and Valckx, 2014).

Equation (4.1) is rarely estimated because of heteroskedasticity. Therefore, Equation (4.1) should be weighted with the standard error of the PCC to reduce heteroskedasticity and yield more efficient estimates (Stanley, 2008). Accordingly, Equation (1) is divided by $SEp_{k,j}$ to obtain Equation (2), which is the weighted least squares (WLS) version of Equation (4.1).

$$t_{k,j} = \beta_0 * \left(\frac{1}{SEp_{k,j}} \right) + \beta_1 + \varepsilon_{k,j} * \left(\frac{1}{SEp_{k,j}} \right) \quad (4.2)$$

here $t_{k,j}$ is the t-statistic of the variables of interest in the respective primary regressions/studies.

But because Equation (4.2) is a WLS regression, the interpretation is in terms of Equation (4.1) (Efendic, Pugh, and Adnett, 2011). That is, the estimated effects are to be interpreted in terms of partial correlations and not in terms of t-statistics (Efendic et al., 2011). In Equation (4.2), the slope and intercept terms are now reversed compared to Equation (4.1), and the inverse standard error becomes the independent variable in the meta-regression (Stanley et al., 2008). Accordingly, in Equation (4.2), the dependent variable is the t-statistic ($t_{k,j}$) of the coefficient of the water institution-performance variables in each primary regression, β_0 measures the underlying water institution-performance effect, while β_1 measures publication selection bias of the literature under investigation.

According to Efendic et al. (2011), as the standard errors rise from zero in Equation (4.1), estimates of the effect size become ever more imprecise, but in the absence of systematic bias, they should remain randomly distributed around the true effect estimate of β_0 . In this case, the authors asserted that β_1 will not be significantly different from zero. However, in the presence of publication selection bias, estimates of the effect size are not randomly distributed around the true effect β_0 , but are biased away from it, because more weakly estimated results are subject to greater selection efforts in accord with some publication selection criteria (Efendic et al., 2011). In this case $\beta_1 \neq 0$ (for detailed explanations see Stanley, 2005).

In addition to estimating the bivariate meta-regression (BMR), which can be biased if important explanatory variables are omitted (Doucouliagos and Stanley, 2008), Equation (4.2) is expanded to include some important independent or moderator variables. This gives Equation (4.3)—the multivariate meta-regression. The multivariate meta-regression, according to

Doucouliaagos and Laroche (2009), enables the investigation of the sources of heterogeneity in the literature through the addition of moderator variables. Accordingly, all the moderator variables are also divided by the standard error of the PCC ($SEp_{k,j}$), and thus the general multivariate meta-regression is specified as follows:

$$t_{k,j} = \beta_0 * \left(\frac{1}{SEp_{k,j}} \right) + \beta_1 + \sum_1^M \delta_m * \left(\frac{1}{SEp_{k,j}} \right) Z_{m,k,j} + v_{k,j} * \left(\frac{1}{SEp_{k,j}} \right) \quad (4.3)$$

where $Z_{m,k,j}$, $m = 1, \dots, M$ are meta variables each weighted by the inverse standard error of the PCC ($1/SEp_{k,j}$), δ_m are m coefficients to be estimated. Each of these coefficients, which represent some study characteristics influence the underlying water institution-performance effect, and $v_{k,j}$ is the meta-regression disturbance term.

A full list of the moderator variables is provided and explained in Table 4.1. Note, however, that the following variables: NAUT, YEAR, SAMSIZE, OUTVAR, and JONAME were not used in the multivariate meta-regression. Excluding these variables did not have any significant influence on the results. Rather, their inclusion worsens them. In addition, the meta-analyst may restrict some of the meta-regression coefficients to zero when they have reasons to do so (Stanley and Doucouliagos, 2012). Given the small number of observations in this chapter, it is only prudent to reduce the number of moderator variables. According to Bellavance et al. (2009), adding dozens of moderator variables will almost certainly create high multicollinearity and thus obscure individual conditional effects. This chapter's reporting standards, however, benefited from the extraction of these variables. First, SAMSIZE (sample size) was used to provide additional weighting that gave each study equal weight in the meta-regressions. Second, NAUT (number of authors), YEAR (year of publication), and JONAME (name of the journal) were to help in identifying the study(ies) with the least and highest number of authors and the earliest and latest years of publication of the primary studies. JONAME was to help identify the peer-reviewed journals with the highest number of publications in this set of literature. Finally, OUTVAR has similarities with the IDA. They both capture the overall performance of water institutions as the output/dependent variable. It was therefore not used to avoid multicollinearity.

Table 4. 1: Meta-Variables for the Meta-Regression Analysis (MRA)

Variable	Description	Mean	Std Dev.	Min	Max
NAUT	Number of authors of the study	3	1.73	1	9
YEAR	Year of publication of the study	2014	6.15	1999	2022
NUMVAR	The number of independent variables used in the primary regression	18	14.85	6	75
PCC	Partial correlation coefficient between the dependent and independent variable	0.32	0.23	0.12	0.87
INVSEPC	Inverse standard error of the partial correlation coefficient	19.71	5.62	11.32	26.39
SAMSIZE	The sample size of the respective primary study	240	190.30	27	568
WATLAW	=1, if the study uses water law or some aspect of it to capture water institutions, 0 otherwise	0.83	0.39	0	1
WATPOL	=1, if the study uses water policy or some aspect of it to capture water institutions, 0 otherwise	0.83	0.39	0	1
WATADM	=1, if the study uses water administration or some aspect of it to capture water institutions, 0 otherwise	0.96	0.21	0	1
COST	=1, if the study covers all or most of the water institutions in Saleth and Dinar (2004), 0 otherwise	0.35	0.49	0	1
ASCOST	=1, if the study covers only some aspects/subcomponents of water institutions, such as water user associations, irrigation basin management institutions among others, 0 otherwise	0.74	0.45	0	1
OUTVAR	=1, if the study uses overall performance of water institutions as the output/dependent variable, 0 otherwise	0.57	0.51	0	1
IDA	=1, if the study uses institutional decomposition analysis framework to analyst performance of water institutions, 0 otherwise	0.30	0.47	0	1
OLS	=1, if the study uses the ordinary least square regression method of estimation, 0 otherwise	0.35	0.49	0	1
THRESLS	=1, if the study uses 3SLS procedure to control for endogeneity in estimation, 0 otherwise	0.17	0.39	0	1
SEM	=1, if the study uses structural equation method of estimation, 0 otherwise	0.57	0.51	0	1
INSOVAR	=1, if the study included other variables beside water institution variables, 0 otherwise	0.78	0.42	0	1
COMINDX	=1, if the study uses a composite index to estimate performance of water institutions, 0 otherwise	0.57	0.51	0	1
EXOGEN	=1, if the study captures the effects of exogeneous factors (economic development, economic and political reforms, technical progress) on performance of water institutions, 0 otherwise	0.83	0.39	0	1
PUST	=1, if the study is published in a peer-reviewed academic journal, 0 otherwise	0.61	0.50	0	1
JONAME	=1, if Water policy, = 2, if Water, = 3, if Policy modelling, = 4, if World Bank policy papers, = 5, if others (book, dissertations, conference papers, etc.)	3.17	1.61	0	5

Having specified the model(s) and determined the meta-moderator variables, the next step in the meta-regression process is the choice of model to estimate. In economics and business, two important models are commonly distinguished: fixed-effect and random-effect models (Lipsey and Wilson, 2001). The concept of both models in MRA is quite different from their definitions used in the panel data literature (Reed, 2015). As applied in the present context, they simply mean that the estimated water institution-performance effects are weighted by the inverse of their standard errors. In this regard, for each study, a weighted average along with a 95 percent confidence interval is computed (Alinaghi, 2017).

Generally, within the fixed effects (FE) framework, it is assumed that there is an identical true effect size across all studies included in the MRA, and the only reason estimates differ is because of sampling error (that is, the source of variance is exclusively due to measurement error within each study). Therefore, it should not be a problem if the estimates in larger studies receive substantially more weight because their "signal" is less distorted by "noise" and their estimates are more precise (Alinaghi, 2017). Accordingly, the conventional optimal weight to assign to each estimate in this framework is the inverse of its standard error. Alternatively, within the random effects (RE) framework, a distribution of true effects is assumed rather than just one true effect. Thus, small studies cannot simply be ignored by assigning a smaller weight to them because these studies provide valuable information about the distribution of effects. According to Kaiser and Menkhoff (2020), this means there is actual heterogeneity in the true effects between studies. Accordingly, the optimal weights assigned in this framework are the weighted standard error (within-study heterogeneity) plus the between-study heterogeneity term (τ^2)²⁹. Therefore, the weight assigned in this framework consists of two parts: (i) within-study variances (same as FE) and (ii) between-study variances (Borenstein et al., 2010).

According to DerSimonian and Laird (1986), most of the canonical meta-analysis models from other disciplines use random-effect models, whereas in economic research, meta-analysts often use fixed-effect models (Stanley and Doucouliagos, 2012). However, given the characteristics of this chapter's sample and its degree of heterogeneity (that is, the disparities in the empirical estimation strategies used to evaluate the effect of water institutions and performance, the diverse proxies for water institutions and performance, and the geographical and environmental differences across primary studies, among others), some studies may be weighted more heavily

²⁹ See Stanley and Doucouliagos (2012), page 123, for a detailed explanation of this weighting procedure.

in their influence on the meta-regression estimates than others. Therefore, this chapter argues that it is difficult to assume that there is indeed one common true effect and proceed to estimate both fixed and random effects models to address the research questions.

Accordingly, as suggested by Stanley and Doucouliagos (2012), additional weights (using weight = 1/sample size (n_k) of the respective primary study) different from the conventional optimal weights are applied to give the same weight to each study in the meta-regressions. This is done by multiplying this additional weight ($1/n_k$) with the conventional optimal weights. This weighting procedure is only additional to—and differently motivated from—the fixed and random effects weighted least squares (WLS) strategy. The WLS strategy is essential in meta-regressions. It helps address the heteroskedasticity inherent in effect sizes from heterogeneous primary studies, give greater weight to more precise estimates, and transform the effect sizes into the t-statistic on the variable of interest in each regression in the sample (Efendic et al., 2011). The additional weighting procedure is, however, not essential. Rather, according to Efendic et al. (2011), it only reflects a preference for giving all studies equal influence rather than potentially allowing some studies to have more influence. Subsequently, this additional weighting procedure is applied to both Equations (4.2) and (4.3). However, the results from these additional weighting procedures are not substantially different compared to those of the optimal WLS strategy in terms of magnitude, signs, and/or significance.

4.5 Results and Discussion

4.5.1 Descriptive Statistics

In Table 1, the meta-variables and their descriptive statistics are reported. However, the emphasis here is on the water institution-performance effect. The data shows that this effect has an average of 0.32, implying somewhat roughly that a 10-percentage point increase in this effect is associated with a 32-percentage point increase in the performance of water institutions, all else being constant. However, according to Stanley and Doucouliagos (2012), the meta-analysts should refrain from drawing any inferences from these averages, as this is premature. In addition, they assert that in the presence of heterogeneity, no measure of average effect size will capture the true nature of the phenomenon in question. Therefore, other, more advanced methods are crucial to further investigating publication selection bias and heterogeneity.

4.5.2 Investigating Heterogeneity in the Meta-Data

For heterogeneity, classical meta-analysis³⁰ procedures are applied using the fixed effects inverse-variance model (see Figure A4.1 in Appendix A4.3). This procedure also calculates Cochran's Q -test and the I^2 statistic to quantify heterogeneity. The Q -test result is statistically significant at 1%, suggesting the presence of heterogeneity between studies. Similarly, the I^2 statistic, the proportion of total variation attributable to between-study heterogeneity is 78.9%. This indicates the presence of high heterogeneity across the studies (Harris et al., 2009; Higgins and Thompson, 2002). This large heterogeneity is suspected to emanate from the disparities in the primary studies used in this meta-analysis. The large I^2 statistic suggests that the heterogeneity across studies goes far beyond just sampling error (Alinaghi, 2017). This is a justification for estimating and emphasizing the random-effects model in the rest of this chapter. Additionally, it is unlikely that all the heterogeneity will be explained after estimation, so there will be "residual heterogeneity", therefore making the random effects rather than the fixed effects meta-regression more appropriate (Benos and Zotou, 2014).

4.5.3 Investigating Publication Selection Bias and Genuine Empirical Effects

Publication selection bias is an issue of primary concern in the meta-analysis literature. It arises when authors, reviewers, and/or editors have a preference for results that are statistically significant (Stanley, 2005) and/or that satisfy theoretical expectations (Doucouliagos, 2005). Studies that report insignificant results and/or have the wrong signs are either not submitted for publication or are routinely rejected by the editors and/or referees (Bom and Ligthart, 2008). This issue, referred to as the "file drawer" problem, is the consequent consignment of studies to the "file drawer," implying that published studies may be a biased sample of the whole population of studies (Efendic et al., 2011). This can make empirical effects appear larger than they are in reality (Stanley et al., 2008). Given the strong tendency of the primary studies to report a positive role of water institutions on the performance of the water sector, in this chapter, the evidence of publication selection bias may be the non-submission or, in the case of submission, non-publication of results suggesting that water institutions do not have a significant effect and/or a negative effect on performance.

³⁰ The classical meta-analysis is basically a pooling of aggregate data from the estimates using either fixed or random effects. The pooled effect gives some information about the overall effect of the partial correlation (Kallager, 2014).

The simplest method used by meta-analysts to detect publication selection bias is a visual inspection of a funnel graph/plot (Doucouliagos, 2005; Stanley, 2005; Stanley and Doucouliagos, 2010). This graph depicts the estimates of the effect size of interest (PCC) on the horizontal axis against its precision (the inverse standard error of the PCC) on the vertical axis. The expected graph (see Stanley, 2005, pages 314–315 for an ideal funnel plot type that suggests the absence of publication selection bias) is an inverted funnel. In the absence of publication selection, estimates should vary randomly and symmetrically around the true population effect (Benos and Zotou, 2014). In Figure 4.4, the funnel graph is asymmetrically positively skewed, suggesting there is publication bias in favour of positive estimates. This visually affirms the presence of publication selection bias favouring positive values of the effects of water institutions on performance. In addition, the wide dispersions are consistent with the substantial heterogeneity hitherto depicted by the I^2 statistic.

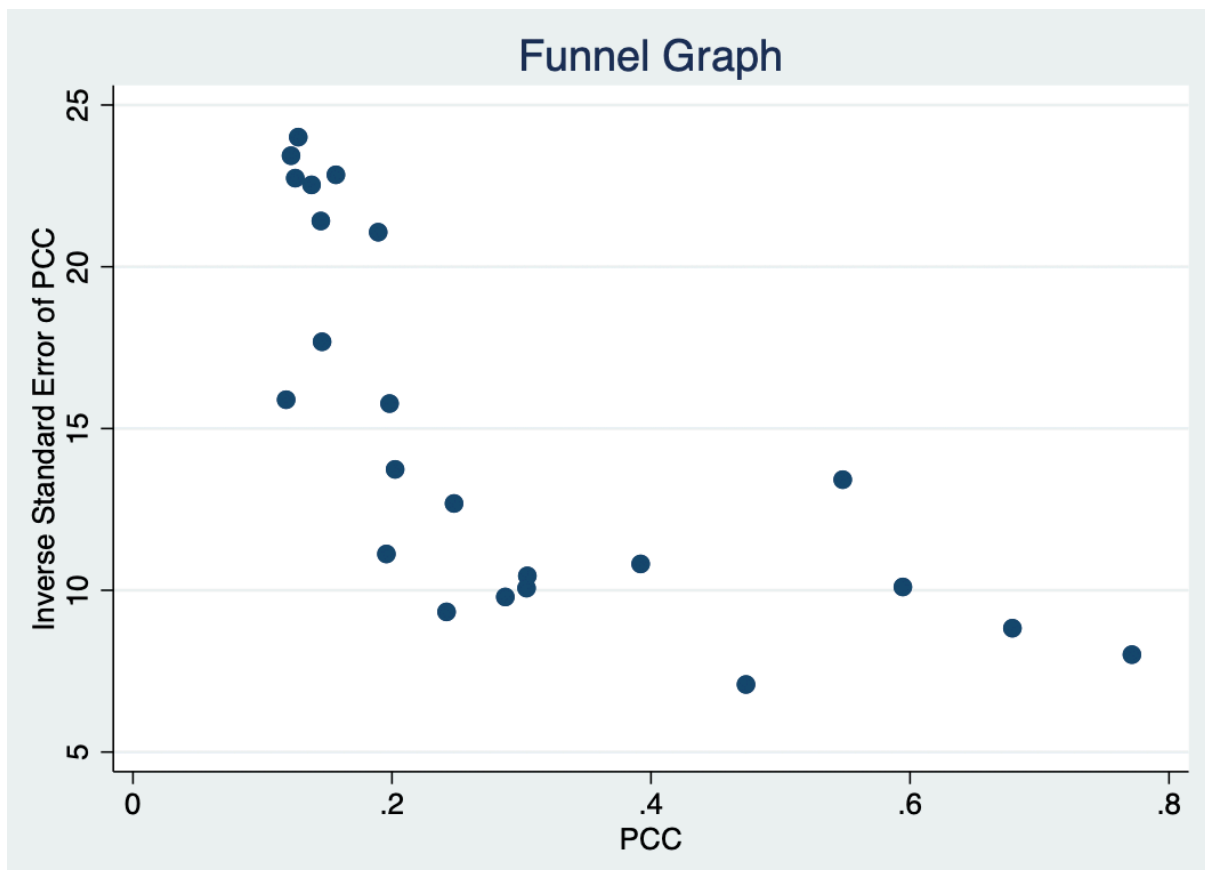


Figure 4. 4: The Funnel Graph

However, graphs are subjective. Therefore, two important tests—the Funnel Asymmetry Test (FAT) and the Precision Effect Test (PET)—are relied on to ascertain this. The FAT is the conventional way of detecting whether the literature suffers from publication selection bias

(Egger et al., 1997; Stanley, 2008), while the PET tests for the significance of the overall effect (Stanley and Doucouliagos, 2012; Shemilt et al., 2011) of the performance of water institutions.

For the purposes of these tests, Equation (4.2) is estimated using four (4) WLS estimators—fixed effects (weight 1), fixed effects (weight 2), random effects (weight 1), and random effects (weight 2)—and a restricted maximum likelihood (REML)³¹ estimator. The four (4) WLS estimators are estimated with cluster-robust standard errors clustered by study ID. Further, to account for data complexities associated with the meta-data, the fixed and random effects WLS estimators are estimated using the conventional optimal weights $(1/SEp_{k,j})$ and $(1/\sqrt{(SEp_{k,j})^2 + \tau^2})$, respectively, for weight 1. However, these weights, as explained above, allow some studies to have more influence than others. Accordingly, for weight 2, which addresses this issue, both sets of the conventional optimal weights above are multiply with the inverse of the sample size $(1/n_k)$ from each primary study. Weight 2 gives approximately the same weight to each study.

For the FAT, the null hypothesis is $H_0: \beta_1 = 0$ in Equation (4.2), while for the PET, it is $H_0: \beta_0 = 0$, for whether or not there is a genuine underlying empirical effect beyond the potential distortion due to publication selection (Stanley, 2005; 2008). The results of these tests are reported in Table 4.2. The results show that the null hypothesis of no publication selection bias for FAT is rejected at the 1% level of significance. This result confirms those of the funnel graph and provides sufficient evidence of a positive publication selection bias in the literature under investigation (Doucouliagos, 2005; Rose and Stanley, 2005; Stanley and Doucouliagos, 2007). The positive coefficients suggest that there is a publication selection bias in favour of a positive water institution-performance effect. This indicates that authors, reviewers, and editors tend to follow a systematic trend where only studies that report positive water institution-performance effects get accepted.

³¹ The REML uses the canned Stata `metareg` command to estimate random effects regression models. It is a weighted regression that contains a random-effects component. Because the standard error, or precision, is always one of the independent variables in the MRA model, a random-effects model is likely to be invalid (Stanley and Doucouliagos, 2012). Therefore, the authors caution against relying on this `metareg` routine. Although it is cautioned against, several studies, including Benos and Zotou (2014) and Kallager (2014), among others, have used this routine in economics. Likewise, this is done to verify the robustness of the findings and to adhere to common econometric reporting requirements.

Table 4. 2: Funnel Asymmetry and Precision Effect Tests (FAT/PET) for Publication Bias and Genuine Empirical Effect

	Fixed Effects (Weight 1)	Fixed Effects (Weight 2)	Random Effects (Weight 1)	Random Effects (Weight 2)	Random Effects (Weight 1)	Random Effects (Weight 2)	REML
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
FAT (Bias)	4.680*** (5.66)	5.534*** (5.49)	9.103*** (4.93)	9.989*** (3.32)	–	–	4.679*** (5.71)
PET (Precision)	0.073* (1.84)	0.116** (2.07)	0.049*** (4.16)	0.156** (2.61)	0.263*** (7.48)	0.403*** (6.37)	0.073 (1.42)
Number of observations	23	23	23	23	23	23	23
R-Squared	0.087	0.123	0.469	0.3695	0.693	0.767	–
F-test	F(1,22) = 3.37	F(1,22) = 4.29	F(1,22) = 17.33	F(1,22) = 6.83	F(1,22) = 55.90	F(1,22) = 40.54	F(1, 21) = 2.00
<i>H₀: Inverse Standard Error of the PCC = 0</i>	Prob > F=0.079	Prob > F=0.050	Prob > F=0.000	Prob > F=0.016	Prob > F=0.000	Prob > F=0.000	Prob > F=0.172
Number of studies	23	23	23	23	23	23	23

^a Dependent variable is the t-statistic for the variables of interest.

^b FAT and PET are estimates of β_1 and β_0 , respectively, from Equation (2)).

^c The coefficient of precision (Inverse Standard Error of the PCC) measures the magnitude of the water institutions-performance effect, corrected for publication selection.

^d Four WLS estimators—fixed effects (weight 1), fixed effects (weight 2), random effects (weight 1), random effects (weight 2)—and a restricted maximum likelihood (REML) estimator—are used to gauge FAT and PET.

^e The four WLS estimators are estimated using cluster robust standard error with clustering by study ID.

^f Associated t-statistic for FAT and PET estimates are reported in the parentheses.

^g Weight 1 is the conventional optimal weight and weight 2 is the additional weight to give each study the same weight

^h *, **, *** denote statistical significance at 10%, 5% and 1% levels respectively

Given this strong preference of reviewers and editors and the seemingly lack of competing hypotheses in the targeted empirical literature, if researchers found a negative water institution-performance effect, they may tend to shelve such results or studies.

With respect to PET, the coefficients of precision are positive and significant at different levels for all four (4) WLS estimators—columns (1) to (4). This provides evidence that, when the overall estimates are corrected for publication bias, there is a genuine empirical effect of water institutions on performance, though this effect may be small. Thus, the evidence gathered provides enough reason to believe that lowering the transaction costs associated with water institutions (the effective performance of water institutions) will, in fact, enhance their performance. Further, in columns (5) and (6) of Table 4.2, the results of the random effects estimates of Equation (4.2) are reported. Here, the constant terms that capture publication bias are omitted so that the overall estimates are not corrected for publication bias. The results show that the overall water institution-performance effect is statistically significant at the 1 percent level. It is also larger in absolute value terms compared to the results of columns (1) to (4). However, the results show that the REML estimator's coefficient of precision is positive but insignificant.

4.5.4 Multivariate Meta-Regression Results

The estimates of the bivariate meta-regression model (Equation 4.2) may be biased if important explanatory variables are omitted (Doucouliagos and Stanley, 2009). Accordingly, the multivariate meta-regression is estimated to account for heterogeneity in the referenced literature as well as explore its consequences on the water institution-performance effect. This is important given that the effect sizes reported in the different primary studies may have been influenced by several factors, including but not limited to differences in methodology and explanatory variables, among others. Thus, Equation (4.3) uses some of the moderator variables in Table 4.1. As noted above, the same conventional optimal and additional weighting procedures (weight 1 and weight 2) are applied in the multivariate meta-regression. In addition, author dependency is accounted for by using robust standard errors clustered by study ID. In Table 4.3, the results of the multivariate meta-regressions are presented.

Table 4. 3: Multivariate Meta-Regression Results

Moderator Variables	Fixed Effects	Fixed Effects	Random Effects	Random Effects	Random Effects	REML
	(Weight 1)	(Weight 2)	(Weight 1)	(Weight 2)	(Weight 1)	
	G-to-S					
	(1)	(2)	(3)	(4)	(5)	(6)
CONSTANT	5.389 *** (5.82)	6.111 *** (5.87)	11.196 *** (9.09)	12.798 *** (9.93)	10.216 *** (10.41)	11.092 *** (8.47)
PRECISION (InvSEp)	0.168* (1.96)	0.264** (2.31)	0.454 *** (6.07)	0.756 *** (6.78)	0.184 *** (7.31)	0.435 *** (5.15)
NUMVAR	-0.002 *** (-4.58)	-0.002** (-2.49)	-0.002** (-2.42)	-0.001 (-1.12)	-0.002 *** (-3.83)	-0.002* (-1.76)
WATLAW	0.156 *** (5.88)	0.160 *** (3.30)	0.152 *** (4.19)	0.162** (2.24)	0.154 *** (6.09)	0.152 *** (3.62)
WATPOL	0.142** (2.70)	0.171** (2.69)	0.154 *** (2.82)	0.186 *** (3.30)	0.124 *** (3.57)	0.151 *** (3.18)
WATADM	-0.084 (-1.68)	-0.072 (-0.96)	-0.070 (-1.20)	-0.063 (-1.08)	-0.075 (-1.29)	-0.071 (-0.83)
COST	0.123** (2.51)	0.136** (2.08)	0.152 *** (3.13)	0.162** (2.22)	0.101* (1.76)	0.152** (2.82)
ASCOST	0.046 (0.51)	0.077 (0.75)	0.085 (1.26)	0.122 (1.66)		0.083 (1.30)
IDA	0.093 *** (3.30)	0.098** (2.26)	0.105 *** (3.14)	0.114** (2.56)	0.099 *** (3.95)	0.104 *** (3.43)
OLS	0.013 (0.20)	0.016 (0.21)	0.002 (0.03)	0.016 (0.26)		0.0028 (0.06)
THRESLS	0.156 *** (3.48)	0.162 *** (3.06)	0.160 *** (3.79)	0.173 *** (5.20)	0.142 *** (4.09)	0.159 *** (3.41)
INSOVAR	-0.109 *** (-3.94)	-0.127 *** (-3.13)	-0.111 *** (-2.90)	-0.127** (-2.54)	-0.108 *** (-4.01)	-0.109** (-2.63)

Table 4.2: (Continued)

Moderator Variables	Fixed Effects	Fixed Effects	Random Effects	Random Effects	Random Effects	REML
	(Weight 1)	(Weight 2)	(Weight 1)	(Weight 2)	(Weight 1)	
	(1)	(2)	(3)	(4)	(5)	(6)
SEM	0.364 ** (2.60)	0.376*** (3.48)	0.383*** (5.18)	0.384*** (7.94)	0.377*** (4.80)	0.383*** (6.20)
COMINDX	-0.315** (-2.31)	-0.309*** (-2.94)	-0.328*** (-5.03)	-0.307*** (-7.04)	-0.349*** (-5.26)	-0.329*** (-5.56)
EXOGEN	0.204*** (5.01)	0.209*** (4.38)	0.210*** (5.36)	0.203*** (3.99)	0.204*** (4.53)	0.209*** (4.46)
PUST	-0.126*** (-3.12)	-0.158*** (-2.92)	-0.158*** (-3.42)	-0.198*** (-4.95)	-0.133*** (-4.11)	-0.155*** (-4.17)
Number of observations	23	23	23	23	23	23
R-Squared	0.908	0.921	0.969	0.982	0.9612	–
F-test	F(14, 22) = 202.4	F(14, 22) = 57.96	F(14, 22) = 217.7	F(14, 22) = 80.36	(12, 22) = 309.8	F(15, 7) = 14.7
H_0 : moderator variables are jointly = 0	Prob > F = 0.000	Prob > F = 0.000	Prob > F = 0.000	Prob > F = 0.000	Prob > F = 0.000	Prob > F = 0.0007
Number of studies	23	23	23	23	23	23

^a The dependent variables are the t-statistics of the variables of interest

^b The coefficient of precision (Inverse Standard Error of the PCC) measures the magnitude of the effects of water institutions on performance, corrected for publication selection.

^c Four WLS estimators—fixed effects (weight 1), fixed effects (weight 2), random effects (weight 1), random effects (weight 2)—and a restricted maximum likelihood (REML) estimator.

^d The four WLS estimators are estimated using cluster robust standard errors with clustering by study ID

^e Associated t-statistic for the estimates are reported in the parentheses.

^f Weight 1 is the conventional optimal weight and weight 2 is the additional weight to give each study the same weight.

^g Column (5) reports the general-to-specific (G-to-S) results of random effects (weight 1) only (the conventional optimal weight)

^h *, **, *** denote statistical significance at 10%, 5% and 1% levels respectively.

All the regressions are estimated using the full meta-data sample. However, the general-to-specific (G-to-S) approach is applied to the random effects model (weight 1) because it is the main model of concern. The G-to-S approach³² has the added advantage of improving the degrees-of-freedom and avoiding the situation of multicollinearity (Afesorgbor and Demena, 2022). First, the results for the models' F-statistics indicate that the estimated meta-regression coefficients are jointly significant. When the joint test shows that the moderator variables and the constant are jointly zero, it indicates genuine, systematic patterns among reported findings (Stanley and Doucouliagos, 2012). In terms of the overall fit of the regressions, the fixed and random effects WLS models report high R-squared statistics ($R^2 > 0.90$). According to Stanley and Doucouliagos (2012), the explanatory power of reported meta-regressions may range from 0.08 to 0.98, depending on the research issue and specification of the meta-regressions. Accordingly, these R-squared statistics are within range and suggest that the models largely capture the main sources of heterogeneity in the water institution-performance literature, which is evidenced by deviations from the overall empirical effect (estimated by the coefficient on the inverse standard error of the PCC). However, the REML model has an adjusted R-squared of 0.92 (not reported in the Table).

Second, on FAT (constant term), it can be seen across all the models that the multivariate meta-regression results are consistent with those of the bivariate meta-regressions. This suggests a substantial positive publication selection bias in the referenced literature. In addition, the genuine empirical effect of water institutions on performance remains robust even after accounting for the various dimensions of heterogeneity in the literature. Its coefficient (precision) is positive and significant across the multivariate meta-regressions. Thus, confirming the robustness of the results of this chapter, that effective water institutions stimulate performance. However, according to Stanley and Doucouliagos (2012) and Doucouliagos and Stanley (2009), in the multivariate meta-regression, the authentic effect size is not as simple as in the bivariate meta-regressions. Instead, the estimated effect size is now a combination of the coefficient of precision and the other moderator variables in the multivariate meta-regression. This is further demonstrated after the analysis of the moderator variables.

³² The G-to-S approach begins with the inclusion of all potential moderator variables in Equation (3), estimating them, and then removing the insignificant variables one at a time until only statistically significant variables remain (Stanley and Doucouliagos, 2012). This is in line with the MAER-Net reporting guidelines (Afesorgbor and Demena, 2022).

Nevertheless, Stanley and Doucouliagos (2012) affirmed that a successful meta-analysis will find consistent overall results between the simple FAT-PET bivariate meta-regression models and those of the multivariate meta-regression models regarding the presence of publication selection bias and the existence of a practically significant empirical effect (or not). The bivariate and multivariate meta-regressions of this chapter exactly confirmed this conclusion.

Third, given that the results of the moderator variables do not substantially vary across the models in terms of magnitude, signs, and/or significance, the analysis will now be limited to the random effects G-to-S model. As noted earlier, the random effects model is the reference model. The G-to-S model reveals that some of the moderator variables are important in explaining the differences in the primary studies. Before proceeding with the analysis, it is worth noting how the moderator variables are interpreted. They are interpreted to mean that they would either increase or lower the water institution-performance effect. If a moderator variable is positive and significant, it suggests that this moderator variable (representing a certain study characteristic) will increase the reported partial correlation between water institutions and performance. On the other hand, a negative and significant coefficient for a moderator variable suggests that this moderator variable will typically reduce the reported partial correlation between water institutions and performance.

In the G-to-S model, when all other moderator variables are constrained to zero, NUMVAR (the number of independent variables used in the primary regressions) is negative and statistically significant at the 1 percent significance level. This suggests that if the number of independent variables are more in the primary regressions, it lowers the water institution-performance effect. This finding is consistent with the econometrics literature, as Zhang (2014) emphasized that overfitting occurs when too many variables are included in a model and the model appears to fit, yet some of these variables are actually ‘noise’ variables.

Furthermore, WATLAW (=1, if the study uses water law or some aspect of it to capture water institutions, 0 otherwise) and WATPOL (=1, if the study uses water policy or some aspect of it to capture water institutions, 0 otherwise) are positive and statistically significant at the 1 percent significance level. These results suggest that primary studies that use the water law and/or water policy or some aspects of these to capture the water institution-performance effect tend to increase it, all else being constant. This implies that the water law and/or water policy, or some aspects of these, exert a greater impact on performance. However, though WATADM

(=1, if the study uses water administration or some aspect of it to capture water institutions, 0 otherwise) is not significant, it is left in the G-to-S model because it improves the model's fit if included, while its exclusion worsens the estimates. This goes to show that even though it is insignificant in the MRA, it is important in the primary literature measuring the water institution-performance relationship. This set of results demonstrates the importance of the three institutional components—water law, water policy, and water administration—in determining the performance of both water institutions as well as the water sector (Saleth and Dinar, 2004). Therefore, it is not surprising that the primary literature emphasizes the importance of these in the water institution-performance relationship (Ahmed and Araral, 2019; Araral and Wang, 2015; Balint et al., 2002; Bandaragoda, 2000; Chopra and Ramachandran, 2021; Saleth and Dinar, 1999b; 2004; 2008).

Consistent with expectations, COST (=1, if the study covers all or most of the important water institutions of Saleth and Dinar (2004), 0 otherwise) is positive and significant at the 10 percent level. This suggests that studies that cover the three institutional components—water law, water policy, and water administration—of Saleth and Dinar (2004) tend to increase the water institution-performance effect, all else being constant.

In line with the results of COST, it is not surprising that IDA (=1, if the study uses the IDA framework to analyze the performance of water institutions, 0 otherwise) has a similar effect on the water institution-performance relationship. These two results (COST and IDA) demonstrate the importance of the IDA methodology in the primary literature concerned. This methodology not only allows for the decomposition of water institutions into minute yet functionally related sets of rules but also allows for the measurement of the overall performance or effectiveness of water institutions and/or their aspects.

THRESLS (=1, if the study uses three-stage least square procedures to control for endogeneity, 0 otherwise), which is mostly used to control for endogeneity in the literature, is positive and significant at the 1 percent level. This result suggests that studies that control for endogeneity are more likely to yield true higher values of the water institution-performance relationship, all else being constant. This result is important and demonstrates that studies that use ordinary least squares estimation strategies, where the problem of endogeneity is prominent, are more likely to report falsely higher correlations of the water institutions and performance effects

relative to studies that use three-stage least squares procedures. In addition, SEM (=1, if the study uses structural equation methods of estimation, 0 otherwise) is positive and significant at the 1 percent level. This result indicates that studies that use SEM to (i) explicitly assess measurement errors and unexplained variances, (ii) execute simultaneous testing of relationships, (iii) link micro- and macro-perspectives, and (iv) develop best-fitting models and theories (Nunkoo and Ramkissoon, 2012; Urbano, 2013) are more likely to report a higher correlation between water institutions and performance compared to other studies that use other methods of estimation, all else being constant.

The results further show that primary studies that included other variables alongside the water institution variables in their regressions (INSOVAR) and those that use a composite index to estimate the performance of water institutions (COMINDX) are more likely to report a lower water institution-performance effect, all else being constant. In addition, there is a negative relationship between a study(ies) being published in a peer-reviewed journal and the water institution-performance effect. This suggests that studies that are published in peer-reviewed academic journals (PUST) tend to have a significant and lower estimates of the water institution-performance effect, all else being constant.

Finally, in accordance with expectations, EXOGEN (=1, if the study captures the effects of exogenous economic factors—economic development, economic and political reforms, technical progress—on the performance of water institutions, 0 otherwise) is positive and highly significant. This indicates that studies that include exogenous economic factors are more likely to report a higher impact of water institutions on performance, all else being constant. This result underscores the importance of the external sector on the water sector and shows the complex inter-linkages of water institutions and/or the water sector with the external economy.

Having demonstrated how the meta-moderator variables affect the genuine water institution-performance effect, this chapter now reverts to determining the correct genuine water institution-performance effect for the multivariate meta-regression. It is worth noting that, though incorporating perceived sources of heterogeneity allows for a better estimate of the genuine performance effect of water institutions, it is no longer a measure of the underlying effect as in the case of the bivariate meta-regressions. As explained above, the underlying genuine water institution-performance effect is now a combination of the coefficient of precision and the moderator variables. But Stanley and Doucouliagos (2012) do not show how

to go about this. However, they argue that determining this underlying effect would depend on the professional judgment of the meta-analyst, conditional on the selected sources of heterogeneity inherent in the primary literature. They classified this procedure as the "best practice" approach (Stanley and Doucouliagos, 2012). Accordingly, following this best practice approach, the authentic water institution-performance effect is constructed and estimated. Here, the selected moderator variables are limited to (i) the number of independent variables used in the primary studies (NUMVAR), (ii) the water law (WATLAW), (iii) the water policy (WATPOL), (iv) studies that cover all the water institution variables of Saleth and Dinar (2004) (COST), (v) studies that used the IDA framework to estimate overall performance, (vi) studies that used three-stage least squares to control for endogeneity (THRESLS), (vii) studies that used a composite index as the dependent variable (COMINDEX), (viii) studies that used exogenous macroeconomic factors (EXOGEN), and (ix) whether the study is published in a peer review journal or not (PUST).

These moderator variables were selected because they are widely used by most of the primary studies included in the MRA. These variables first border on the definition of water institutions as covered in Saleth and Dinar (2004)—water law and water policy. Second, they border on methodology/estimation strategy, and the dependent variables used in the primary studies—IDA and COMINDEX, among others. Third, on the control and non-control of potential endogeneity in the primary studies—THRESLS. Fourth, on exogenous economic factors—EXOGEN—and finally, on whether the study was published in a peer-reviewed journal or not—PUST. The best practice approach yielded an authentic water institution-performance effect of 0.524³³, which is statistically significant at the 5 percent level. Such a result is large in terms of the typical size of a PCC in applied economics (Doucouliagos, 2011) and suggests a high impact of the effectiveness of water institutions on performance in the water sector. This confirms the primary literature's assertion that the various institutional components of water institutions are important for performance (Ahmed and Araral, 2019; Chopra and Ramachandran, 2021; Saleth and Dinar, 1999b; 2004; 2005; and 2008).

³³ Using Stata's nlcom command

4.6 Conclusion and Policy Implications

This chapter reports the results of a meta-regression analysis of the effect of water institutions and water sector performance using 23 primary studies. Four WLS estimators and a restricted maximum likelihood (REML) estimator are estimated in the bivariate and multivariate meta-regressions. First, the results from the graphical analysis and bivariate meta-regressions confirm the presence of a positive publication selection bias in the targeted literature. These results suggest that authors, reviewers, and editors tend to have preferences for only results or studies that report a positive water institution-performance effect. Therefore, if authors find a negative water institution-performance effect, they may tend to shun such results. In addition, the bivariate and multivariate meta-regressions confirm the presence of a positive, authentic, and large empirical water institution-performance effect. This evidence demonstrates that effective water institutions are important and lower transaction costs, which enhance the performance of water institutions and the water sector as a whole.

Second, the results of all the multivariate meta-regressions, regardless of the model/estimator used, produced robust results. These results, however, did not differ substantially in terms of magnitude, signs, and/or significance. Therefore, the analyses were limited to the general-to-specific model. This model shows that the moderator variables are important in explaining the heterogeneity in the primary studies. The results reveal that the sources of variation in this literature are explained by many factors. These include how the water institution-performance relationship is measured, the type of variables used to capture water institutions, the type of dependent variable used to capture performance, and, importantly, the empirical strategy used in the primary study, among others.

Specifically, the higher the number of independent variables in the primary regressions, the inclusion of other variables alongside the water institution variables in the primary regressions, the use of composite indices to estimate the performance of water institutions, and whether the study is published in a peer-reviewed academic journal or not tend to lower the water institution-performance effect, all else being constant. While studies that use the water law, water policy, and/or some aspect of these to capture water institutions in the primary regressions, studies that cover all or most of the important water institutions of Saleth and Dinar (2004), studies that use the IDA framework to analyze the overall performance of water institutions, and studies that use methodologies that control for endogeneity, among others, are

more likely to report a higher impact of water institutions on performance, all else being held constant.

Overall, the combined weight of the evidence gathered in this MRA indicates that after correcting for publication selection bias, controlling for the potential effects of moderator variables, and applying the best-practice approach, effective water institutions exert a positive impact on the performance of the water sector.

These findings are important for institutional economists, stakeholders in the water space, and researchers in this field, among others. First, this chapter confirms the positive water institution-performance relationship in the literature and concludes that effective-performing water institutions are not only critical in providing the appropriate and adequate arrangements to steer individual and group behaviour in lowering transaction costs in the water sector but are also important for the effective allocation and utilization of the resource in all sectors of the economy. Second, the findings provide further insights for the further development, facilitation, and strengthening of the water law, policies, and administration in the water space to reduce the high transaction costs and related poor management issues associated with the sector. This is especially critical in efforts to engender reforms in the water sector. Such reforms may focus on the three main pillars of water institutions—water laws, water policies, and water administration—which this chapter confirms are important for performance. Lastly, these findings are timely and demonstrate the critical need for improvements across the research cycle to improve the quality of research, reporting, review, and publication in the water space.

In addition, given that MRA allows the researcher to unravel various factors and discrepancies responsible for conflicting results in the literature, the results of this chapter point to the importance of using the appropriate methodologies, representative samples, the right dependent variables to capture the performance of water institutions, and/or the right independent variables that capture water institutions, among others. Accordingly, given the seemingly lack or absence of a competing hypothesis or theory in respect of the water institution-performance relationship, this chapter offers some clearer guidelines for authors, reviewers, and editors on research reporting.

The findings of this chapter have interesting policy implications. First, the water law and the water policy, or some aspects of these, exert a greater influence on the performance of water

institutions. Therefore, these or their aspects could be used to maximize the positive impacts of water institutions on performance. Accordingly, to engender water sector reforms and/or for the further development, facilitation, and strengthening of water institutions, this chapter advocates the incorporation and strengthening of the water law and the water policy in policy formulation and reforms for successful water resource management and governance. Second, studies using the IDA framework, studies that use methodologies that control for endogeneity and those that capture the effects of exogenous economic factors—are more likely to report a higher impact of water institutions on performance, all else being held constant. Therefore, researchers should endeavour to use these to amplify the water institutions-performance effects. Third, when a composite index is used to capture performance in the models, a lower water institution-performance effect is evident. This result is, however, important given the advantage that composite indicators or indexes can easily summarize the complex and multidimensional nature of water institutions and their performance. This makes it simpler to compare the performance of water institutions over time. From the perspectives of policymakers, water resource managers, and institutional economists, it is easier to follow the trend of an index or a few indices to make better predictions of events than if multiple sets of performance indicators of water institutions were involved. Accordingly, more estimation of such indicators or indexes in the water sector is recommended to ease comparisons of the performance of water institutions over time and across nations. This would then serve as a guide to promote water sector reforms across countries.

This chapter, no doubt, provides important guidelines for future studies evaluating the role of water institutions on performance. However, there are still a number of issues that require further investigation. The chapter acknowledges that it is generally not prudent to rely on the results of only a handful of studies. Therefore, given that this subject of the performance of water institutions is generating keen professional discourse within policy circles—national and international—with the literature continuously growing, additional quantitative studies are needed in this area to make the findings of this chapter clearer and more generalizable. Many important studies were excluded because of the lack of information on key variables, such as sample size, t-statistics, and standard errors, among others, that are required for meta-analysis. Future quantitative studies in this area should, therefore, endeavour to report these statistics.

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Appendices

Appendix A4.1: List of Studies Included in the Meta-Regression

Table A4.1: List of the Studies

Study	Author(s) and Year of Publication	Publication	Number of variables	T-Statistic extracted
1	Ahmed and Araral (2019)	Water	17	3.145
2	Ahmad et al. (2020)	Water	75	3.064
3	Araral and Wang (2015)	Water Policy	17	2.781
4	Araral and Ratra (2016)	Water Policy	17	2.816
5	Bhamoriya and Gandhi (2010)	Working paper	21	3,990
6	Chopra and Ramachandran (2021)	Water Policy	6	3.356
7	Dinar et al. (2007)	Policy Modelling	8	6.180
8	Dinar et al. (2016)	African Economies	12	2.260
9	Dirwai et al. (2019)	Water Policy	15	3.125
10	Gandhi and Johnson (2019)	Water	9	2.850
11	Gandhi and Sharma (2009)	Book	7	3.181
12	Gandhi and Roy (2009)	Book	11	4.240
13	Gandhi et al. (2009)	Book	18	3.107
14	Gandhi et al. (2020)	Water	17	3.580
15	Jain and Gandhi (2012)	Working paper	6	2.860
16	Johnson et al. (2020)	Water	8	3.107
17	Li et al. (2022)	Water	6	3.060
18	Muchara (2014)	Dissertation	18	2.582
19	Namboodiri and Gandhi (2009)	Book	12	1.880
20	Nhundu et al. (2015)	Irrigation and Drainage	33	2.177
21	Saleth and Dinar (1999)	World Bank	30	5.995
22	Saleth and Dinar (2004)	World Bank	26	7.355
23	Saleth and Dinar (2008)	World Bank	32	6.006

Appendix A4.2: List of Studies Used in the Meta-analysis and how they Measured Water Institutions as well as Performance.

Table A4.2: List of the Studies and how they Measured Water Institutions as well as Performance.

Study	Author(s) and Year of Publication	Water Institutions Used in the Study	How Performance was Measured in the Study
1	Ahmed and Araral (2019)	Water law, water policy and water administration	Water governance/performance measured based on an average score of water law, water policy, and water administration before and after the announcement of the SDGs. An increase or improvement in the governance score indicated effective performance.
2	Ahmad et al. (2020)	Water user associations (WUAs) <ul style="list-style-type: none"> • compliance • adaptiveness • clarity of objectives • good interaction, and • appropriate scale 	Overall performance of WUAs was measured with a five-point Likert scale, ranging from 1 to 5 (1 = strongly disagree, 2 = disagree, 3 = indecisive, 4 = agree, and 5 = strongly agreed).
3	Araral and Wang (2015)	Water law, water policy and water administration	Water sector performance is measured in terms of the adequacy of drinking water, the availability of water resources, and water productivity. This is measured on a scale of 0 to 10. For instance, for the adequacy of drinking water, 10 means ‘highly adequate’, while 0 means ‘inadequate’, etc.
4	Araral and Ratra (2016)	Water law, water policy and water administration	Water sector governance/performance measured in terms of a standardized score on a scale of 100. Anything between 0 and 49 is low, 50 is average, and above 50 is high.

5	Bhamoriya and Gandhi (2010)	WUAs, canal cooperatives, tube-well partnerships, check dam groups, tank irrigation associations, and lift irrigation cooperatives	Performance of water institutions is measured as a function of all factors (composite performance) covering features ³⁴ of structure, processes, controls, and governance.
6	Chopra and Ramachandran (2021)	Water law, water policy, and water administration	Overall water sector performance is measured as a function of the overall performance of the physical, financial, economic, equity, and ecological performance variables. It has a bounded scale in the range of 1–10, where 1 and 10 indicate the worst and ideal situation, respectively.
7	Dinar et al. (2007)	River basin organizations (RBOs) <ul style="list-style-type: none"> • WUAs and/or governments at the river basin level and below. 	Performance of river basin management institutions before and after decentralization. That is, the decentralization success/progress of water users or governments at the river basin level or below is measured as a function of the level of participation, local responsibility, financial performance, and economic activity.
8	Dinar et al. (2016)	River basin organizations (RBOs) <ul style="list-style-type: none"> • WUAs involvements 	Performance of decentralization of water resource management measured by comparing performance between present and the pre-decentralization period. Performance variables included level of participation, local responsibility, financial performance, economic activity, etc.
9	Dirwai et al. (2019)	Government, WUAs, irrigation management committees (IMCs) and traditional authorities.	Performance is measured as the impacts of water governance on the adequacy of water in irrigation schemes. (Adequacy indicates whether the water delivery system supplies the required amount to a section in the irrigation scheme over a period of time (daily, monthly, or seasonally). Water adequacy is measured as 1 and 0, where 1 is water adequacy and 0 is water inadequacy.

³⁴ The managing committee is active, the secretary is active, management has the expertise, rules are determined by the government, the objectives are clear to the members, the institution regularly plans for the achievement of objectives, there is good interaction between the members of the institution, there is good interaction between the institution and the government, there is good leadership to facilitate, improve, and guide the interaction, there are clear mechanisms for changing the rules, the management has authority to adapt the rules and systems, and the institution uses its powers to bring compliance, among others.

10	Gandhi and Johnson (2019)	<p>Participatory irrigation management institutions (PIM)—WUAs,</p> <ul style="list-style-type: none"> • Eight institutional rationalities: technical, environmental, economic, social, political organizational, financial and government. • As well as five institutional features: clear objectives, good interaction, adaptiveness, right scale, and compliance. 	<p>Overall performance of participatory water institutions based on a composite of six performance indicators (overall assessment of the performance of the WUAs, performance on water availability and use, performance on economic benefits, performance on equity in water distribution and benefits, performance on environment care and impact, and performance on financial management) measured on a Likert scale of 5 to 1: Excellent (5) Good (4) Satisfactory (3) Somewhat Poor (2) Very Poor (1).</p>
11	Gandhi and Sharma (2009)	<p>Rainwater harvesting institutions.</p> <ul style="list-style-type: none"> • Five institutional features: clear objectives, water situation, adaptiveness, role activities, and compliance. 	<p>Overall institutional performance/success is measured as a function of all factors (composite performance) covering features of structure, processes, controls, and governance.</p>
12	Gandhi and Roy (2009)	<p>Groundwater institutions (tube-well cooperatives and tube-well partnerships)</p> <ul style="list-style-type: none"> • Five institutional features: clear objectives, water situation, adaptiveness, role activities, and compliance. 	<p>Overall success or performance of the institution is measured based on a Likert scale of 4 to 1. 4 is very successful, and 1 is poor. This measure covers features of structure, processes, controls, and governance.</p>
13	Gandhi et al. (2009)	<p>WUAs, canal cooperatives, tube-well partnerships, tube-well cooperatives, and check dam groups</p>	<p>The overall performance of these institutions is measured on a Likert scale of 5 to 1. 5 is strongly disagrees, and 1 is strongly agrees. The measure covers features of structure, processes, controls, and governance.</p>
14	Gandhi et al. (2020)	<p>Participatory irrigation management (PIM)—WUAs</p> <ul style="list-style-type: none"> • Involvement of Central Level Committee (CLC) • Involvement of Village Level Committee (VLC). 	<p>Overall performance based on a composite of six performance indicators (overall assessment of the performance of the WUAs, performance on water availability and use, performance on economic benefits, performance on equity in water distribution and benefits, performance on environment care and impact, and performance on financial management) measured on a Likert scale of 5 to 1: Excellent (5) Good (4) Satisfactory (3) Somewhat Poor (2) Very Poor (1).</p>

15	Jain and Gandhi (2012)	Watershed development (WSD) institutions	Overall success of the WSD institution is based on aggregate scores obtained for different rationalities and some included features of structure, processes, and governance, which are measured on a Likert scale from 1 to 5. Excellent (5) Good (4) Satisfactory (3) Somewhat Poor (2) Very Poor (1).
16	Johnson et al. (2020)	Participatory water management institutions—WUAs, <ul style="list-style-type: none"> • Eight institutional rationalities: technical, environmental, economic, social, political organizational, financial and government. • As well as five institutional features: clear objectives, good interaction, adaptiveness, appropriate scale, and compliance. 	Overall performance/success of performance of WUA based on different goals, rationalities, and institutional features assessed through a 5-point Likert scale: Excellent (5) Good (4) Satisfactory (3) Somewhat Poor (2) Very Poor (1).
17	Li et al. (2022)	Water resources management (WRM) levels <ul style="list-style-type: none"> • Environmental management capabilities • Water resources development and utilization rate • Smart water management capabilities • Water-saving irrigation rate 	WRM performance is measured as overall efficiency of decision-making units in the WRM
18	Muchara (2014)	Collective participation in irrigation water management. <ul style="list-style-type: none"> • Conflict resolution mechanisms • Adequacy • Irrigation committees 	Effectiveness of irrigation committees and farmers in participating in maintaining irrigation infrastructure and management.
19	Namboodiri and Gandhi (2009)	Surface water institutions <ul style="list-style-type: none"> • Canal cooperatives • WUAs 	Overall composite performance of institutional performance based on the features of structure, processes, and governance and measured on a Likert scale from 1 to 5: Very high (5) high (4) neither (3) low (2) very low (1).

20	Nhundu et al. (2015)	Irrigation water law, irrigation water policy, irrigation water administration and some informal water institutions (clearly defined boundaries to withdraw from common pool resources (CPRs), local appropriation rules related to local conditions, mechanisms to assist in irrigation water management, e.g., constitutions, effectiveness of management mechanisms, effectiveness of monitoring of CPR conditions and the behaviour of appropriators, etc.)	The effectiveness of irrigation water management institutions is measured as a function of the performance of irrigation water law, irrigation water policy, irrigation water administration, and informal water institutions.
21	Saleth and Dinar (1999)	Water law, water policy, and water administration	The overall effectiveness or performance of the water sector is measured as a function of the overall effectiveness of the water law, water policy, and water administration and/or their aspects, as well as some economic factors.
22	Saleth and Dinar (2004)	Water law, water policy, and water administration	The overall effectiveness or performance of the water sector is measured as a function of the overall effectiveness of the water law, water policy, and water administration and/or their aspects, as well as some economic factors.
23	Saleth and Dinar (2008)	Water law, water policy, and water administration	The overall effectiveness or performance of the water sector is measured as a function of the overall effectiveness of the water law, water policy, and water administration and/or their aspects, as well as some economic factors.

Appendix A4.3: Testing Heterogeneity Using the Fixed-Effects Inverse-Variance Model.

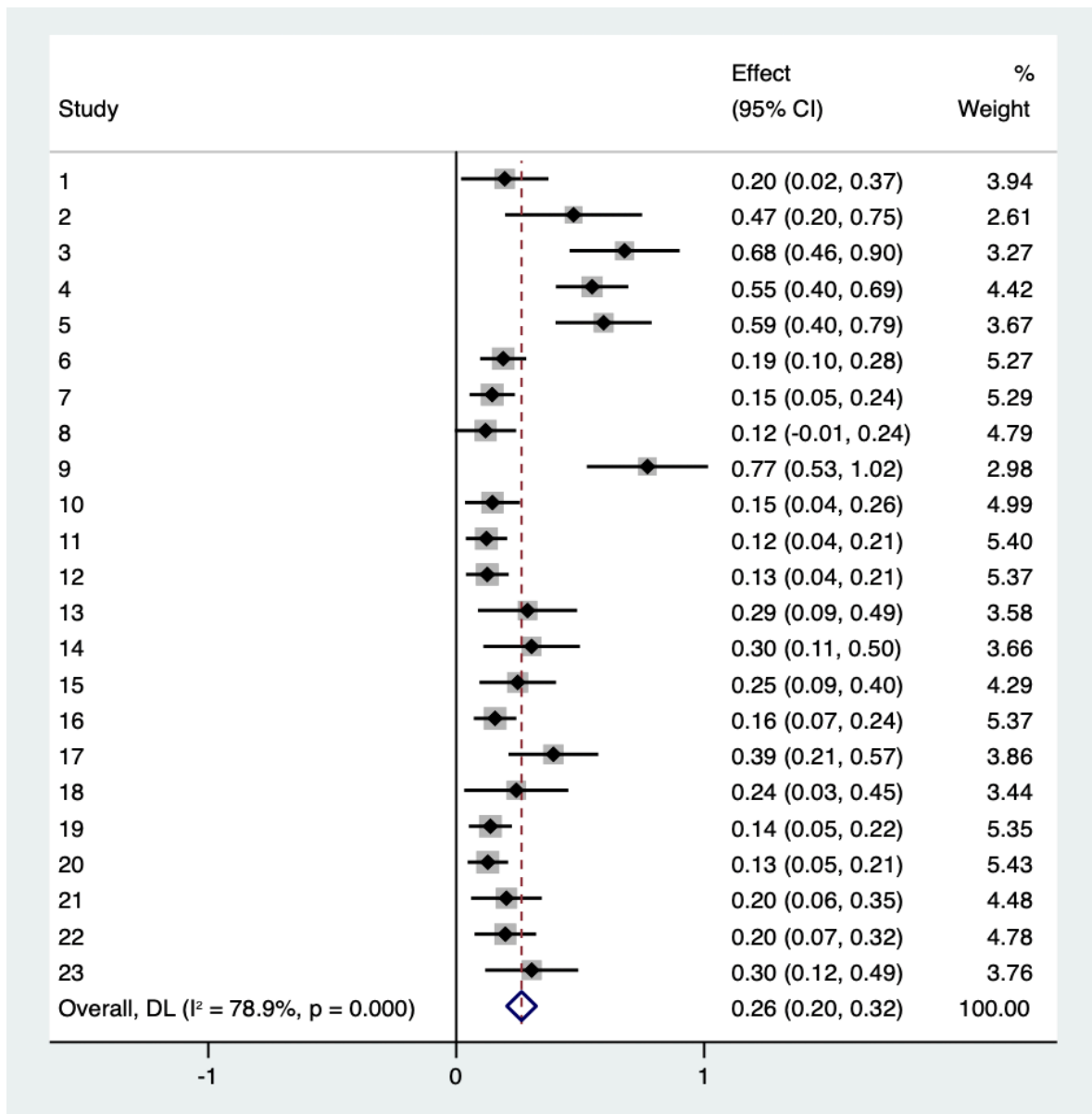


Figure A4.1: Meta-analysis Pooling of Aggregate Data Using the Fixed-Effects Inverse-Variance Model.

Chapter 5: General Conclusion

The objective of this thesis is to contribute to the literature on water resources management in the agricultural sector in general and, in particular, to the literature on the adoption and uptake of WCPs, agNPS pollution control, and performance of water management institutions. Accordingly, this thesis has three important related core chapters with the common objective of finding solutions to the water scarcity problem, exacerbated by intensified climate change, unsustainable agricultural farming practices that deteriorate water quality, and the poor performance of water management institutions that lower transaction costs in the water sector.

The first chapter, titled "farming under drought, an analysis of the factors influencing farmers' multiple adoption of water conservation practices to mitigate farm-level water scarcity" is set out to identify and analyze the factors that influence farmers' multiple adoption or bundling of WCPs, the intensity of their adoption, and their interrelatedness in countering the water scarcity problem. Using six WCPs and data from 555 farmers from the Limpopo Province of South Africa, a multivariate probit (MVP) model is estimated to determine the factors that influence farmers' multiple adoption of WCPs, while for the intensity of their adoption an ordered probit model (OPM) is estimated. The insights from this chapter are essential for the design of relevant and effective water management strategies that improve water use efficiency at the farm level. It also offers farmers the guidance to prepare appropriately to cope with the effects of DWSs and thus, build climate change resilience to maintain their production cycles, among others.

The second core chapter is titled "farmers' willingness to accept compensation to control agricultural nonpoint source pollution in the Limpopo River Basin (LRB) of South Africa". This chapter sought to determine the appropriate compensation that farmers are willing to accept to participate in an agNPS pollution control programme to mitigate water quality deterioration in the LRB. This chapter makes the argument that farmers differ in their farm management practices, cost structures, socio-economic and attitudinal factors, suggesting that they are different in terms of these variables and therefore require different compensation payments to be incentivized to participate in water quality improvement agri-environmental schemes (AESs). However, these differences are rarely characterized in the design and implementation of AESs. Using conditional logit and latent class models to estimate the data from 552 farmers from the basin, one random choice class of farmers making random responses and three preference classes of farmers (low-, moderate-, and high-resistance) with dissimilar

compensation requirements to improve water quality are identified. This chapter provides new insights to enrich the efficient design of tailored water quality improvement-related AESs for full participation with persistent environmental benefits that would ultimately generate positive externalities that would not only benefit farmers but the environment and society at large.

The third core chapter is titled "a meta-analysis of water institutions and their performance implications for water resource management". This core chapter applied meta-regression analysis to the empirical literature on the performance of water institutions. It synthesized and quantified the overall water institution-performance effect using data extracted from 23 original studies that reported the impact of water institutions on performance of the water sector. Bivariate and multivariate meta-regressions are estimated to determine publication selection bias in the water institution-performance literature and the overall genuine empirical effect of water institutions on performance in this literature. The results suggest the presence of a publication selection bias that favours a positive impact of water institutions on performance. This chapter provides insights to improve the quality of research, reporting, review, and publication in the water space on the institutional performance of water institutions.

The rest of this section summarizes the key findings and contributions of this thesis and discusses its limitations and possible future areas of research.

5.1 Main Findings and Contributions of this Thesis

The second core chapter, Chapter 2 contributes to the growing literature on the promotion, adoption and uptake of WCPs. Though there are several studies in this area, none have used the multivariate probit model to determine the factors that motivate the multiple adoption of this chapter's six unique WCPs and their interrelationships. That is, none of these studies have examined how farmers are bundling these WCPs to adapt to climate change, improve resilience to droughts and water shortages (DWSs), and promote water quality improvement. This thesis thus contributes in various ways to the literature in question. First, it provides evidence that enhances the understanding of the factors that influence farmers' simultaneous adoption or bundling of WCPs and their interrelatedness in countering water scarcity, engendering climate change resilience and water use efficiency at the farm level. Second, it provides a better understanding of the water sustainability behaviour of water conservation-conscious farmers' response to intensified climate change and DWSs. Third, beyond this thesis's academic

contribution, it provides policymakers with key insights for the design of relevant and proactive water-management policies in the agricultural sector to enable farmers to build defenses against the effects of intensified climate change and future DWSs. Fourth, this thesis offers guidance for farmers and policymakers in South Africa and other water-risk hotspots across the globe on how to cope with absolute and relative water scarcity.

The results of this chapter show, first, that key farm, farmer, institutional, and environmental factors, like gender, age, education, off-farm and farm incomes, and access to markets, among others, trigger the probability and extent of adoption of the WCPs differently. While some determinants influence the adoption of the various WCPs positively, others do so negatively, and yet others are statistically insignificant. Second, the interrelationships or interdependence among the six WCPs show significant and positive associations amongst practices such as cover cropping and MEPIDs (more efficient performing irrigation methods, like drip and sprinkler irrigations), intercropping and MEPIDs, mulching and MEPIDs, intercropping and conservation tillage, intercropping and cover cropping, and growing drought-tolerant crops and intercropping. This suggests that farmers adopt these practices simultaneously or together, thus confirming a significant bundling of these WCPs. Finally, in the intensity of adoption model, the findings show that a minimum of two practices to a maximum of six were being adopted simultaneously in some instances by farmers. This confirms the assertion that water conservation-conscious farmers usually adopt not just one practice to conserve water but a multitude of practices to achieve this goal.

The findings of this chapter first underscore the important need for farmers to consider combining several WCPs (bundling) in mitigating their farm-level water scarcity or, in response to climate change intensification, consider the adoption of the best bundle mix and the supporting technologies that are appropriate for tackling the different levels of DWSs encountered. Second, the six unique WCPs provide farmers and policymakers with a mixed toolset that is effective at helping farmers counter climate change effects and DWSs in water-stressed areas. These findings are relevant not only for farmers, decision-makers, and other stakeholders in the Limpopo Province of South Africa but also for their counterparts in other water-risk hotspots for the promotion, uptake, and adoption of WCPs. The framework in this chapter is not only critical for long-term planning under likely changes in climate but also provides farmers with more flexibility, better resilience, and a wide range of toolsets to adapt to increased climate volatility. This way, farmers have more control over climate change effects

and their related impacts over time. This thesis, therefore, critically adds an important angle to the study of policy regulations on the promotion, uptake, and adoption of WCPs under extreme water-scarce conditions.

The third core chapter, Chapter 3 adds to the scant but growing literature on the control of agricultural nonpoint source (agNPS) pollution as part of the larger agri-environmental schemes (AESs) literature. Although there is a growing literature on farmers' WTA compensation to adopt agNPS pollution control measures (Beharry-Borg et al., 2013; Christensen et al., 2011; Li et al., 2019; Lu et al., 2021), such studies are non-existent in South Africa or even Africa to the best of my knowledge. The lack of empirical studies on how monetary incentives are used to incentivize farmers to alter their farming practices to control agNPS pollution creates a gap in understanding the challenges associated with agricultural water quality deterioration and how best to control it. This lack of empirical studies means the absence of a guide to inform policy formulation and implementation (the policy gap) in agriculture to curtail the deterioration of water quality caused by undesirable agricultural practices. This chapter underscores that farmers differ in behaviour with a diversity of farm management practices, cost structures, etc. but water quality improvement-related AESs do not characterize into their design and implementation these differences. The current practice, where farmers are lumped together and paid a lump sum irrespective of these differences, is no longer fit for purpose. Accordingly, this thesis provides new insights to enrich the efficient design of tailored water quality improvement-related AESs for more persistent environmental benefits that would ultimately result in positive externalities beyond benefits to farmers and the environment.

This thesis contributes variously to the literature on agNPS pollution control in particular and agricultural water management in general. It does this, first, by providing a baseline water-quality improvement testament that advocates for the inclusion of WTA compensation in decision-making in agriculture in South Africa and beyond to control agNPS pollution. This testament would also contribute to bridging the two gaps mentioned above—the empirical research and the policy gaps in South Africa. Second, it enhances the understanding of the factors that influence farmers' willingness to control agNPS pollution and the levels by which agricultural practices must be altered to deliver the required river health goals or water-quality improvements. Third, this thesis's inclusion of important attributes such as the construction of ecological ditches (vegetative buffer strips) and monitoring for compliance is especially novel,

as none of the agNPS pollution control studies seen and reviewed have used these attributes. The use of these attributes would provide policymakers and water quality improvement-related AESs implementers with a wide range of practices to control agNPS pollution at the farm level. Finally, beyond its academic contributions, this thesis offers some policy guidance to decision-makers, water resource managers, and AESs implementers on the importance of integrating farmers' divergent behaviour and preference heterogeneity into the design and implementation of AES contracts.

The results of this chapter first indicate that some demographic, socio-economic, and attitudinal factors such as age, education, farm ownership, farming experience, source of water, farm and off-farm incomes, membership of a cooperative, secured tenure rights, awareness of agNPS pollution, and perceived benefits if the quality of water is improved, among others, are the main drivers that underlie preference heterogeneity in this thesis. Second, the results of the restricted latent class model (LCM) identified three sub-groups of farmers (in total, representing 97% of the sample) with dissimilar compensation requirements to alter their current undesirable farm practices to improve water quality. In addition, one random choice class (3% of the sample) where farmers were classified as making inconsistent (random) choices for the agNPS pollution control attributes or providing inattentive responses was identified. This result of the random choice class shows that, in general, farmers did not make random choices and they did not provide inattentive responses. For the preference choice classes, high-resistance farmers required 1,331 and 1,793 USD hectare⁻¹ year⁻¹ for the 25 and 50% reductions in fertilizer, respectively. While moderate resistance farmers required 151 and 319 USD hectare⁻¹ year⁻¹ for the 25 and 50% reductions in fertilizer, respectively. For 50% pesticide reductions, high-resistance farmers required 1,047 USD, moderate resistance farmers required 347 USD, while low resistance farmers required 205 USD, respectively. These results are indicative that farmers are different and require different compensation payments to fully participate in this water quality improvement-related AES. The results also imply that lumping farmers together and treating them as one unit is simply dated.

Generally, the marginal WTA and CS estimates demonstrate that the cost of using monetary incentives to incentivize farmers to alter their status quo farm management practices to control agNPS pollution may not be prohibitive. However, sufficient financial inducements may be required to overcome some of the strong aversions of some of the sub-farmer groups for some of scheme's attributes. These findings are relevant for AES scheme implementers. They offer

a cost-effective framework and robust basis for the formulation of water-quality improvement policies in the agricultural sector to stop the wanton deterioration of water quality caused by undesirable agricultural practices. Within this framework, water resource managers and AES scheme implementers may consider several water-quality improvement scenarios and estimate the costs of each to identify their preferred option for managing water quality. This would not only ensure the protection and restoration of river health and water quality but also the sustainability of water resources, enabling farmers to make meaningful and continuous contributions to economic and social development.

Accordingly, the findings of this thesis would enrich the policy discourse on regulating agNPS pollution and, therefore, water quality at the farm level and enhance water resource management in agriculture.

The fourth core chapter, Chapter 4 contributes to the scant literature on institutional economics, especially those on the performance of water management institutions. To achieve this objective, the chapter applied meta-regression analysis (MRA) to investigate the empirical literature on the performance of water institutions. The main novelty of this chapter is its use of meta-analysis to increase the statistical power of results from a growing literature on the performance of water institutions that covers different methodologies, water institutions, geographic and environmental conditions compared to studies specifically focused on one location or a given narrow set of conditions. In addition, given that MRA allows the researcher to unravel various factors and discrepancies responsible for conflicting results in a literature, the chapter points to the importance of using the appropriate methodologies, representative samples, the right dependent variables to capture the performance of water institutions, and/or the right independent variables that capture water institutions, among others. Accordingly, given the seemingly lack or absence of a competing hypothesis or theory in respect of the water institution-performance relationship, the chapter contributes by offering some clearer guidelines on improving the quality of research, reporting, review, and publication in the water space on institutional performance. Finally, beyond the academic contributions to the literature, the chapter importantly confirms the positive water institution-performance relationship and, therefore, provides further insights for additional development, facilitation, and strengthening of the water laws, policies, and administration in the water space to reduce the high transaction costs and related poor management issues associated with the sector. This is critical not only

for efforts to engender reforms in the water sector but also for the effective allocation and utilization of the resource in all sectors of the economy.

The findings from the graphical analysis and bivariate meta-regressions, confirm the presence of a positive publication selection bias in the targeted literature. This indicates that authors, reviewers, and editors tend to have preferences for results or studies that report a positive water institution-performance effect. If authors found a negative water institution-performance effect, they may tend to shelve such results, leading to the file drawer problem, where studies are consequently consigned to the file drawer. Accordingly, published primary studies of the water institution-performance literature may be a biased sample of the whole population of studies (Efendic et al., 2011). In addition, the bivariate and multivariate meta-regressions confirm the presence of a positive, authentic, and large empirical water institution-performance effect (0.524). This evidence demonstrates that effective water institutions are not only critical in providing the appropriate and adequate arrangements to steer individual and group behaviour in lowering transaction costs in the water sector but are also relevant for enhancing the performance of water institutions and the water sector as a whole.

5.2 Policy Implication of the Findings

This thesis has several policy implications for farmers, water resource managers, stakeholders in the agriculture and water spaces, researchers, and institutional economists. The findings from Chapter 2 point to the critical need not only for long-term planning under likely changes in climate but also to the effect that farmers must have more flexibility, have better resilience to DWSs, and have a wide range of toolsets to adapt to increased climate volatility. In this regard, this thesis first advocates that WCPs are interdependent; therefore, the design of any effective strategy(ies) aimed at increasing their uptake rate must take this interdependence into consideration. Second, education increases the adoption of MEPIDs, implying that improving farmers' knowledge will positively impact adoption decisions. Therefore, policies that encourage onsite demonstration and sensitization on the potentials of irrigation among the farmers and the education of farmers on the likely effects of climate change on water resources and agricultural productivity are recommended. In addition, this thesis recommends the education and training of extension service officers on modern best agricultural practices that incorporate the adoption of WCPs into farming in response to DWSs. Finally, the government should strive to create a conducive atmosphere for farmers to secure tenure rights to their

farmlands, as tenure rights significantly influence the adoption of MEPIDs. These suggestions are critical to increasing the adoption rate of WCPs to improve water conservation efforts, efficiency of use, and sustainability of water resources for increased agricultural production, food security, improved incomes, poverty alleviation, and rural employment, among others.

The findings of Chapter 3 underscore the important need to adopt better farm management practices and policies that lessen agriculture's negative impact on water quality. Specifically, this thesis first suggests that farmers are willing to accept monetary compensation to control agNPS pollution. Therefore, the promotion and use of monetary incentives in the agricultural sector to induce farmers to lessen agriculture's impact on water quality is recommended. Second, the divergent behaviour of farmers noted is driven by differences in age, farming experience, secured land rights, awareness of agNPS pollution, and farm ownership. Thus, policies aimed at increasing farmers' participation in future AESs must, of necessity, tailor AESs contracts specific to farmers (the sub-groups) needs initially with the option of scaling up. This is important for successful environmental outcomes. Finally, awareness through public education and campaigns of the dangers of agNPS pollution is essential and, thus, recommended. However, all these would require further investment in research and development toward the promotion and advancement of agNPS pollution control programmes.

The results of Chapter 4 point to the important need that effective-performing water institutions are critical in providing the appropriate arrangements that lower transaction costs in the water sector for the effective allocation and utilization of water resources in all sectors of the economy. This thesis, therefore, first recommends, based on the findings, that the water law and the water policy, or some aspects of these, exert a greater influence on the performance of water institutions. Therefore, to engender water sector reforms and/or for the further development, facilitation, and strengthening of water institutions, this thesis advocates the incorporation and strengthening of the water law and the water policy in policy formulation and reforms for successful water resource management and governance.

Secondly, studies using the Institutional Decomposition and Analysis (IDA) framework, studies that use methodologies that control for endogeneity and those that capture the effects of exogenous economic factors—are more likely to report a higher impact of water institutions on performance, all else being held constant. Therefore, researchers should endeavor to use

these to amplify the water institutions-performance effects. Third, when a composite index is used to capture performance in the models, a lower water institution-performance effect is evident. This result is, however, important given the advantage that composite indicators and indexes can easily summarize the complex and multidimensional nature of water institutions and their performance. This makes it simpler to compare the performance of water institutions over time. From the perspectives of policymakers, water resource managers, and institutional economists, it is easier to follow the trend of an index or a few indices to make better predictions of events than if multiple sets of performance indicators of water institutions were involved. Accordingly, this thesis advocates for more estimation of such indicators and indexes in the water sector to ease comparisons of the performance of water institutions over time and across nations. This would then serve as a guide to promote water sector reforms across countries.

5.3 Suggested Areas of Further Research

This thesis, like any other academic endeavour, is not without limitations. First, due to budget and time constraints, the survey data for chapters 2 and 3 of this thesis were collected from only two farming communities in the Limpopo Water Management Area (WMA). Not including the entire Limpopo WMA or even the entire portion of the Limpopo River in South Africa means the findings of this thesis are entirely based on those two farming communities. Despite this, the farmers included in this thesis represent the population that would most likely be targeted for such investigations in the Limpopo Province. Therefore, research of similar nature to those of chapters 2 and 3 that covers the entire Limpopo WMA or even the entire portion of the LRB in South Africa could have a higher power of generalizability and further advance this thesis.

For instance, Chapter 2 focused only on the determinants of the multiple adoption and the interrelationships of six WCPs, however, a wider perspective would be to look at the impact of the multiple adoption of WCPs on farm output and profits in future studies. Such a research could be conducted by including other variables (like temperature and rainfall changes, weather forecast figures, and soil types, among others) and examining how these variables pre-inform or affect farmers' adaptation behaviour. Furthermore, it is important to understand and establish the actual costs and benefits of the WTA compensation to control agNPS pollution under different policy situations in Chapter 3. Understanding how the cost of the mitigation

actions will change if the monetary values of the agNPS pollution control attributes and the welfare estimates of the future alternative policy scenarios are taken into consideration in decision-making is necessary. Such a cost-benefit analysis would provide policymakers with more information to design effective agNPS pollution control programmes in the future.

Secondly, there are a number of issues that require further investigation to augment this thesis. Specifically, as stated in Chapter 4, it is not prudent to rely on the results of only a handful of studies. Therefore, given that this subject of the performance of water institutions is generating keen professional discourse within policy circles—national and international—with the literature continuously growing, additional quantitative studies are needed in this area to make the findings of this thesis clearer and more generalizable. Many important studies were excluded from the analysis of this thesis because of the lack of information on key variables, such as sample size, t-statistics, and standard errors, among others, that are important for meta-regression analysis. Therefore, future quantitative studies on the water institutions and performance relationship should endeavour to report these statistics.

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