ENGINEERING AND WATER GOVERNANCE INTERACTIONS IN SMALLHOLDER IRRIGATION SCHEMES FOR IMPROVED WATER MANAGEMENT

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PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Bioresources Engineering, School of Engineering, College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by the Water Research Commission (WRC) South Africa. The work is part of an ongoing research project funded by the WRC South Africa. The project is entitled "Assessment of Policies and Strategies for the Governance of Smallholder Irrigation Farming in KwaZulu-Natal Province, South Africa" (Project No. K5/2556).

ABSTRACT

Smallholder Irrigation Schemes (SISs) in South Africa have reported below expectation performance, despite massive investments. A diagnosis of the SISs poor performance indicates prevalence of infrastructural deficiencies, as well as poor institutional setup. The government's Irrigation Management Transfer (IMT) initiative compounds the problem. IMT placed irrigators in self-governance, which inadvertently made irrigators carry the burden of scheme Operation and Maintenance (O&M) costs. This study sought to investigate and evaluate how technical design principles i.e., technical aspect of irrigation design, interact with irrigation water governance for SISs in KwaZulu-Natal Province. The study hypothesized that the existing current water control infrastructure does relate to the water governance frameworks in the selected study sites. The study was carried out in Tugela Ferry Irrigation Scheme (TFIS) and Mooi-River Irrigation Scheme (MRIS). An infrastructure condition assessment was carried out followed by a root cause analysis. Questionnaires were then administered to relevant stakeholders to rate the degree of identified causal factors. Key informants ranked how water governance and infrastructure aspects are related. The data was processed using a fuzzy theory approach. Finally, structured questionnaires were administered to irrigators to establish how water governance impacted on water adequacy for crop production. A binary logit regression model was employed to process the data. Assessments revealed the poor condition of the infrastructure, such as deep cracks in canals and missing latches on hydrants. The study revealed that TFIS had a strong institutional setups according to the Closeness Coefficients$(CC_i = 0.18)$, and clearly defined goals and objectives for the scheme operation. However, other governance aspects such as procedures $(CC_{TFIS} = 0.17, CC_{MRIS} = 0.16)$ were not strong. MRIS $(CC_{MRIS} = 0.20)$ had a good standing on rules and regulations as compared to TFIS $(CC_{TFIS} = 0.14)$. Eight water governance related statistically significant variables that influenced water adequacy were identified. The eight variables were irrigation scheme $(p = 0.000)$, location of plot within the scheme $(p = 0.008)$, training in water management $(p = 0.012)$, satisfaction with irrigation schedule $(p = 0.000)$, irrigation training $(p = 0.085)$, farmer knowledge of governments aims in SIS $(p = 0.012)$, availability of water licenses $(p = 0.002)$, and water fees $(p = 0.022)$. A descriptive analysis showed that 24% and 86% of the farmers in MRIS and TFIS respectively, had adequate water. The study concluded that the SISs lacked an O&M plan and the farmers were not willing to opt for collective action and cooperate in Water Users Association (WUAs) and Irrigation Management Committees (IMCs). Some of the water governance aspects were discordant with infrastructure characteristics and requirements, consequently, impacting on the water adequacy for the irrigators. Overall, the study proved the hypothesis that the water control infrastructure does not relate with the water governance framework. This study recommends that the stakeholders involved in SISs, i.e., government, extension workers, NGOs, should aid the irrigators in policy articulation. In addition, the WUA and IMCs should provide incentives to motivate farmers to actively participate in scheme O&M.

DECLARATION OF PLAGIARISM

I, Tinashe Lindel Dirwai, declare that:

(i) The research reported in this thesis, except where otherwise indicated, is my original work.

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Dr A Senzanje

Co-supervisor: Date 30/01/2019

Dr M Mudhara

DECLARATION OF PUBLICATIONS

This section outlines the sections in this dissertation that have been presented/submitted to a conference, and submitted to peer-reviewed international journals for publication. The research reported is based on the questionnaire data I collected from the field. I designed the questionnaires, collected, analysed the data, and wrote the presentation and the manuscripts. This work was done under the supervision, guidance and review of my supervisors; Dr A Senzanje and Dr M Mudhara. The * indicates the corresponding author.

Chapter 3

Dirwai, TL*, Senzanje, A, Mudhara M. (under review). An investigation and condition assessment of water control infrastructure in Tugela Ferry and Mooi-River Irrigation Schemes. Submitted to the Irrigation and Drainage Journal of ICID.

Chapter 4

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Dirwai, TL*, Senzanje, A, Mudhara M. (2017). Assessing the relationship between water control infrastructure and water governance: A case of Tugela Ferry and Mooi-River Irrigation Schemes. Oral presentation to the 18th Waternet/WARFSA/GWP-SA Symposium (25th to 27th of October 2017, Swakopmund, Namibia).

Chapter 5

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SUPERVISORS' APPROVAL

Subject to the regulations of the School of Engineering, we the supervisors of the candidate, consent to the submission of this dissertation:

Supervisor Date…30…./…01…./2019

Dr A Senzanje

Co-supervisor_ Date…30…./…01…./2019

Dr M Mudhara

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LIST OF ABBREVIATIONS

Acronym	Meaning
AHP	Analytical Hierarchy process
BNL	Binary Logit
CC	Closeness Coefficient
CPR	Common Pool Resource
CWR	Crop Water Requirement
DARD	Department of Agriculture and Rural Development
DEA	Data Envelope Analysis
DWAS	Department of Water and Sanitation
FAHP	Fuzzy Analytical Hierarchy Process
FCA	Facility Condition Assessment
FTOPSIS	Fuzzy Technique for Order Preference by Similarity to Ideal Solution
GEAR	Growth, Employment and Redistribution
HDI	Human Development Index
ICA	Infrastructure Condition Assessment
IMC	Irrigation Management Committee
IMT	Irrigation Management Transfer
MCDM	Multi-Criteria Decision Making
MDG	Millennium Development Goals
MPC	Model Predictive Control
MRIS	Mooi-River Irrigation Scheme
MTSF	Medium Term Strategic Framework
NDP	National Development Plan
NGP	New Growth Plan
NIS	Negative Ideal Solution
NWA	National Water Act
NWRS	National Water Resource Strategy
O&M	Operation and Maintenance
PE	Physical Externalities

Acronym	Meaning
PIM	Participatory Irrigation Management
PIS	Positive Ideal Solution
RCA	Root Cause Analysis
RCI	Relative Causal Index
RDP	Reconstruction Development Plan
RESIS	Revitalization of Smallholder Irrigation Schemes
SDGs	Sustainable Development Goals
SSA	sub-Sahara Africa
TFIS	Tugela Ferry Irrigation Scheme
WUA	Water Users Association

1 INTRODUCTION

Irrigation remains the key driver for agricultural productivity and increased food security (Hayami & Kikuchi, 1978; Van Koppen, 1998). Smallholder farming in South Africa is described as the best vehicle to mitigate poverty (Machethe, 2004). Smallholder irrigation schemes (SISs) are defined as a group of farmers collectively sharing and managing Common Pool Resources (CPRs) such as water and irrigation infrastructure (Van Averbeke *et al.*, 2011). The CPRs are treated, as common property, as such, there is complex interactions amongst physical, technical and socio-economic factors that dictate scheme dynamics (Javaid & Falk, 2015; Abel *et al.*, 2016). In order to boost productivity governments and non-governmental agencies have devoted financial, organisational and technical investments in construction and rehabilitation of the infrastructure in SISs. Tortajada (2016) asserts that built infrastructure is pivotal in attaining a correct irrigation function as evidenced by the Asian green revolution whose success is attributed to improved irrigation infrastructure (Machethe, 2004), coupled with plant breeding and marketing support policies.

To minimise expenditure and liability, government adopted Irrigation Management Transfer (IMT). The government's IMT facilitated the hand-over take-over of scheme affairs from government to irrigators. IMT facilitated the creation of institutions such as Water Users Association (WUAs) and Irrigation Management Committees (IMCs), which are, by definition legal entities that are primarily concerned with Operation and Maintenance (O&M) of the irrigation scheme infrastructure and water governance (Samad, 2002). Water governance in this document is defined as institutions, processes, procedures, rules and regulations involved in water management as shown in Figure 1.1. Effective water governance in irrigation schemes entails the design of policies and institutional frameworks that are congruent with the physical, technical and the dynamic socio-economic setup (Rogers & Hall, 2003).

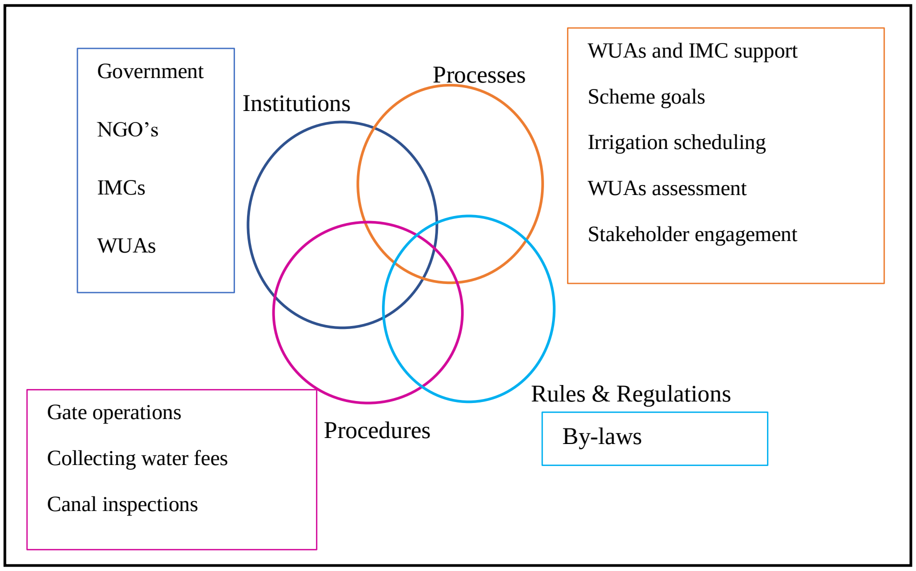


Figure 1.1 The water governance nexus linking institutions, processes, procedures, rules and regulations

Sustainability in irrigation schemes is brought about through reconciling the physical and technical attributes of the irrigation scheme and the irrigators characteristics in terms of their socioeconomic status (Marothia, 2002). In South Africa the IMT process transferred an infrastructure incompatible with the local management capabilities (Vermillion, 1997).

1.1 Typical SISs Infrastructure

Sambo (2015) argued that there is no gold standard in defining water infrastructure used by rural farmers. However, Hunter *et al.* (2009) cited by Sambo (2015) based their definition on population size, whereas Senzanje *et al.* (2012) based the definition on scale and use. Senzanje *et al.* (2012) defined smallholder water infrastructure as *"any technical hardware that is used by rural farmers or communities in capturing, collecting, controlling, using, managing and disposing of water"* (see Figure 1.2).

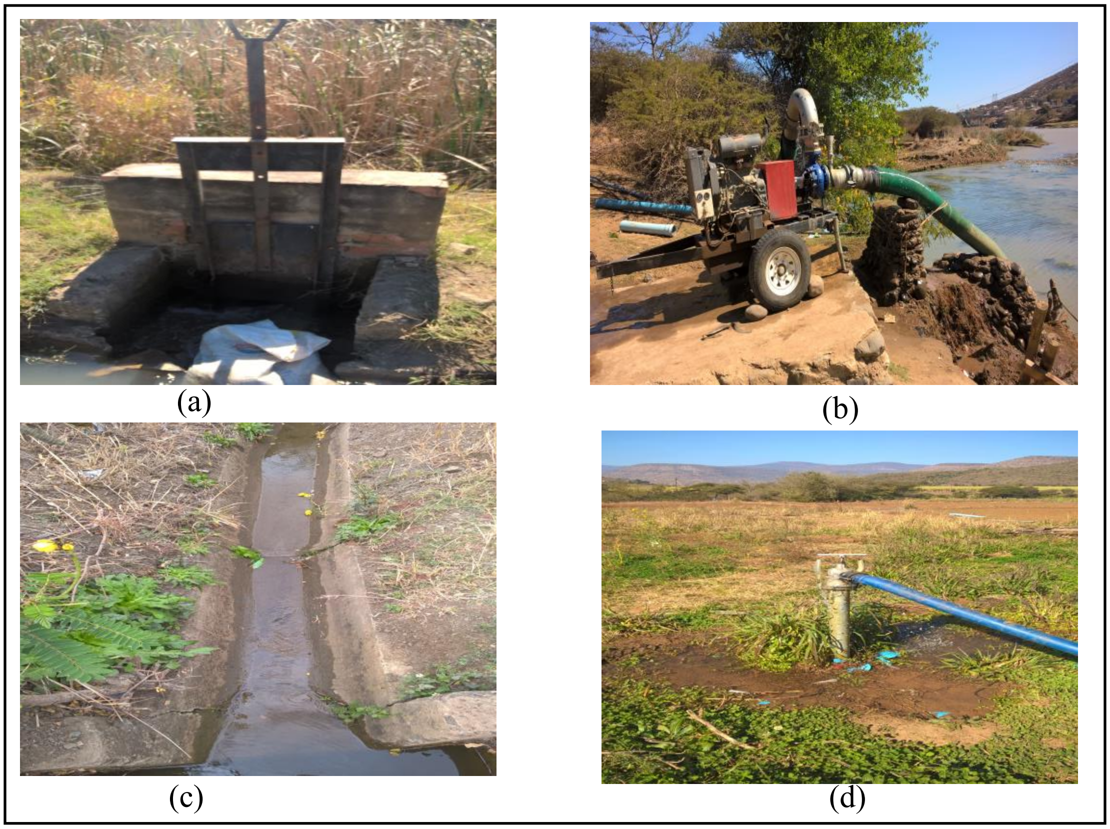
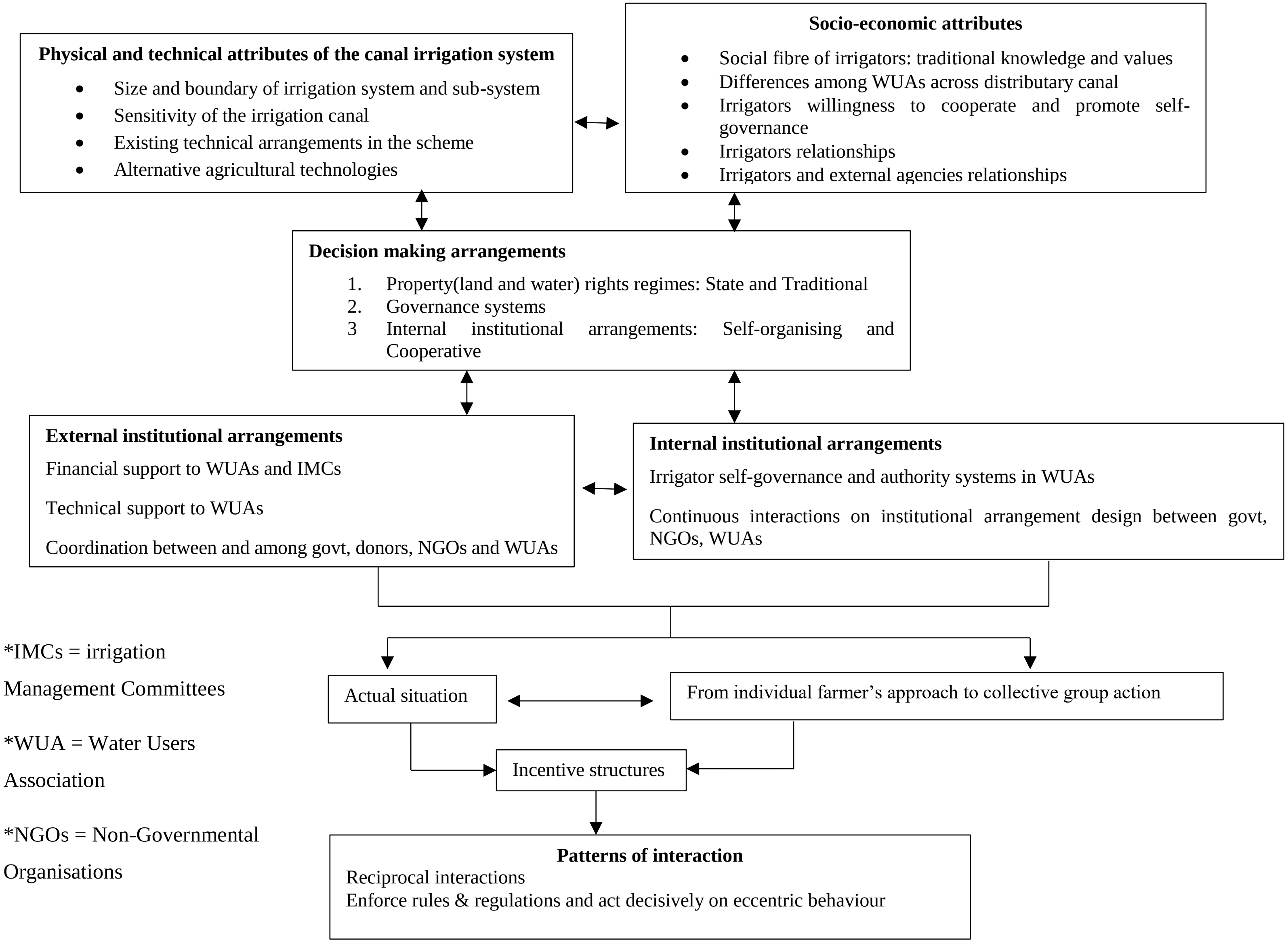


Figure 1.2 Typical SISs infrastructure: (a) Sluice gate for controlling the flow of water, (b) A diesel pump abstracting water from Thukela river, (c) Concrete lined canal conveying water to plots and (d) A hydrant and a canvas hose

Marothia (2002) proposed a framework of interacting physical-technical and socioeconomic attributes that are at play in irrigation scheme dynamics (Figure 1.3). These attributes more often than not combine in a configurational manner i.e., to understand the effect of one attribute on has to be aware of what other attributes are also in effect. In SISs, a disruption in one attribute or CPR will create a completely new outcome and situation.



*IMCs = irrigation Management Committees

*WUA = Water Users Association

*NGOs = Non-Governmental Organisations

Figure 1.3 Conceptual framework for analysing SISs under IMT (after Marothia, 2002)

Following IMT, Horst (1998) pointed that the irrigators inherited irrigation infrastructure that were built and rehabilitated by designers from different irrigation schools (Dutch, British, American). This rendered the infrastructure to be out of sync with the socio-economic local dynamics of SISs and subsequently affected the irrigators' capability to understand and operate the hydraulic infrastructure. Consequently, the water governance structures in SISs are formulated to a pre-existing technology (infrastructure) which subsequently offsets the equilibrium between the O&M of the technical aspects and the socio-economic dynamics (human dimension).

The research questions for this study were:

i. Does governance affect infrastructure handling and its condition?
ii. What are the effects of water governance on SISs understanding of infrastructure characteristics and its functional and operational requirements?
iii. How does water governance affect adequacy of water for cropping requirements in SISs?

The research aim for this study was to investigate and evaluate how technical design principles (technical aspect of irrigation design) interact with irrigation governance for SISs in KwaZulu-Natal Province. This study integrated a wide spectrum of research aspects from engineering to partly socio-institutional factors. The specific objectives were to:

i. Investigate and evaluate the water control infrastructure in selected SISs in KwaZulu-Natal.
ii. Assess the functional and operational relationships between the water control infrastructure and water governance in the study irrigation schemes.
iii. Evaluate the impact of water governance on adequacy of water for crop production in selected SISs in KwaZulu-Natal.

The hypotheses for the specific objectives were:

i. The existing infrastructure is sound and resilient, i.e., it serves the purpose.
ii. There exists a relationship between the water control infrastructure and the governance framework/arrangement.

iii. The governance arrangements in place have a significant effect on water adequacy and its availability to the farmers.

1.2 Outline of Dissertation Structure

This dissertation is organised into six chapters.

Chapter 1	Provides a general overview of the study detailing its justification and the objectives.
Chapter 2	Details a holistic outlook on Smallholder irrigation schemes (SISs) in South Africa. It reviews literature on SISs characteristics, government policy and objectives for the SISs. It discusses the irrigation management transfer (IMT) initiative and how it has impacted SISs performance. The chapter lastly discusses policies that hinder performance of the SISs.
Chapter 3	Investigates and analyses the condition of the existing water control infrastructure in the selected irrigation schemes.
Chapter 4	Focuses on assessing the functional and operational relationship between water governance and the existing water control infrastructure.
Chapter 5	Assesses how water governance impacted adequacy of water for crop production and other uses in SISs.
Chapter 6	This contains the summary, conclusions and recommendations chapter of this study. It highlights the major findings of this work and makes recommendations arising from the study.

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2. LITERATURE REVIEW

2.1 Background

Attaining food security status for the budding global population has always been an issue that takes priority on the global stage. Irrigation is pivotal in reducing world poverty by maximising production, boosting employment opportunities which subsequently leads to income stabilization and finally it facilitates the attainment of a positive nutritional status, health and societal equity (Mati, 2011; Valipour, 2015). Research has shown that irrigation has the potential to increase yields of most crops by between 100 and 400 % and by the year 2046 it is expected that 70% of grain will be produced from the world's irrigable land (Rockström *et al.*, 2009). Nearly half of the world's arable lands (46%), are not suitable for rain-fed agriculture due to unpredictable and accelerated climatic changes and the respective prevailing environmental conditions.

Previous studies have produced empirical evidence that indicated a relationship between irrigation and the Human Development Index (HDI). HDI constitutes development indicators such as environment, energy, food and population and determining their relations is imperative because collectively they combat food insecurity and poverty (Inocencio, 2007; Franks *et al.*, 2008; Khan *et al.*, 2009; Mati, 2011; Burney *et al.*, 2013; Ngenoh *et al.*, 2015).

Agriculture, through irrigation, is the biggest water consumer in South Africa and prudently a water management policy must be implemented to limit the agricultural water demand. The vast majority of South Africa's Agro-ecological regions (60%), receive less than 500 mm of rain per annum and only 10% receives 750 mm. This inherently limits the country's agricultural potential (Cousins, 2013). The South African government needs to meet the MDGs (Millennium Development Goals) turned SDGs (Sustainable Development Goals) of employment creation and poverty reduction, predominantly among rural African population. As a consequence of the skyrocketing unemployment levels and trying to fulfil its mandate of creating five million jobs by 2020, the government of South Africa unrolled a strategy called the New Growth Path (NGP). A huge fraction of these jobs, 300,000 are to be created from the establishment and revitalization of smallholder irrigation schemes (SISs) (NGP, 2011).

2.2 Smallholder Agriculture: A Historical Perspective

The pre- 1994 Segregationist policies that reigned over South Africa caused a disturbance in traditional agricultural practices. These restrictive polices resulted in limiting the amount of land the native Africans could own to about 13% of the total arable land in 1994 (Nieuwoudt & Groenewald, 2003). From their advent in 1913, the homelands typified high populations per square kilometre, small hectarage allotments of arable land and shared grazing land. The rangeland availed to communities were insufficient for supporting livestock (Van Averbeke, 2012) given that livestock has always played an important role in African homesteads. It facilitates multi uses through providing draught power, nutrition (milk, and meat) and social needs like traditional ceremonies (Mills & Wilson, 1952; Van Averbeke, 2012).

The Tomlinson Commission (Tomlinson, 1955) revealed that small-holder farmers that registered a significant development in key dimensions of household income, sending children to school and considerable health were those that were living on existing irrigation schemes of 1.28 ha in size and had enough access to grazing lands. The Tomlinson Commission (Tomlinson, 1955) aimed to promote economic viability of rural farm units. However, it was never implemented.

2.3 African Smallholder Irrigation Schemes and Irrigation Management Transfer (IMT)

The size of allotments defined the course of agricultural practices of the African smallholder farmers. The established smallholder lots varied from 5 ha – 12 ha of lands. Van Averbeke *et al.* (2011) reported that the subsistence farming model was set in motion by providing a large population of African homesteads with access to farm land (plots) which ranged from 0.1 ha – 0.3 ha in size. Post-apartheid South Africa saw a lot of provincial governments dismantling the agricultural homeland parastatals and allowing direct farmer involvement in the irrigation scheme management. This saw the decentralisation of the management of the schemes. Simultaneously a process called Irrigation Management Transfer (IMT) was happening in other parts of the world.

IMT was to be a vehicle that would facilitate the reduction of civic disbursement on irrigation, enhancing productivity of irrigation and stabilizing the management of irrigation systems (Vermillion, 1997). The advent of IMT had a negative effect on parastatal controlled projects and the disturbance was predominant on the large turned small scale irrigation schemes because of the complexity in their management. Centralised management caused a high-level dependency on external management amongst the small-holder farmers (Van Averbeke et al., 1998).

Bembridge & Sebotja (1992) and Laker (2004) reported that with the implementation of IMT, a regressive effect was experienced on these schemes. Canal schemes at small-holder level withstood the effects and operated at moderated levels (Kamara *et al.*, 2002; Machethe *et al.*, 2004). With IMT, already on the roll out in the 1990's, there also emerged several new SISs, which were part of to the Reconstruction and Development Programme (RDP). The agenda targeted poverty alleviation and improving the human development index among poor rural population and those that occupied the informal urban settlements. A total number of 62 SISs were instituted in 2006 and they covered a total land area of 2,383 ha. This, however, showed that size was limited to approximately 38.4 ha per scheme on average. According to Denison & Manona (2007), the means of water abstraction and application were pumps and sprinkler technology.

Policy revision saw Growth, Employment and Redistribution (GEAR) superseding the RDP as the overall development policy of South Africa. The plan redefined poverty eradication by funding community-based projects to privatising development. Already established irrigation schemes were the earmarked drivers of the gradual economic absorptive capacity of the rural areas. However, for the schemes to realise improved efficiency, revitalization was required first. Thus the Revitalization of Small-holder Irrigation Schemes (RESIS) was initiated (Denison & Manona, 2007).

The Water Care Programme was the vehicle for RESIS and it targeted the revitalization of identified small-holder irrigation schemes. The programme was not limited to infrastructure but extended to capacity building of leadership, management and productivity. A multi-pronged and holistic approach was used which saw Water Care integrating the knowledge and judgements of rural people in the planning and management of development projects and programmes (Denison & Manona, 2007).

To show dedicated furtherance of IMT, Water Care invested one-third of its budget into revitalization and capacity building among farmers. Shah *et al.* (2002a) states that procedures for sustainable revitalization and capacity development were put in place for the small-holder farmers and their subsequent schemes. Rehabilitation of existing scheme infrastructure, sustainable IMT and substantial commercialization were the chief accents of the Water Care programme and RESIS in its initial stages (1998-2005). Schemes that used canals for water conveyance before and after the revitalization phase remained canal schemes.

2.4 Smallholder Irrigation Schemes Performance in South Africa

South Africa's irrigation sector has evolved into a stable physical and administrative system. The evolution can be attributed to transitions in social and administrative sectors, i.e., transitions, from empires to colonial systems, from shared water resources to a self-regulating network of reservoirs and connected waterways or channels (Bandaragoda & Firdousi, 1992). In addition, Bandaragoda & Firdousi (1992), assert that the long experience has seen the evolution of stable and sustainable irrigation traditions that have supported the diverse community appeal in the schemes. This subsequently resulted in an intricate institutional milieu in which a set of legally established irrigation rules and organizations existed side by side with an intricate set of unsanctioned social institutions (Abemethy, 1993). This resulted in a dual system that was discordant in which erratic changes developed that disturbed the composite physical system, and a multifaceted, but relatively inharmonious institutional framework.

Bandaragoda & Firdousi (1992) pointed out the complex multifaceted characteristics of the South African irrigation situation, with allocation of resources by government, irrigation management at provincial level, large centralized institutions, a sundry of water users with slim or zero involvement in irrigation management decisions, difficult coordination among agencies and their sub-units and functions, numerous laws and procedures mixed with traditional concepts and erratic amendments by occasional enactments and promulgations and, more importantly, the countervailing forces that acted against formal rules. The dominant features, however, appear to be the discordancy between the outdated institutional framework and the emerging new requirements of irrigation management, on the one hand, and the general ineptness of most of the formally established institutions in view of strong socially evolved institutions, on the other (Abemethy, 1993). Nevertheless, low agricultural yields from small-holder irrigation schemes downplay the invested efforts to achieve stability through enhanced physical infrastructure and technological inputs, all in a bid to improve performance and, hence yields are an important performance indicator of revitalized schemes (Bandaragoda & Firdousi, 1992). According to Bandaragoda & Firdousi (1992), the predominant institutional factors, which impacted negatively on irrigation performance in South Africa, are acknowledged as:

- discordancy between infrastructure and the social setting i.e.; infrastructure is not mirroring the societal set-up, and
- the obsolescence of irrigation rules, codes and procedures.

Bandaragoda & Firdousi (1992) further stated that changes in irrigation rules and organizational structures have not matched the fast-paced developments in other facets of irrigation in the form of resource base and technology, and in social demand. Manpower and financial resource levels in irrigation agencies have declined (Abemethy, 1993), while the subsequent workloads have intensified many folds. Similarly, established data collection and processing procedures cannot augment the need for more information. Slow developments and progress have been compounded by redundant formal rules and inappropriate infrastructure.

2.5 Governments Intervention and Action Plans in Smallholder Irrigation Schemes

2.5.1 Emerging policy issues and strategy formulation

Policy makers have been gradually acknowledging the part smallholder irrigation farming plays in improving better rural livelihoods. This has subsequently prompted South Africa to incentivize the process of construction and revitalizing irrigation infrastructure. Water allocation and appropriate management of common pool resources (CPRs) are the most prevalent problems in communally managed irrigation schemes. These problems stem from a failure to understand the scheme design and operability. Water conflicts are often the consequence of mismanagement in such circumstances (Muchara, 2014). The National Water Resource Strategy (NWRS 2) is based on the current National Water Act (NWA) of 1998. However, while reviewing the NWRS1, it became clear that there are several emerging policy issues that could not be included as strategies in the NWRS2 as the current legislation does not make provision for these. The NWRS outlines the need to eliminate poverty through improved water equity and water supports developments. The developments can be contextualized as infrastructure developments, WUAs and IMCs support. These developments are water governance related.

2.5.2 Institutional arrangements

The KwaZulu-Natal Department of Agriculture and Rural Development presented its five-year plan for the period 2015-2020 (DARD, 2015). The blue print marked a five-year plan for policy and strategies that interact with the smallholder farmers for improved rural economies. This five-year year plan (2015-2020) set out goals that are parallel with the New Growth Path (NGP) of eliminating poverty and attaining food security at rural level through the construction and resuscitation of existing irrigation schemes. The construction was aligned with societal set-up that has informally evolved, thus promoting a synergy between the water control infrastructure and the water governance section for maximized agricultural production (DARD, 2015)

The NGP which is an accelerator to rapid economic growth has earmarked agriculture which contributes significantly to the GDP as one of the key targets to the attainment of the SDG's. Thus, strategies have been lined up to boost SISs (DARD, 2015). The NGP stipulates that the government agricultural policy focuses on restructuring institutions and procedures that are involved in water resource management at identified SISs so that they align with the existing infrastructure and avail comprehensive support around infrastructure upgrade and revitalisation.

Medium term strategic framework (MTSF) 2015-2020

The government in its pursuit of strategic configuration and policy consistency has resolved to use the 2015-2020 Medium Term Strategic Framework (MTSF) as lustrum phase for implementing the National Development Plan (NDP). The NDP targets infrastructure development in South Africa. SISs are set to benefit through infrastructure upgrades, and irrigation schemes revatilisation. The NDP is a vehicle for accelerated agrarian transformation in the SISs which were previous poverty nodes during apartheid.

Agrarian transformation strategy

Agrarian transformation strategy is a holistic programme that is founded on several interventions ranging from the provision of basic services and social amenities for rural communities, food security support, and interventions in crop production. Increased crop production is facilitated by a functional irrigation scheme (KwaZulu-Natal Provincial Government, 2012). This strategy aims at again revitalising the irrigation schemes. The revitalization will focus on modern upgrades that will be consistent with the evolving informal governance institutions and procedures (KwaZulu-Natal Provincial Government, 2012).

2.6 Water Access and Water Security

Variations in the level of water access are experienced in community-managed schemes. The greatest challenges are the deficiency of interaction between institutions and functionality and the operability of the water control structures. This subsequently influences the understanding of water security issues and local management systems (WUAs) (Muchara, 2014). The performance of irrigation schemes is influenced by a sundry of factors. The level of understanding of the scheme design and operability influences the individual in charge of water appropriation and it plays a critical role in equitable distribution. Farms are grouped into lots which are further sub-divided into smaller units, where each subdivision comes with an overlooking authority who manages and operates the infrastructure. The smallest indivisible sub-group of water users has little or no say when it comes to implementing water use and appropriation strategies as they are normally represented by an authority slightly above them in the hierarchy. This setup can be best be illustrated by Figure 2.1.

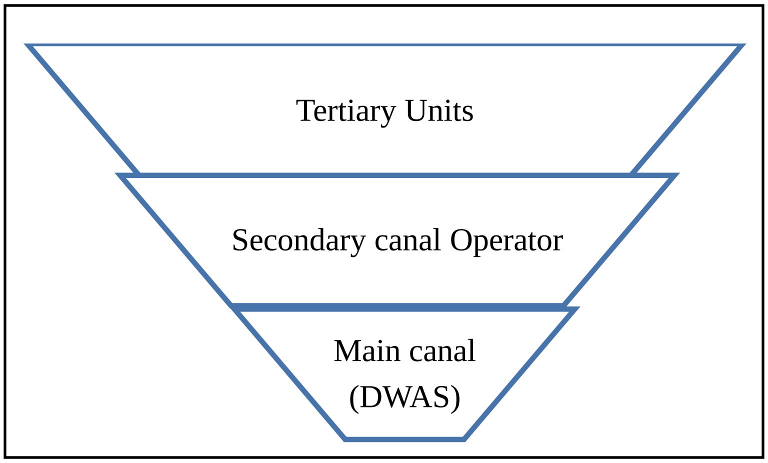

Figure 2.1 Conceptual hierarchal set-up on water distribution and water management at each level

The main canal has a manager and a user's committee that comprise of irrigators. The hierarchal arrangement ensures that the overseeing authority at the main canal adheres to the rules and regulations as per the prescribed water budget from Department of Water and Sanitations (DWAS). However, this setting has proved to be ineffective as it is constantly disturbed by politics i.e., offtake managers that have access to, and close ties, with main canal operator will get favourable allocation. Mbatha & Antrobus (2008) applied the Physical Externalities (PE) model to evaluate irrigation water distribution challenges among farmers along the Kat River Valley in South Africa. The geographical location of farmers along a given watercourse, in which water is diverted by individuals, leads to structural inefficiencies that unconstructively affect the whole farming community, with more significant effects felt at downstream sites than upstream (Mbatha & Antrobus, 2008; Muchara *et al.*, 2014).

Poor coordination and non-compliance with institutional and regulatory instruments lead to such water allocation inefficiencies. Continuous assessment of irrigation governance institutions in Sub-Saharan Africa (SSA), is critical given the transfer from the state-driven management regimes towards community-based management regimes (Dorward & Omamo, 2009). The paradigm shift in irrigation management has been to a greater part been influenced by the IMT and Participatory Irrigation Management (PIM) approaches within the water sector (Perret & Geyser, 2007; Gomo *et al.*, 2014). As such, several frameworks borrowed from ecological, sociological, political and economics schools have been implemented to assess institutional performance. In several occasions, frameworks have been merged to analyse complex governance systems. Due to the convolution of the institutions and the need to streamline the focus of the analysis to local water management issues, some studies by Alt & Shepsle (1990) and Dorward *et al.* (2009) applied the Institutional Development Analysis (IDA) approach to investigate and analyse a possible combination of institutions, social structure, rules and regulations that can be merged to provide a correct irrigation function for farmers.

2.7 Farmer Participation: Development of Water User Associations (WUAs)

The past five years has seen smallholder irrigation development going through drastic change. The dynamics have seen the government agricultural parastatals assuming the role of developing and handling irrigation systems and has paved the way for water user participation which has subsequently seen the creation of farmer organizations. Frederick (1993) described the change and the new methodologies being implemented in this sector as focused on the demand-led development of water services and decentralized management.

The centralized methodology to water resource management has proven to be unsustainable because it has neglected incentives for users to participate in system funding and management and to provide services based on user affordability (Hamdy & Lacirignola, 1997). Poorly adapted services created problems including users' refusal to pay for services, public institutions complaining about the lack of ownership by farmers and residents, operation and maintenance are ignored, and costly infrastructure begins to deteriorate prematurely. Typically, Water User's Associations (WUAs) can be categorised as shown in Figure 2.2 where, each category represent the levels involved in catchment and canal management. Sun & Fu (2016) argued that despite enormous government spending in infrastructure upgrades there still exists a plethora of challenges that are analogous to irrigation water management at farm level for which both structural and non-structural (Governance is the critical non-structural measure) measures are not addressing. Figure 2.2 shows the administrative structure involved in SISs.

The DWAS is the overall water resources basin planner/regulator. The irrigation district management has a dual role of water planning/regulating and operations. Their roles extend to construction of water control infrastructure, planning, operation and management of irrigation. The farm-level authority regulates and controls the construction of canal and lateral within the scheme. Sub-fam level prefecture reports to the farm level authorities and they indulge in canal maintenance. At the village level and below are field canals and ditches, which are maintained by the farmers who own or occupy leased land. They handle on farm water management under the direction of block committees and WUAs.

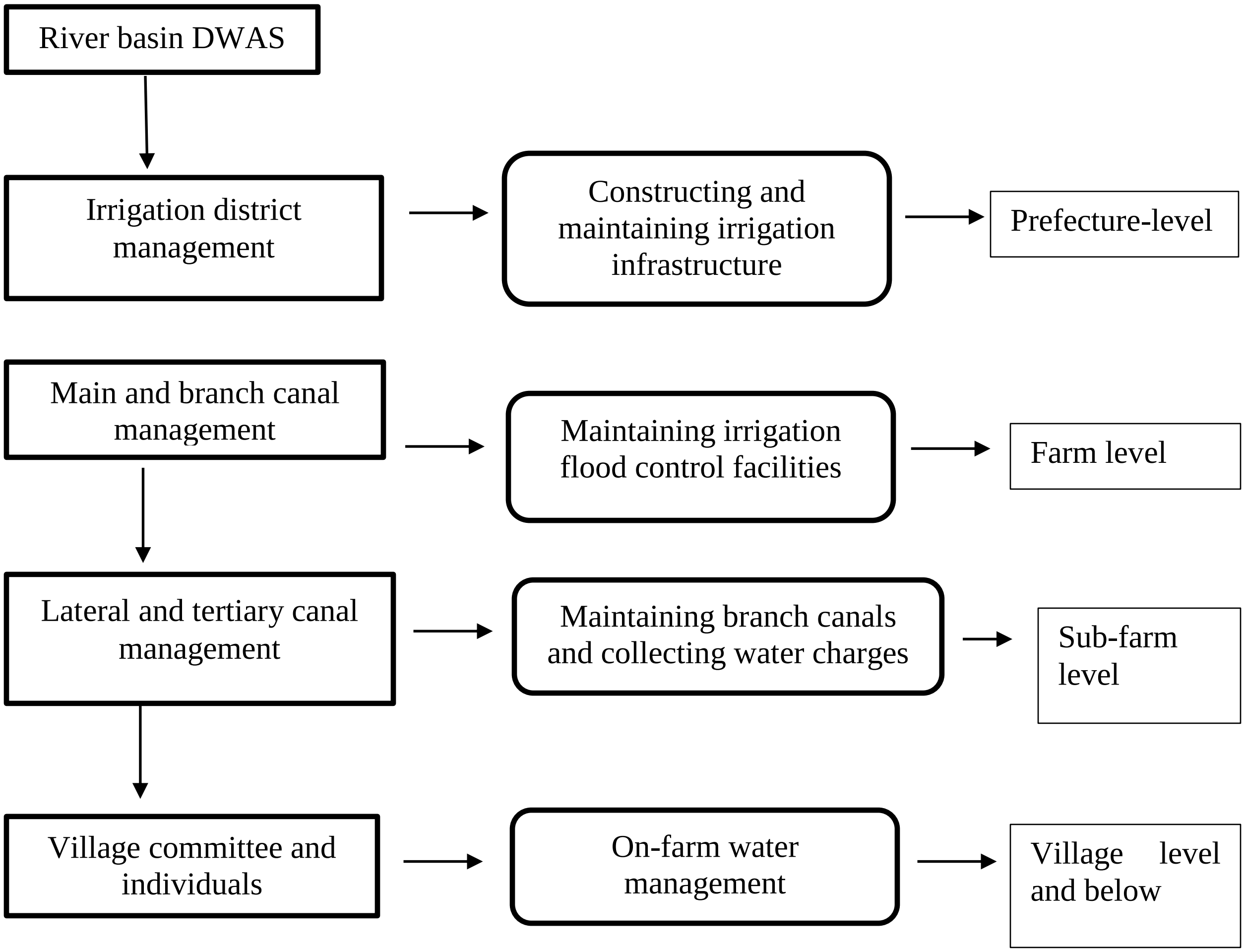

Figure 2.2 The hierarchal nature of the WUAs (Yang *et al*., 2003)

Although water resource management was introduced to promote harmony between water users and the improved technology, there are often always conflicts and misallocations. Common Pool Resources (CPRs) usage is heterogeneous, hence water requirements vary across the scheme. As a consequence, there is conflict amongst water controlling agencies at each level shown in Figure 2.2 (Yang *et al*., 2003).

The non-cohesiveness can be attributed to the technology adoption capacity at each water governing body along the hierarchy. The top water users association (WUAs) and irrigation management committees (IMCs) tend to be well versed in the technology and the bottom level (village level) is rocked with design assumptions whereby the technology implemented tends to cater for the top management level with little or no consideration of the bottom level water governing institutions (Horst, 1998). The operational reality and the design assumption tend to be in parallels and the management staff at the various level of the system "inherit" systems with hydraulic defects which are incompatible with the staff capabilities and hardly understood by farmers (Horst, 1998).

2.8 Policies Hindering the Performance from a Technical Perspective

The systematized observation, documentation and interpretation of irrigation scheme management and operations are classified as scheme performance evaluation (Mengü & Akkuzu, 2009). Performance evaluation is done so as to check that the input of resources, operational schedules, intended outputs and required actions proceed as planned (Bos *et al.*, 2005). Irrigation scheme assessment is done so as to gauge progress against strategic goals, evaluate the condition of the scheme, to measure the impacts of interventions, to improve scheme operations, to better understand determinants of performance, and finally it is a fundamental process of analysing performance-oriented management (Molden *et al.*, 1998; Awulachew & Ayana, 2011).

Malano *et al.* (2004) defined benchmarking in irrigation as "*as a useful tool for continuous improvement, it infers on upgrading all aspects of service delivery and resource utilization by comparison with other schemes*". However, benchmarking is a change process that goes beyond comparison. Diagnosis of irrigation performance fundamentally must absorb the multi-pronged characteristics of irrigated agricultural systems including institutional setups, resources used, services delivered and agricultural outputs.

Irrigation performance indicators have been compartmentalized into internal and external indicators that best describe the afore-mentioned irrigation agriculture characteristics. Internal indicators are a useful tool in assessing internal irrigation services and processes. This can be further broken down into the following modules: operational procedures of the systems, institutional setups for management, irrigation infrastructure, and water delivery services. Internal indicators facilitate a comprehensive understanding of the processes that effect water delivery service and the overall performance of a system (Facon et al., 2008). Hence, they are informative in showing what would have to be done to improve the internal and hence the external performance.

External indicators primarily focus on input and output evaluation to and from irrigation schemes, which narrow down to the efficiency of the inputs, i.e., resource base (land, water, finance) in irrigated agriculture. External indicators can be best employed as part of a strategic performance assessment and benchmarking performance of schemes (Burt & Styles, 2004). Molden *et al*. (2014) mentioned in as much as policies, institutions (both formal and informal), procedures and regulations are critical in defining pliability of a scheme; effective understanding of infrastructure is critical.

2.8.1 Hydraulic water delivery performance in irrigation schemes

The ideal irrigation design meets all the requirements of conveyance and application efficiencies. However, due to engineering and water governance reasons the irrigation system more often than not does not meet the design objective. Water governance in this section means the institutions and procedures that are involved in water management, hydraulic performance refers to the adequacy of conveyance, distribution, and delivery of irrigation water in spatial and temporal scales. There is an established criterion used for hydraulic performance measurement which incorporates factors like adequacy, operational efficiency, equity, reliability, timeliness, delivery performance ratio (Molden *et al.*, 1998; Tariq *et al.*, 2004; Unal *et al.*, 2004; Vos, 2005).

Many SISs are gravity operated and poor hydraulic performance is a constant in hindering maximum productivity of the design system. The poor performance is attributed to the incongruous relationship between designs, i.e. the hydraulic perturbations, and design sensitivity vis-à-vis the operational procedures as set out by the established water management institutions, i.e. WUAs and IMCs. Knowledge on when, where and how operations should be made, and understanding the effects of operational decisions are key to effective canal control (Renault, 2000b). Chancellor (2000) pointed out that the long-term sustainability of SISs is chiefly reliant on design suitability of the scheme. However, the present designs were/are driven by crop water requirements and the type of soils in the respective region. A great number of irrigation schemes in South Africa were planned and developed using design assumptions without consulting with farmers. This has led to a persistent inconsistency of design assumption and operational reality has been prevalent in all the modern-day schemes across the KwaZulu-Natal region (Fanadzo, 2012); cited by (Phakathi, 2016). The Makhantini Flats Irrigation Scheme design in KwaZulu-Natal has resulted in a lot of conflict amongst water users as the design delivers large volumes of water to about 100 ha or more on a fixed irrigation cycle of 7 days. There are 10 ha allotments/plots, which meant to maintain frugality in water delivery each lot had to synchronize their water delivery schedules and they should plant crops with the same water requirements (A'Bear & Louw, 1994).

Lack of the required technical knowledge of water manager at smallholder scheme level has greatly affected the potential and benefits that should be derived from the schemes. Water conflicts amongst head, middle, and tail ends of the scheme have been the end result of ineffectual water appropriation to the various tertiary units (Dejen, 2015). The set out operational procedures tend to deliver water in excess in some parts of the scheme. In addition, illegal water abstractions and unauthorized infrastructure handling subsequently cause a deficit to other parts.

The other impact of the discordancy between system design and operational procedures is the reduced efficiency of the system due to losses in conveyance and application. Due to over-application there tends to be runoff losses at the tail ends. This signifies the low water productivities involved in the SISs that subsequently lead to reduced downstream availability of the available water resources for irrigation. Environmental issues have also been noted in poorly run schemes. Many cases of water logging and salinization have been observed, especially in schemes that have poorly drained soils, and this inherently affects the sustainability of the schemes (Dejen, 2015).

2.8.2 Canal operation

The principle of canal operation is typically a complex procedure that has inputs, processing, and outputs. Figure 2.3 depicts an irrigation scheme nexus composed of hydraulic structures, water users, institutions and processes. The whole process leading to water discharge requires each element to transform an input variable into a common output variable.

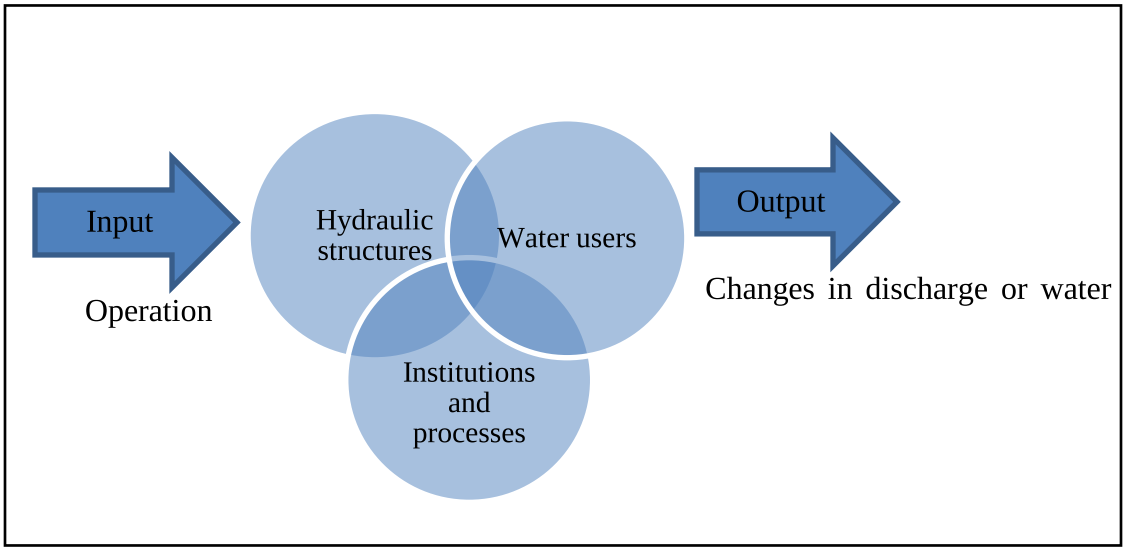

Figure 2.3 The principle of Input-Output in a hydraulic structure (Renault, 2008)

The operation can best be described as sensitive. Sensitivity is a reaction to external stimuli (Dictionary, 1991). The output is a function of the actions of the water users and the institutions and processes that are effected on the hydraulic structures (Renault, 2008). For maximum effectiveness, there should be a thorough knowledge of the relationship between the inputs and the outputs. Due to the complexity of the canal system, which arises from their interactive operation and hydraulic behaviour, it poses a problem whereby operators fail to comprehend the operability and functionality of the system (Horst, 1998; Dejen, 2015).

System design determines irrigation performance. There are chiefly two design principles used during irrigation system design and these are bifurcating systems and hierarchical systems. The bifurcating systems divides water among two or three large groups of farmers which is subdivided again into two to three smaller groups. The hierarchical system is mostly adopted in modern irrigation projects whereby the water is dispensed to large (secondary) blocks and subdivided into smaller (tertiary) units. Van Averbeke *et al.* (2011) stated that weak institutional and organizational arrangement hinder effective canal operation and performance. Poor maintenance of the infrastructure results in poor performance in terms of water delivery through leaks. This subsequently lowers the schemes life span. Figure 2.4 shows a bifurcating system with lower order canals branching from the main one. At the point of bifurcating water division is realized by the hydraulic structures (Horst, 1998).

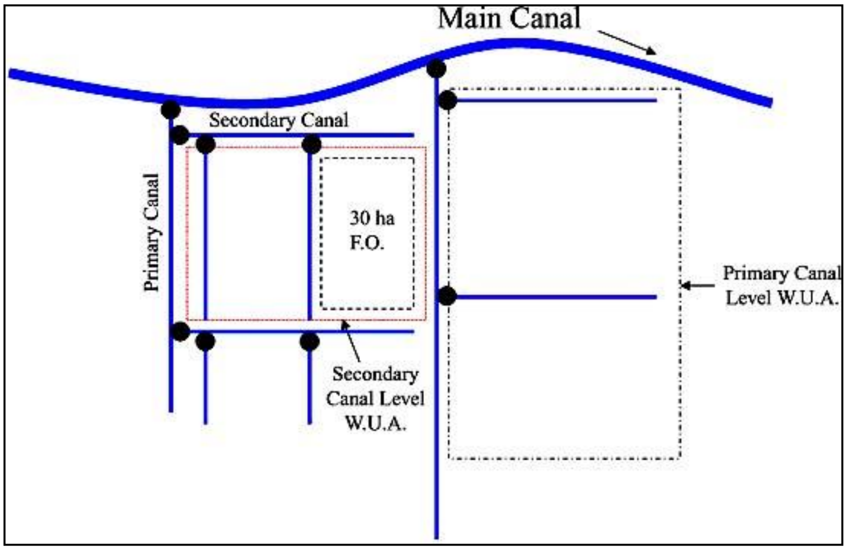

Figure 2.4 The birfurcal system (Plusquellec, 2002)

Figure 2.5 shows a hierarchical setting. The tertiary canals branch from the main canal. Tertiary units are established from the secondary canal. The system promotes locational unequal positioning which leads to unfair water distribution (Horst, 1998). Horst (1998) explains in both settings, the primary canal divides into secondary canals, which subsequently canal divides and supplies various tertiary units. Each tertiary canal has an outlet that is hydraulically designed as open flumes or orifices. The hydraulic design corresponds with the irrigated area.

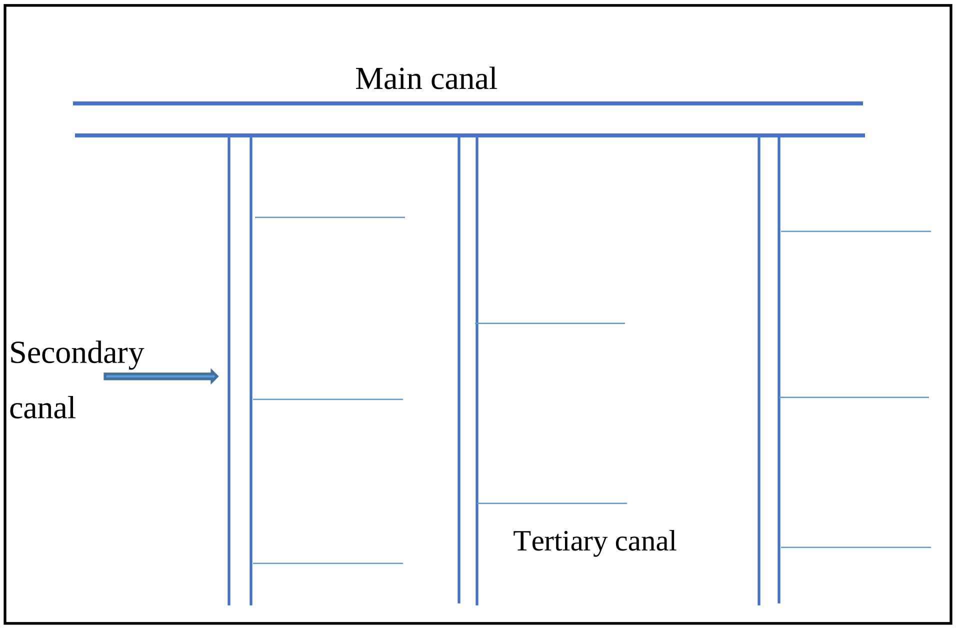

Figure 2.5 The hierarchical system (Horst, 1998)

Horst (1998) states that canal outlets are particularly critical because outlets control the discharge into water courses because of their size and hydraulic characteristics (orifice or flumes). The outlet dimensions are fixed, however, there are sluice gates along the canals that are adjustable to control flows (active human management).

Canal outlets are also critical because beyond this point the flow is managed sequentially whereas above the canal outlet flow is managed simultaneously (Petr, 2003). Downstream of an outlet farmers receive water consecutively i.e. two farmers on a given field channel will not receive water simultaneously rather they will receive water in sequence according to a fixed weekly schedule. It is the farmer’s onus to convey water to their own plots by constructing tertiary canals and waterways. This typified a scenario where there was no on-farm development and it subsequently was a paradigm for irrigation development in many countries in the 1960s. This model promoted an accelerated evolution in irrigation. However, it did not suit countries where the smallholder farmers had to organise themselves for the bankrolling and carrying out of on-farm works to implement up-to-date irrigation water delivery. This inevitably forced farmers to endure the orthodox methods of cultivation and irrigation that yielded poor harvests.

2.8.3 Choice of technology

Bhattacharya *et al.* (2012) identified irrigation infrastructure as a fundamental constituent of economic growth and poverty mitigation i.e. it has the distinct ability to subdue economic growth potential at farm level. Infrastructure as an ongoing and continuous priority boosts competitiveness and productivity and underpins improvements in the HDI. A proposed choice of technology for irrigation should mirror the geo-social setting i.e., it must define its function and by properly aligning with the cultural, traditional and informal methods of water sharing.

An irrigation scheme caters for a population with various and diverse nutritional needs thus promoting varying cropping patterns. Hence, the system design should be congruent with such factors. The level of technology should be at the same degree of ease of operation of the system thus WUAs and IMCs are central to the choice of technology to be implemented. Tortajada (2016) states that water control infrastructure designed in isolation with development policies is at a risk of not meeting the societal needs, as there will be a lack of effective management. Modern technology has emerged that regulates flow and control water appropriation for the farmers.

These technologies aim to increase water use efficiency and from a design perspective to counter hydraulic instability from the manual gated operating systems. For equitable and more effective water use methods drip kits have been introduced amongst Indian and Nepalese smallholder farmers (Postel *et al.*, 2001). Drip irrigation success is pinned on the type of crop cultivated and for many smallholder farmers vegetables are key to their diets, which go along with the drip technology (Postel, 1999).

Automation of water control has been implemented through the use of Model Predictive Control (MPC) strategy (Negenborn *et al.*, 2009). The automated systems were successfully implemented in South Asia. The system is based on feed-forward loop mechanisms which entails selecting actions in a pre-defined way using measured disturbances only (Negenborn *et al.*, 2009). The technology was however, limited to irrigation district with inert-dependent water schedules.

2.9 Discussion and Conclusions

There has been little qualitative and quantitative analysis on water governance and its interactions with irrigation systems design and operability in SISs in KwaZulu-Natal. Water governance involves the institutions processes, procedures,rules and regulations involved in water management and irrigation design narrows down toward technicality with no regard to the set institutions and procedures in place (Horst, 1998; Tortajada, 2016). The revitalised schemes still mirror the old designs that have been promoting discordancy between the Water Users and the functionality of the scheme. Thus there is a need to analyse and synergise the two for optimised water use efficiency, equitable water distribution, and ultimately attaining food security.

The South African government policies have been effected with the bid to resuscitate and improve water handling techniques with little focus on technology improvements. The government's sought to empower the marginalised by constructing irrigation schemes and allow them to run the schemes. The scheme operation were handed to the new scheme dwellers under the auspices of IMT. The IMT has become the prominent domestic agricultural policy in many countries (Howsam *et al.*, 2003; Marshall, 2003). The move was to target efficient use of resources, limit liability on government and encourage farmers to actively participate in scheme matters.

The initiative backfired on the government as the scheme managers inherited a system that was built during the colonial era. This rendered the scheme users and managers disempowered as they have little knowledge on operations and functionality of the water control infrastructure (Horst, 1998). The point of departure is, therefore, infrastructure is a constant that is not built with a proper governance framework that caters for the dynamic local institutions. It was assumed that transfer of scheme management to farmers would foster better O&M systems, less conflicts and effective water management (Shah *et al.*, 2002b). This has not been the case as water security is still an issue. Irrigators face challenges ranging from inadequacy, unequitable water distribution and an unreliable delivery schedule. Hydraulic stability can be achieved if water managers are better equipped with knowledge on canal sensitivity and flow perturbations. The knowledge allows water managers and bailiffs to pin point points where the water delivery system is most likely to deviate from the functional norm (Renault & Hemakumara, 1997).

It is imperative to encourage PIM as this will allow water users and water managers to formulate within the existing governance framework information systems that allows them to identify points where unscheduled changes might occur along the water conveyance system. Hydraulic sensitivity is a major player in water allotment procedures, as losses and ineffective operation of the infrastructure contribute to the equity and reliability of irrigation water utility. Another point of departure is technology refurbishment focused i.e., infrastructure upgrades and revitalization are not consistent with water governance frameworks that exist in SISs (Horst, 1998).

Scheme revitalisation has been implemented in a bid to improve water delivery. However, such efforts have been in vain since the operational requirements of the water control infrastructure clashes with indigenous socio-technical knowledge (Richards, 1985). The disconnect between design and operation is the chief cause of discrepancies between design assumptions and operational reality (Horst, 1998). Design assumptions look at policy planning, and mainly the type of water allocation procedures.

Establishing a synergy between governance and water control infrastructure is essential as this can minimise water conflicts and promote effective water usage within the irrigation schemes. Understanding the condition of water control infrastructure and how the operability and functionality of the infrastructure relates to governance can address the shortfalls on governance aspects that are directly involved in water control and appropriation.

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3 AN INVESTIGATION AND ASSESSMENT OF THE CONDITION OF EXISTING WATER CONTROL INFRASTRUCTURE IN SELECTED SMALLHOLDER IRRIGATION SCHEMES: CASE OF TUGELA FERRY IRRIGATION SCHEME AND MOOI RIVER IRRIGATION SCHEME, SOUTH AFRICA

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Abstract

The condition of irrigation infrastructure deteriorates because of neglect, and the unwillingness of the irrigators to participate in operation and maintenance (O&M). Condition is the status of irrigation infrastructure that is structurally sound, adequate and has integrity. Poor structural condition can be attributed to a governance framework that does not relate to the existing infrastructure. Infrastructure longevity depends on O&M, thus institutional arrangements that have robust processes, procedures and enforcement of rules and regulations ensure prolonged infrastructure service-life. This study investigated and evaluated the condition of the existing water conveyancing, storage and control infrastructure at the Mooi River Irrigation Scheme (MRIS) and the Tugela Ferry Irrigation Scheme (TFIS), in KwaZulu-Natal, South Africa. The study was premised on the hypothesis that the characteristics and requirements of the existing water control infrastructure was not consistent with water governance structures in the respective irrigation schemes. An Infrastructure Condition Assessment (ICA) was undertaken based on inspections and condition scoring or grading. In addition, technical experts were consulted to determine weights of the structural evaluation criteria using the Analytical Hierarchy Process (AHP). Furthermore, the Fishbone "Ishikawa" Diagram and the Relative Causal Index (RCI) method were used to carry out the root cause analysis (RCA). For RCI, questionnaires were administered to stakeholders (technical experts and extension workers) to capture their perception on the causal factors. According to the study the Fishbone “Ishikawa” Diagram characterized, and identified 23 probable causal factors that led to infrastructure dilapidation. ICA revealed the poor condition of infrastructure i.e., deep cracks in canals and missing latches on hydrants. The RCI quantified the causal factors and revealed the convergance between technical experts (te) and the extension workers (ex) regarding causal factors. The converging causal factors were maintenance $(RCI_{te} = 0.8,\ RCI_{ex} = 0.7)$, people $(RCI_{te} = 0.7,\ RCI_{ex} = 0.7)$, institutional $(RCI_{te} = 0.7,\ RCI_{ex} = 0.6)$ and environmental $(RCI_{te} = 0.8,\ RCI_{ex} = 0.7)$. The study further revealed that, the stakeholders involved had points of divergence on causes of infrastructure decay. Follow-up questionnaires were again administered to capture the reasons of diverging thoughts. The stakeholders identified varying causal factors as accelerators to infrastructure dilapidation, for instance, the infrastructure designers argued that lack of compliance was a major driver to infrastructure dilapidation whereas extension workers thought otherwise. The study recommends participatory engagement in process and procedure design for enhanced infrastructure condition.

Keywords: infrastructural condition assessment, relative causal index, root cause analysis, smallholder irrigation, water infrastructure

3.1 Introduction

Irrigation infrastructure is an essential component of development. Governments in developing countries have invested a significant amount of resources in construction, maintenance and rehabilitation of irrigation infrastructure (Chambers *et al.*, 1989). Water is life, and it has been proven beyond doubt that new irrigation facilities have improved land and labor productivity of smallholder farmers, whenever they get access to the water (Ahluwalia, 1985; Boyce, 1987; Hossain, 1989). Infrastructure development leads to economic growth and reduces inequality. Bhattacharya *et al.* (2012) and Mwase & Yang (2012) noted that the more the government invests in infrastructure the better the prospects of economic growth.

The growth theory, which is premised on infrastructure and growth, provides literature from a survey by Straub (2008) that gives evidence that infrastructure is a vehicle for growth. Functional water conveyancing and storage infrastructure which facilitates multiple water use in a scheme subsequently results in multiple benefits (Adank, 2006). Low income countries are prone to water deficiencies because the water supply infrastructure is badly engineered and managed (Carter et al., 1999). For example, leaking canals result in poor water conveyance, which subsequently leads to unreliable water supplies (Sharaunga & Mudhara, 2016). Well maintained built infrastructure plays a pivotal role in ensuring water security (Sharaunga & Mudhara, 2016).

Poor infrastructure condition in the sub-Sahara Africa (SSA) is compounded by the irrigation communities' failure to maintain and run the operation and maintenance (O&M) programmes set out by the donor constructed infrastructure (Sakaki & Koga, 2013). In a bid to limit liability, governments transferred management to irrigators through Irrigation Management Transfer (IMT) scheme (Vermillion, 1997). Water users' failure to stretch their budget further exacerbate the deteriorating condition of the infrastructure. This consequently leads to poor infrastructure that stands neglected for years before proper maintenance is carried out (Shah *et al.*, 2002a).

Many irrigation schemes' infrastructure have backlogs or lagging in terms of maintenance due to deferred maintenance (Teicholz & Edgar, 2001). High transaction costs associated with operation and maintenance (O&M), inadequate support from government and NGOs have attributed to collapse in irrigation infrastructure in South Africa (Machethe, 2004; Fujiie *et al.*, 2005; Muchara *et al.*, 2014). Literature cited infrastructural problems as the leading cause of poor performance in South African irrigation schemes (Fanadzo, 2012).

Despite substantial investments in upgrading infrastructure, the are reversed because the untrained, unskilled and less committed human capital do not effectively manage the structures (de Lange *et al.*, 2000; Mnkeni *et al.*, 2010). For example, Sinyolo *et al.* (2014) cited insufficient institutional support as a driver to infrastructure dilapidation in the Tugela Ferry Irrigation Scheme (TFIS). Muchara *et al.* (2014) argued lack of support as one of the causes of backlogs in O&M in the Mooi-River Irrigation Scheme (MRIS). The irrigation schemes exhibit both similar and dissimilar governance related characteristics as shown in Table 3.1.

Table 3.1 Some governance characteristic in MRIS and TFIS

	Irrigation scheme	
Governance aspect	MRIS	TFIS
Land allocation	Tribal authority	Tribal authority
Water allocation and access	Scheduled irrigation	Subject to fee payment
Conflict management	Reported to the scheme committee or tribal authority	Executive committee or tribal authority
Election of committee	irrigators	Irrigators
Penalties for non-compliance	Pay fines	Not enforced
Active stakeholders	Techno-serve, DARD, Lima	DARD and Lima

The paper investigated and evaluated the condition of the water control infrastructure in TFIS and MRIS.. The objective of the study was to conduct an infrastructure condition assessment exercise and profile the condition of the water control infrastructure in the selected irrigation schemes. Furthermore, it sought to carry-out a root cause analysis to identify water governance related factors that contributed to infrastructure deterioration.

3.2 Materials and Methods

This section presents an overview of the two irrigation schemes their locations and characteristics. It further presents methods and tools used for data collection and analysis.

3.2.1 Study site

The study was conducted at two irrigation schemes, Mooi River Irrigation Scheme (MRIS) and Tugela Ferry Irrigation Scheme (TFIS) in KwaZulu-Natal, South Africa. Both schemes are located in Msinga Local Municipality (Figure 3.1) in Midlands region of KwaZulu-Natal and they are within a 30 km radius of each other. The characteristics of each scheme are detailed in Table 3.2.

Table 3.2 Some scheme characteristics of TFIS and MRIS (after Cousins, 2012; Fanadzo, 2012; Gomo *et al.*, 2014; Sinyolo *et al.*, 2014)

	TFIS	MRIS
Canal length (Km)	34	25
Land area(Ha)	800	600
No. of Plots	1500	842
Year(s) of construction	1898 - 1902	After world war II
Year of last rehabilitation	2013	On-going
IMT	1997	1997 - 1998
Number of blocks	8	15
Main canal flow rates ($m^3.s^{-1}$)	0.1 to 0.4	0.36
Management system	Consultative and Democratic	Consultative and Democratic
Main crops	M*, T, SP**, C	M*, T, SP**, C

Key: M- Maize, SP-Sweet Potatoes, Cabbages, *Summer crop, **Winter crop

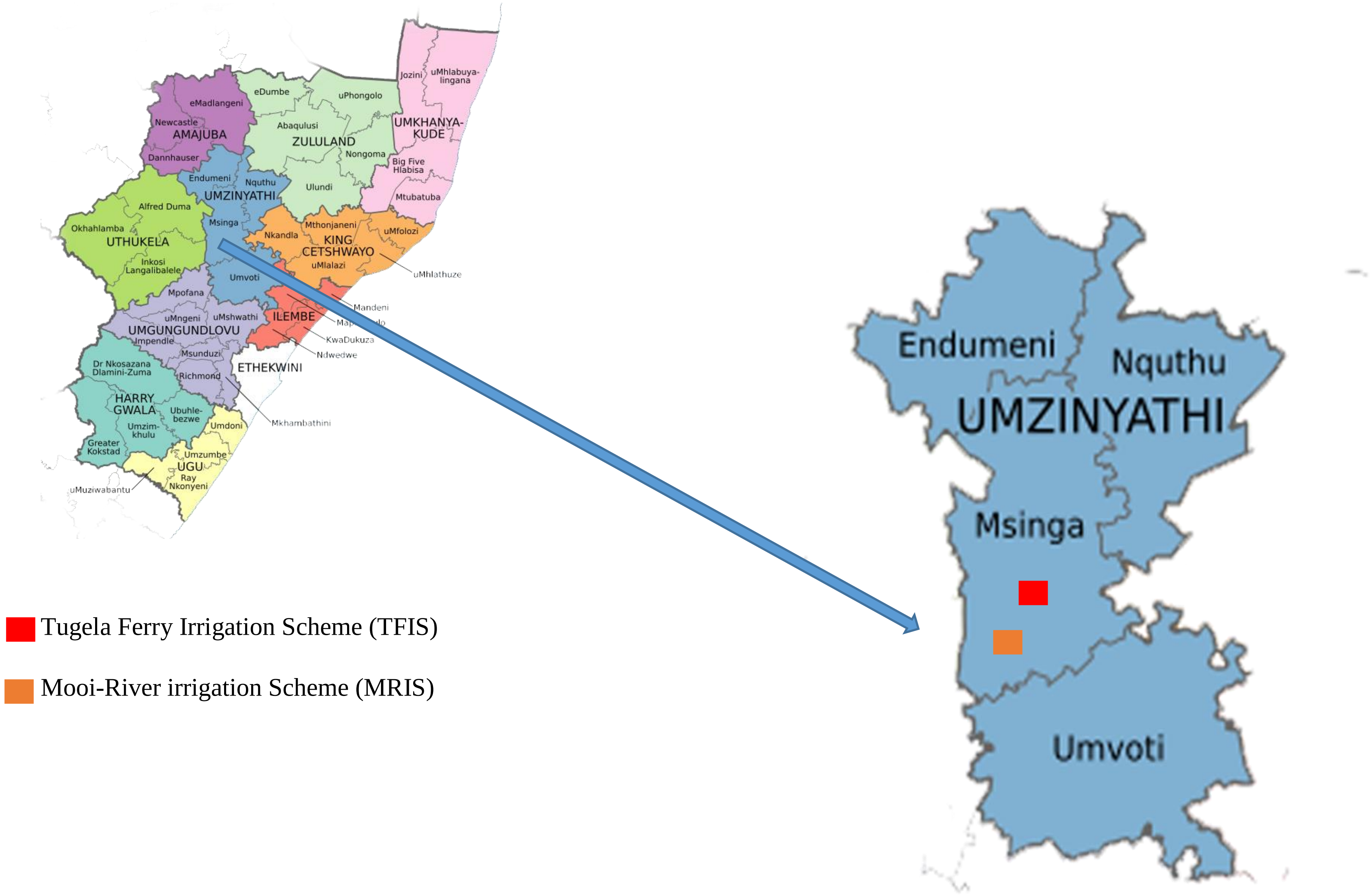

Figure 3.1 Study sites location within KwaZulu-Natal province (Source: Google).

3.2.2 Infrastructure condition assessment (ICA)

Infrastructure Condition Assessment (ICA) is a continuous process that involves systematic gathering of information through observation, investigation, direct monitoring and reporting. Infrastructure assessment in itself is defined by deterministic and interrelated parameters (Afgan & Carvalho, 2002) as shown in Table 3.3. ICA capitalizes on multi-criteria assessment, which bridges uncertainties such as: differences in design codes by the various contractors hired to perform O&M and lack of in-service measurements and records. Such uncertainties complicate the evaluation of infrastructure (Ellingwood, 2005).

Table 3.3 Deterministic and interrelated infrastructure parameters (after PEO, 2016)

Criteria	Definition
Structural adequacy	Assessed whether the current condition of the structure could withstand external shock e.g. vandalism.
Structural efficiency	Assessed whether the structures were built and or repaired to minimum requirement.
Structural soundness	Assessed if the structure is damaged or not and assessed the severity of the damage.
Structural integrity	Assessed whether the structure had the capacity to absorb damage.

An infrastructure condition assessment based on condition scoring was adopted, as the condition scoring technique makes it possible to pin point defects (Le Gauffre *et al.*, 2007). The condition scoring based on rating scale used by Le Gauffre et al. (2007) and Abbott *et al.* (2007) was adopted for this study (Table 3.4). Furthermore, a multi-criteria assessment outcome was employed based on the selected criteria (Davis *et al.*, 2013).

Table 3.4 Infrastructure condition assessment rating (after Abbott et al., 2007; Le Gauffre et al., 2007)

	Description	Condition rating
Excellent	Components may still be new or may have been recently maintained	1
Good	Hydraulic structures exhibit superficial wear and tear, minor defects observed	0.8
Fair	Significant portions require maintenance. Infrastructure has suffered abuse or disrepair	0.6
Bad	Significant portions have deteriorated badly. Maintenance needed. The infrastructure and some components have exceeded service life	0.4
Very bad	Critically damaged components(s). Immediate repair needed.	0.2

3.2.3 Data collection and analysis

A visual assessment and survey were undertaken on the irrigation schemes during August 2017 at Mooi-River and Tugela Ferry. Data was collected from all three strata of the schemes i.e., head, middle and tail sections (Table 3.5**Error! Reference source not found.**). A photo record was produced and defects were documented. The photo record showed hydraulic structure and their defects at 40 m to 50 m intervals along selected canal reaches.

Table 3.5 Blocks from which inspection data were collected.

Strata	Irrigation scheme	
	MRIS (Blocks)	TFIS (Blocks)
Head	2, 3 and 4	1 and 2
Mid	5 and 9	4A and 4B
Tail	11 and 15	5 and 7

Tugela Ferry irrigation scheme (TFIS)

The scheme is located at approximate co-ordinates 28^{o} 45’ S and 30^{o} 21’ to 30^{o} 26’E and the supply is from a weir on Thukela River (Figure 3.3). Average annual rainfall ranges from 650 mm - 1 400 mm. The scheme has undergone numerous upgrades and maintenance since its inception in 1902 (Cousins, 2013). The scheme is characterised by the following hydraulic infrastructure:

Offtake and main supply route

The offtake structure is situated 3 km upstream of the first irrigated fields and comprises of a weir at the base of a steep gorge on a left hand bend of the river. The control structure is situated on the outside of this bend and sluice gates control the first section of piping. The supply line comprises a combination of piping and parabolic, concrete lined canals. Some leaks were observed in the piping section and this will need attention.

Infield infrastructure

The scheme has 19 earthen-lined balancing dams and many seem to be unused. Approximately 23% are in good condition. Dam repair will be a relatively easy process comprising of silt removal, reshaping and repairing of outlet pipes and valves. Distribution canals run through the fields at right angles to the contour. Irrigation is effected by diverting the flow by means of stones and earth or a shaped metal plate into lateral canals in the fields or plots.

The earthen-lined balancing dams act as buffers for when the water levels drop below a certain level. This ensures there is equitable water distribution. A small number of dams are still in use, however, a majority have been breached and are considered unserviceable.

Supply to the irrigated plots

Supply through the irrigated fields comprise of the main canal with short sections of piping where the canal is impractical. Inverted siphons convey water across the Thukela River in two places and link the canal across minor watercourses, dongas and tributaries. Due to lack of maintenance and, poor handling the infrastructure was visibly in poor condition (Figure 3.2).

(a)

(b)

Figure 3.2 A water hydrant (a) with makeshift connections, (b) a canal with an illegal diversion point. Vegetative growth impedes water conveyance along the canal

Mooi-River irrigation scheme (MRIS)

The scheme is located on the banks of Mooi-River. Water is diverted by a weir constructed across the Mooi River into a parabolic canal, which runs for 20.8 km from the diversion point to the end of the scheme (DAEA, 2001). The irrigation scheme covers a land area of 600 ha demarcated into 0.1 ha plots. However, some farmers are multiple land holders such that land ownership extends to 0.5 ha (Sharaunga & Mudhara, 2016). The scheme accommodates 842 farmers across 15 blocks of different sizes (Gomo, 2012). The scheme layout is depicted in Figure 3.4.

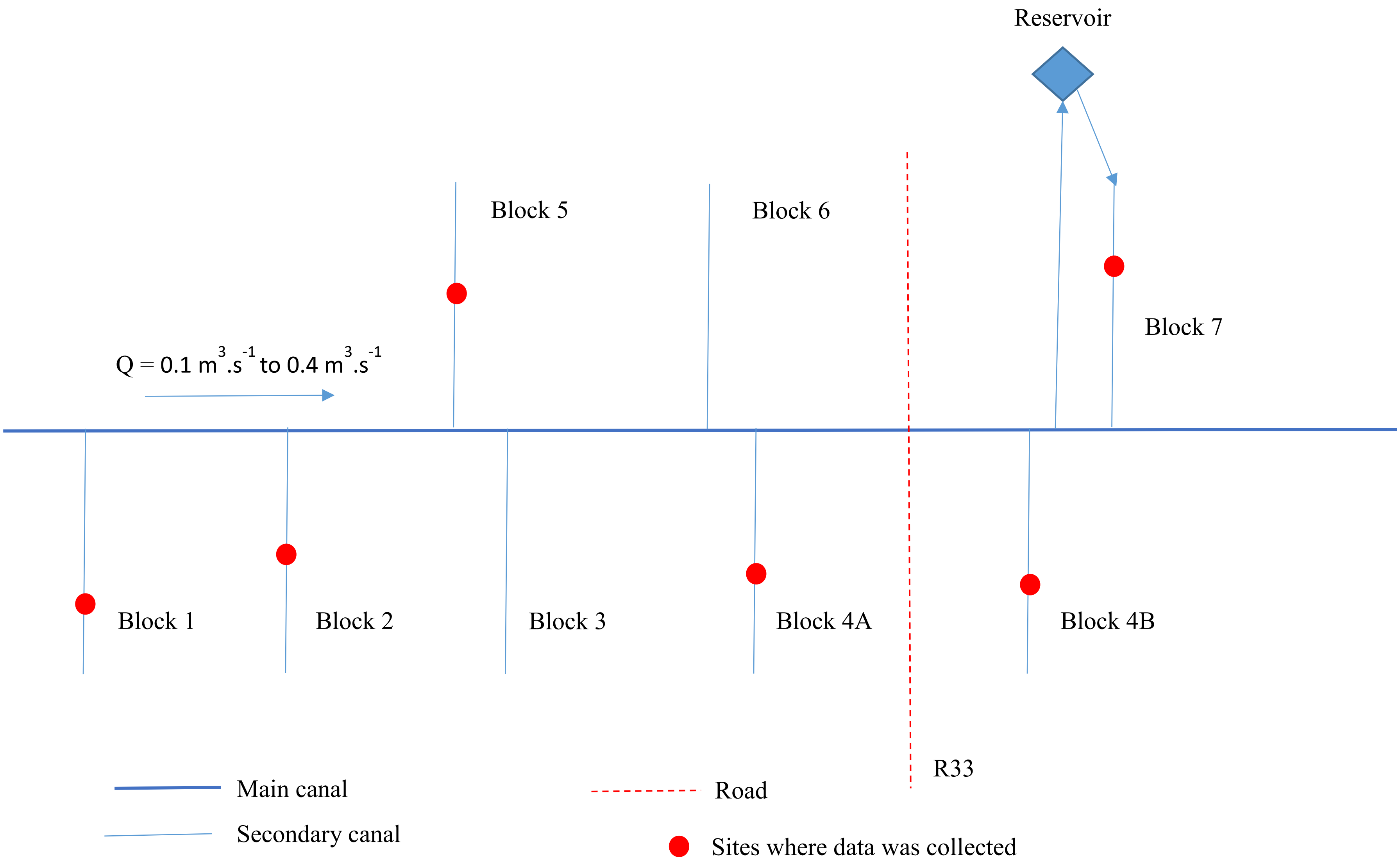

Figure 3.3 Schematic of Tugela Ferry irrigation scheme lay-out

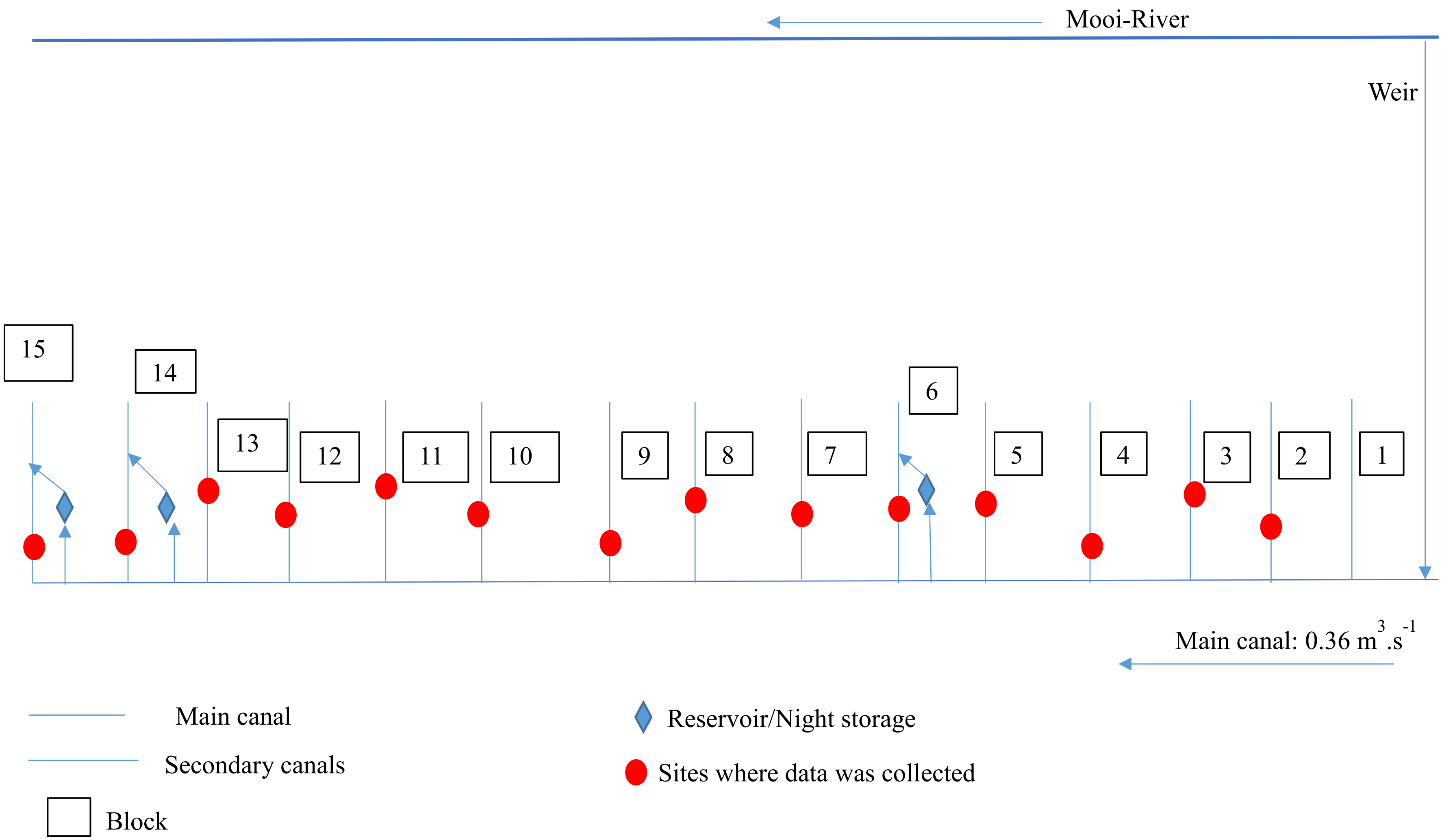

Figure 3.4 Schematic lay-out of Mooi-River Irrigation Scheme (MRIS)

3.2.4 Hydraulic components of the Mooi-River irrigation scheme

Transitions in the canal

The 25 km MRIS long canal has transitions at various points. The canal shape and width varies across the scheme. The main canal is concrete lined canal with a parabolic shaped cross-section. The cross-sectional area and dimensions are inherently the same and only becomes smaller after chainage 14,200 m from the head end of the scheme. In some instances, the canal transits from a parabolic shape to pipes and canals of varying diameters as shown in Figure 3.4 (a) and (b).

(a)

(b)

Figure 3.5 (a) Transition from canal to a $\emptyset\,750\,mm$ pipe and (b) Typical parabolic shaped concrete lined canal changing in cross-section

Siphons

MRIS has 10 siphons located at strategic points (Figure 3.6). The design capacity of a siphon usually exceeds the capacity of the canal section by 20% and the velocities should be between 1 $m.s^{-1}$ and 3 $m.s^{-1}$ (Element Consulting Engineers, 2014). Since most siphons have a local low point, it should be equipped with a scour valve (at least 300 mm diameter) to allow for proper flushing and dewatering of the siphon. The siphons have sediment scour chambers and can be used for dewatering the siphons. The siphons are normally filled with sediment.

(a) (b) (c) (d)

Figure 3.6 (a) The siphon inlet, (b) siphon outlet (c) the scouring chambers at head end and (d) the scouring chambers at the tail end

Sluice gates

Mooi-River irrigation scheme has 15 blocks and each block has 2 to 5 sluice gates or valves that divert water. The standard sluice in the canal comprises of a 300 mm by 300 mm plate covering a 160 mm diameter pipe mouth or orifice. The sluice gate is operated by means of a long handle or a spindle that is lifted or turned to allow water to flow-through a partly opened orifice. Some cover slabs for the control valves adjacent to the canals were missing and the valves and gates were not operational hence there was continuous flow of water to some parts of the scheme (Figure 3.7)

Discharge weirs

The discharge weirs are installed along the MRIS canal (Figure 3.8). The spacing, lengths and crest heights vary along the canal system. The weirs were clogged with debris and silt.

(a) (b)

Figure 3.7 (a) Typical sluice at abstraction point and (b) typical valve at the abstraction point

Figure 3.8 Debris clogged discharge weirs in MRIS

Side channel spillway

These structures allow excess flow in the canal to be diverted back to the water source mainly the river (Figure 3.9). The structures maintain a safe freeboard in the canal. MRIS scheme had one side spillway along the 25 km canal.

Figure 3.9 Side spillway located along the 25 km canal (Element Consulting Engineers, 2014)

Storage dams

The MRIS has three balancing dams (Table 3.6). These were constructed as a contingency in the wake of erratic water supply.

Table 3.6 Balancing dam characteristics (Element Consulting Engineers, 2014)

Block	**Characteristics**	**Capacity (m^3)**
6	Earth lined dam	Unknown
14	Plastic lined dams	16,000
15	Plastic lined dam	16,000

Three block have dams i.e., Block 6, Block 14 and Block 15 (Figure 3.10). The dams required de-silting (Figure 3.10b)

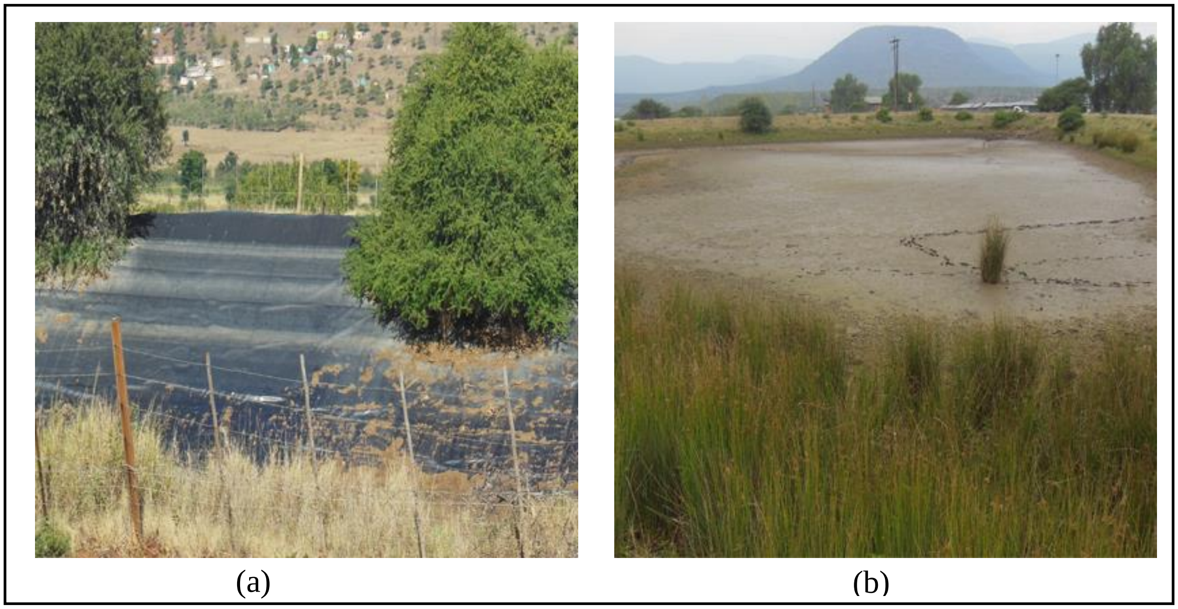
(a) (b)

Figure 3.10 (a) Balancing dam at Block 14 and (b) silted balancing dam at Block 6

3.3 Sampling Procedure

The study employed snowball sampling to identify possible respondents. Snowball sampling is a non-probability sampling method developed by Coleman (1958). As the name implies, the sampling population is derived from a hard to reach population (Goodman, 2011) or equivalently, hidden populations (Heckathorn, 2011). The method was predicted to work well in scenarios where the respondents were geographically dispersed and where the networks are difficult for outsiders to penetrate (Sudman & Kalton, 1986).

A structured questionnaire was distributed to known extension workers in the TFIS and MRIS and technical experts. Technical experts were accessed via referral methods through the South African Institute of Agricultural Engineers (SAIAE). Interviewees evaluated the questionnaire based on their professional judgement considering the institutions, manpower, policies, maintenance, and environment, related factor groups. A total of 18 respondents gave feedback for analysis. The questionnaire captured the extension workers and technical experts' perception on factors causing infrastructure dilapidation. Furthermore, a follow-up questionnaire was issued to capture the diverging view points of the respondents. Since the study does not depend on statistical conception a minimum of five respondents can be used for analysis (Gündüz *et al*,. 2012).

3.4 Root Cause Analysis (RCA): Fishbone "Ishikawa" Diagram

Root Cause Analysis (RCA) is a process used to investigate and compartmentalize the root causes of a problem (Rooney & Heuvel, 2004). RCA is an effective tool used in identifying "what", "how" and "why" a problem occurs, originally developed for psychology and systems engineering. RCA has since expanded to other facets of human development exercises like medicine (Wu *et al.*, 2008), infrastructure assessment (Rosenfeld, 2013), computer server systems (Fraenkel *et al.*, 2004), to mention a few. A favorable tool for RCA is the Fishbone "Ishikawa" diagram because of the following advantages: it aids in determining the root cause of a problem using a holistic and structured approach, suggestive presentation for the correlations between an event (effect) and its multiple happening causes are easily depicted, and . it is easy to use compared to other methods like tree diagrams, and Event and Causal Factor Analysis (ECFA) (Berry *et al.*, 1990; Sarazen, 1990; Dorsch *et al.*, 1997; Ilie & Ciocoiu, 2010):

3.5 Determining the Relative Causal Index (RCI)

Kometa *et al.* (1994), Sambasivan & Soon (2007) and Gündüz *et al.* (2012) used the Relative Causal Index (RCI) method to rank and determine the major causal factors to a common problem. This study adopted the same approach, however for adaptability the study employed a three-point scale range: 3 (Very likely), 2: (Somewhat likely) and 1: (Not likely). The adopted three-point scale was then transformed into relative causal indices (RCI) for each factor using the equation 3.1:

$$RCI = \frac{\sum w}{A*N} \qquad 3.1$$

where:

RCI = Relative Causal Index,

w = Weighting given to each factor by the respondents,

A = highest weight i.e., 3 in this case, and

N = total number of respondents.

The RCI has values ranging from 0 to 1, and the higher the RCI the most likely the factor was to cause infrastructure deterioration (Kometa *et al.*, 1994).

3.6 Results and Discussion

This section presents the research findings and the discussion.

3.6.1 Visual assessment and hydraulic infrastructure survey: Mooi River and Tugela Ferry irrigation schemes

The results from the site inspections showed cracks and failures in the concrete lining with associated leaks and collapse, in severe cases, was evident in both schemes. The farmers had no recollection of how long the cracks had been present. There were sightings of exposed aggregate on the canal lining leaving a poor rough finish, siltation by pebbles, aggregates and sand accelerated by years of no maintenance combined with the removal of the storm water berm in some places. There were also sightings of broken and lost sluices, which resulted in unrestricted flow, illegal connections that allowed continuous abstraction and displaced and eroded expansion joints with associated leaks (Figure 3.11 and Figure 3.12).

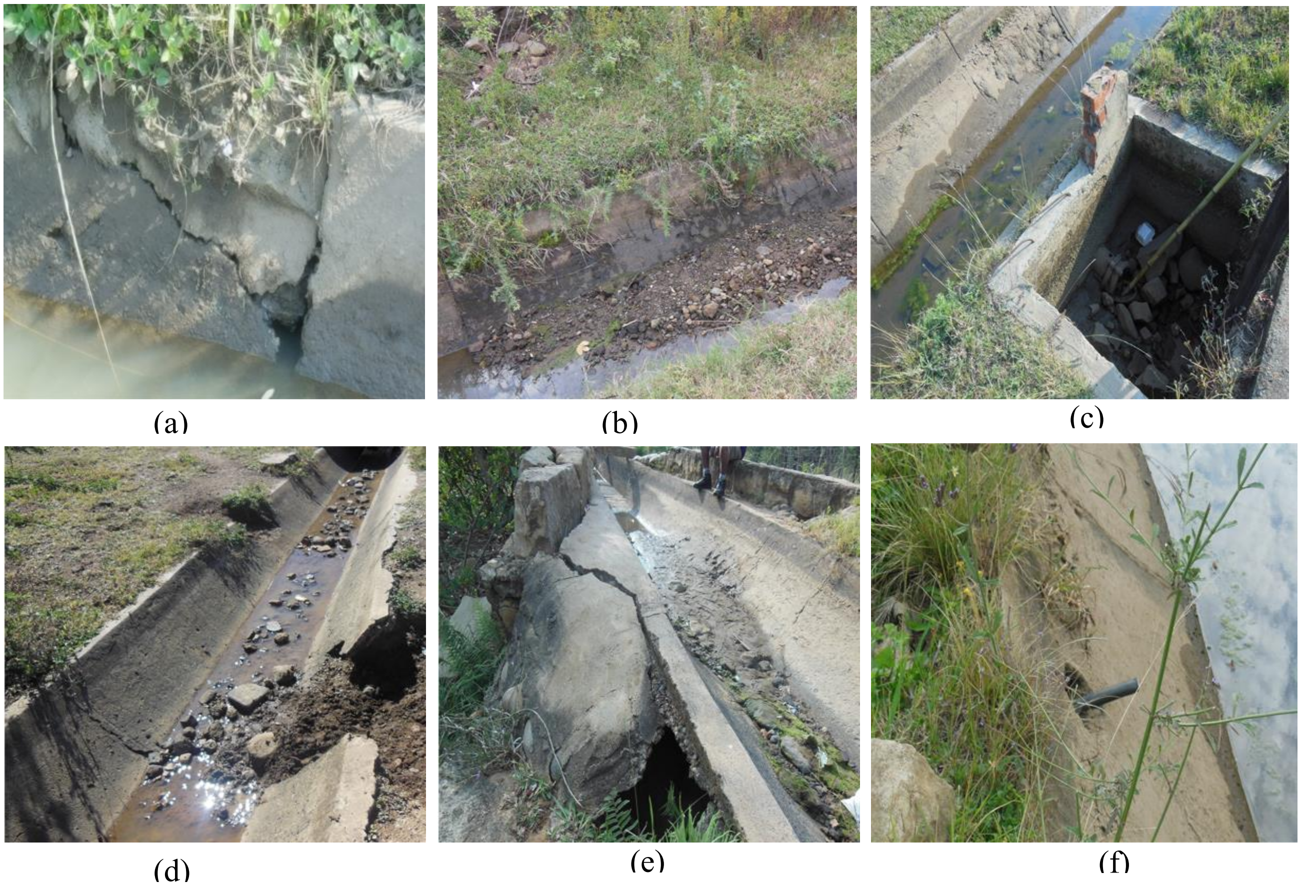
(a) (b) (c)
(d) (e) (f)

Figure 3.11 Example of canal condition along the scheme, (a) vertical crack (MRIS) (b) debris filled canal (TFIS), (c) malfunctioning sluice gate (MRIS), (d) collapsed canal wall (TFIS), (e) damaged embankment (MRIS), (f) illegal connection for abstracting water (MRIS)

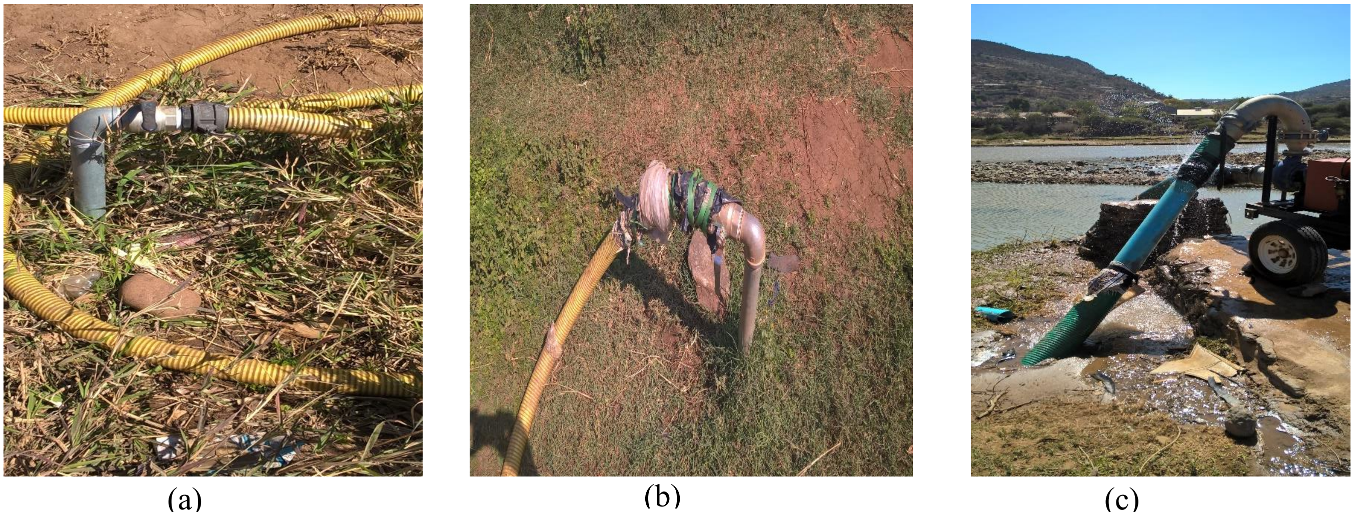
(a) (b) (c)

Figure 3.12 (a) Hydrant and hosepipe in pristine condition in TFIS, (b) a vandalised hydrant in TFIS, (c) leaking secondary pipe abstracting from Tugela river supplying Block 4B

3.6.2 Infrastructure condition assessment (ICA)

The seven sampled sites in the MRIS showed that the canals at the upper reaches of the scheme (Blocks 2, 3 and 4) were marginally deteriorated (Figure 3.13). The canals at the middle section and tail end of the scheme were inpoor condition (Blocks 5, 9, 11 and 15), with condition ratings (CR) of 0.2, 0.2, 0.4 and 0.3 respectively, and thus needed immediate maintenance. The sluice gates (Figure 3.13) in Blocks 2 $(CR = 0.4)$, 3 $(CR = 0.3)$, 4 $(CR = 0.4)$, 5 $(CR = 0.4)$, 9$(CR = 0.2)$, and 11 $(CR = 0.2)$, were all in critically poor condition except for the gates in Block 15. The regulators also showed signs of deterioration that required replacement. All siphons were functional with some components exhibiting deterioration due to abuse and vandalism.

The facility condition assessment for the TFIS sampled six sites. The results (Figure 3.14) revealed deteriorated condition of the hydrants (abstraction points). Due to the varying infrastructure characteristics, the dysfunctional status varied across the scheme. The secondary canal system for the Blocks 1 $(CR = 0.4)$, and 2 $(CR = 0.4)$, at the head end exhibited defective canal linings that needed repairing and replacement. The hosepipes used for water application in the field had a CR

of 0.2, thus exhibited critical damage and required replacement. The $CR = 04$ for hydrants indicated significant damage had occurred and maintenance was due. The PVC pipes for Block 4B were deteriorated however, the infrastructure did not show signs of having exceeded the service life

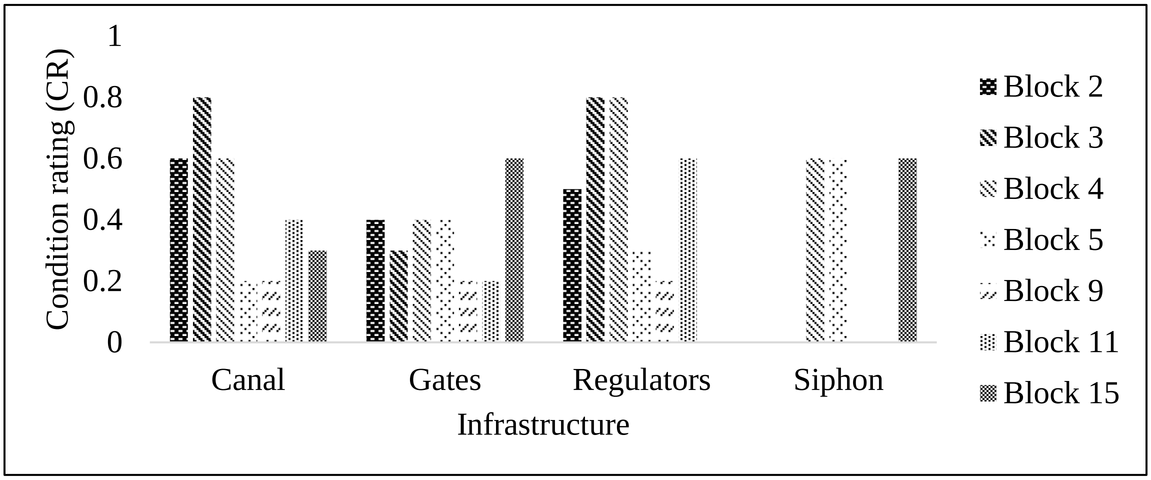

Figure 3.13 Infrastructure Condition Assessment (ICA) results for Mooi-River Irrigation Scheme

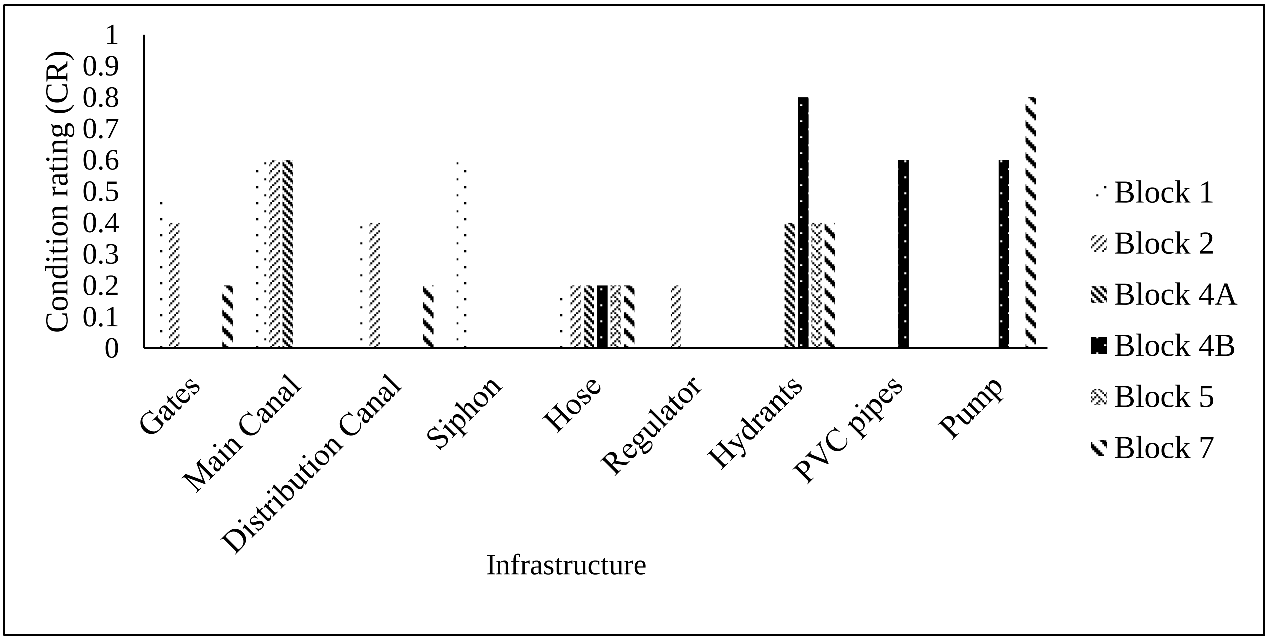

Figure 3.14 Infrastructure Condition Assessment (ICA) results for Tugela Ferry Irrigation Scheme

3.6.3 Root cause analysis: fishbone “ishikawa” diagram

For this study, 23 causal sub-factors were identified and categorized into 5 distinct factors namely: Maintenance, People, Institutions, Policies, and Environment,. The categories were similar to other studies carried out in different industries (Odeh & Battaineh, 2002; Long *et al.*, 2004; Assaf & Al-Hejji, 2006; Gündüz *et al.*, 2012). The factors and sub-factors were visualized using the Fishbone “Ishikawa” Diagram (Figure 3.15):

- Maintenance related factors. These were identified as causal drivers for accelerated infrastructure dilapidation. IMT led to farmers being responsible of O&M. Literature documents the effects of IMT on infrastructure (Johnson III, 1997; Vermillion, 1997; Fujiie *et al.*, 2005). Based on the literature, the study extracted four sub-factors and these were: water users’ unwillingness to contribute to the scheme, none existence of an O&M programme, water users failure to pay for water, and management’s disinterest in infrastructure management (Figure 3.15).

- People driven factors. Factors comprised of the second group of causal drivers. Horst (1998) argued that the human dimension is the epicentre of infrastructure management. The argument identified eight sub-factors namely: insufficient manpower, a lack of formal education, no participation, no training, no reporting of damaged infrastructure, negligent irrigators, no reporting of unlawful behaviour and lack of financial contribution (Figure 3.15).

- Institutions related factors. These were identified as another set of factors that cause infrastructure deterioration. Institutional arrangements in schemes are either farmer led or agency led. Studies have revealed that institutions are at the center of the infrastructure handling and management (Lam, 1998; Chereni, 2007; Denby *et al.*, 2017). Based on this literature, six sub-factors were: identified and these were unaccountability, unfair election process, none existence of WUAs and IMCs, unsustainable stakeholder intervention, ineffective implementation of the constitution and disharmony between WUAs and traditional councils (Figure 3.15).

- Policy related factors. These were the fourth group of causal factors. Several studies have identified policy issues as having an impact on infrastructure condition (Cherlet & Venot, 2013; Manzungu & Derman, 2016). From this category, three sub-factors were identified and these were: ineffective water management laws, ineffective irrigation policies and poor rule enforcement (Figure 3.15).

- Environment related factors. These were identified as the fifth group of factors that contribute to infrastructure deterioration. Literature reveals how environmental and naturally occurring hazards have a negative impact on infrastructure (Mirza, 2003; Smith, 2013). Based on the literature, the study identified two sub-factors such as vegetative growth and induced soil failure (Figure 3.15).

After the RCA, the identified causal factors were quantified using RCI. The RCI ranked the causal factors and the results are shown in Table 3.7. Based on the ranking for TFIS and MRIS, the top six causal factors as perceived by technical experts (Table 3.7) were: water users unwilling to participate in O&M (RCI = 0.93), waters users unwilling to contribute financially to scheme maintenance (RCI = 0.926), recklessness of water users (RCI = 0.93), none existence of an O&M plan (RCI = 0.89), lack of compliance (RCI = 0.85) and lack of formal education (RCI = 0.40).

The top six causal factors as perceived by the extension (Table 3.7) workers were: non-existence of WUAs and IMCs (RCI = 0.87), WUAs and IMCs ineffectiveness in implementing constitution (RCI = 0.800), none existence of an O&M programme (RCI = 0.80), incapacitated scheme managers (RCI= 0.800) farmers unwilling to pay for water use (RCI = 0.67) and lack of formal education (RCI = 0.40). Table 3.7 shows a comparative assessment of the quantified causal factors by the two groups.

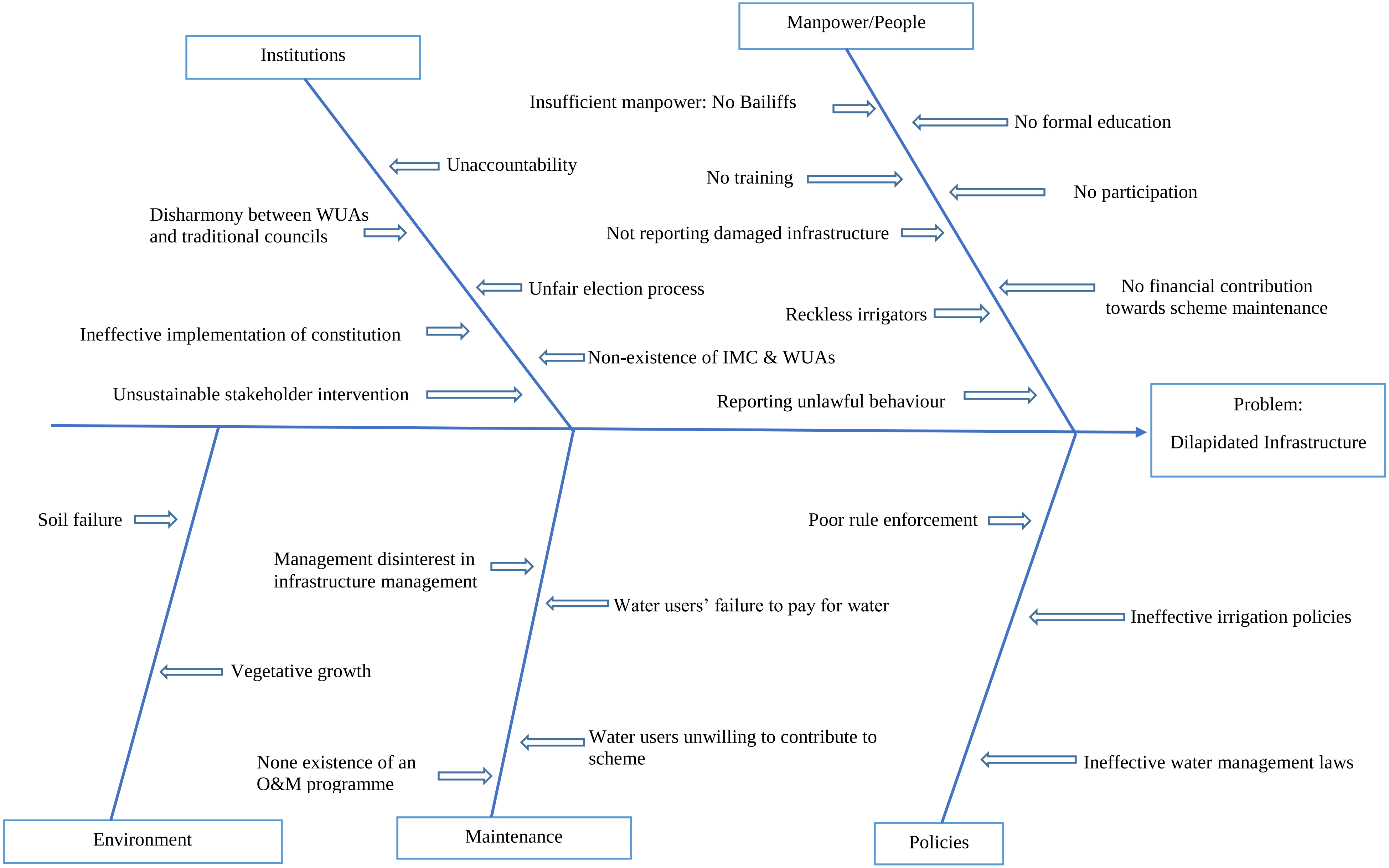

Figure 3.15 Fishbone "Ishikawa" Diagram for TFIS and MRIS.

Table 3.7 RCI and Ranking of causal factors by extension workers and external stakeholders after Gündüz *et al.* (2012) for TFIS and MRIS.

		Extension workers		Technical experts	
		(RCI_{ew})	Rank	(RCI_{te})	Rank
Factor group	Sub-factor causing deterioration				
Maintenance	None existence of an O&M programme	0.8	2	0.9	4
	Water users unwilling to contribute to scheme maintenance	0.5	11	0.9	8
	Uncommitted management	0.5	8	0.9	4
	Water users not willing to pay for water use	0.7	5	0.8	12
People	Water users unwilling to report unlawful behaviour	0.60	7	0.7	17
	Water user not willing to contribute financially to the scheme	0.47	11	0.9	1
	Water users unwilling to participate in O&M	0.33	17	0.9	1
	Water users lacking irrigation training	0.47	11	0.9	8
	A lack of formal education for the water users	0.40	16	0.2	23
	Water users not reporting damaged infrastructure	0.33	17	0.9	4
	Scheme managers incapacitated by insufficient labour	0.80	2	0.9	4
	Recklessness of water users	0.53	8	0.9	1
Institutions	None existing WUAs and IMC	0.8	1	0.8	12
	WUAs and IMC ineffective in implementing the constitution	0.8	0	0.8	11
	Unfair election process in the scheme	0.3	5	0.6	22
	Unsustainable stakeholder intervention	0.5	3	0.8	12
	Disharmony between farmer organisations and traditional council	0.5	3	0.7	19
	Unaccountable institutions	0.3	5	0.8	12
Policies	No compliance	0.3	17	0.9	8
	Ineffective irrigation water laws	0.3	17	0.7	21
	Ineffective irrigation water policies	0.2	23	0.7	19
Environment	Vegetative growth	0.8	5	0.8	12
	Soil failure on embankments	0.6	8	0.7	17

The results indicated some convergence points from both stakeholders. The two groups showed similar positions with respect to the factors shown in Table 3.8.

Table 3.8 Converging points for the two stakeholders

		Relative Causal Index	
Factor	Sub-factor	Technical experts (RCI_{te})	Extension workers (RCI_{ew})
Maintenance	None existence of an O&M programme	0.9	0.8
	Water users unwilling to report unlawful behaviour	0.8	0.7
	Farmers not willing to pay for water use	0.7	0.6
People	Scheme managers incapacitated	0.9	0.8
	lack of formal education	0.4	0.4
Institutions	None existence of WUAs and IMCs	0.8	0.9
	WUAs and IMCs ineffective in implementing constitution	0.8	0.8
	Disharmony between farmers and traditional councils	0.7	0.6
Environment	Soil failure on embankments	0.7	0.6
	Vegetative growth	0.8	0.8

3.7 Further Discussion on Root Cause Analysis and Relative Causal Index

The results as evidenced by the $RCI_{te} = 0.9\ and\ RCI_{ew} = 0.8$ (Table 3.8) revealed that the farmers often lacked a proper operation and maintenance (O&M) programme, which consequently contributed to accelerated infrastructure deterioration. The hand-overtake-over of the scheme management from government to farmers has accelerated infrastructure dilapidation. Irrigation Management Transfer (IMT), in reality, meant farmers adopted a technology they never had a hand in during development, thus there is minimal understanding of the maintenance and operation requirement of the infrastructure. According to Frederiksen & Vissia (1998) Water Users Association (WUAs) and Irrigation Management Committees (IMCs) are key to pushing O&M agendas because the clustered WUAs are supposed to coordinate within the scheme to put in place an O&M programme. Johnson (1997) argued that the lack of will from institutions in organizing and adopting O&M strategies ultimately results in failed irrigation infrastructure.

Unwillingness to pay for water was identified as another convergence point for the different stakeholders ($RCI_{te} = 0.7, RCI_{ew} = 0.6$), and as a factor causing infrastructure dilapidation. IMT has had negative impacts on scheme maintenance, and a participatory approach ensures that farmers are more involved and as such possess a capacity to monitor and execute O&M (Marothia, 2002).

Water payments to WUAs and public agencies are used for funding O&M exercises in the scheme. However, farmers' refusal to pay for water strains the schemes budget hence leading to inadequate funds for O&M. Water payments represent an administrative order that mediate water and its means of abstraction, i.e. infrastructure handling (Scott, 1998; Alba *et al.*, 2016). Boelens & Zwarteveen (2005) argued that water payments awards a water license to the farmer, as such, it gives a sense of formal authority to irrigators that handle infrastructure, consequently if one is legally authorized to handle infrastructure they do so with extra care. Water payments provide a good basis for allocating funds for maintenance, and a lack there-of contributes to infrastructure decay. van Koppen *et al.* (2004), Mdee *et al.* (2014) and van Koppen *et al.* (2016) argued that irrigators' refusal to pay for water was motivated by their belief that God provided water for free and hence they should not pay tariffs, which subsequently limits the budget intended for O&M. Samad (2002) and Burton (2010) also revealed that in situations where WUAs and IMCs do not receive water payments, the sustainability of the water delivery and control infrastructure is compromised.

People driven factors such as incapacitated scheme management, in terms of numbers and a lack of formal education $RCI_{te} = 04, RCI_{ew} = 0.4$, were also converging points. A formal education enlightens irrigators, meaning an educated irrigator is most likely to make informed decisions. The finding is consistent with Nyambose & Jumbe (2013) who argued that education is a helpful tool for farmers in analyzing choices and making decisions about forecasts of the anticipated benefits of participating and actively contributing to better infrastructure handling, thus limiting abuse and vandalism.

Results showed institutional arrangements contributed to infrastructure deterioration as per the stakeholders view. The results revealed that WUAs and IMCs are almost non-existent at farm and village level ($RCI_{te} = 0.8, RCI_{ew} = 0.9$), and where they exist, they fail to implement the irrigation scheme constitution or by-laws, and there is disharmony between the organizations and the traditional leadership. The institutional arrangements tend not to be clearly defined as to who does what and when, i.e. roles and responsibilities. During scheme construction, the irrigation officers worked closely with the contractors and sidelined the intended beneficiaries. This top-down model led to poor policy articulation when the schemes were finally handed to farmers. Wester (2008) defines policy articulation as a process by which policy actors support, modify and translate the tool so that an agreed outcome is reached.

Poor policy articulation has adverse effects at the irrigation scheme level. These results are in line with the findings by Manzungu & Derman (2016) who argued that institutions like the World Bank and the International Monetary Fund (IMF) that fund irrigation scheme projects in Africa set policy regarding water allocation distribution and infrastructure handling. However, there is serious policy disarticulation at national level and eventually at farm level. The disarticulation by the institutions leads to discordancy and constricts the necessary action needed to be taken to meet the infrastructure requirements at the lowest water-use level. Under environmental factors, vegetative growth ($RCI_{te} = 0.8, RCI_{ew} = 0.8$) (see Figure 3.17) and soil failure ($RCI_{te} = 0.7, RCI_{ew} = 0.6$) were also identified by both parties as contributors to infrastructure dilapidation. Repeated tractor movements over canals overwhelms the soils and the canal lining which eventually lead to failure.

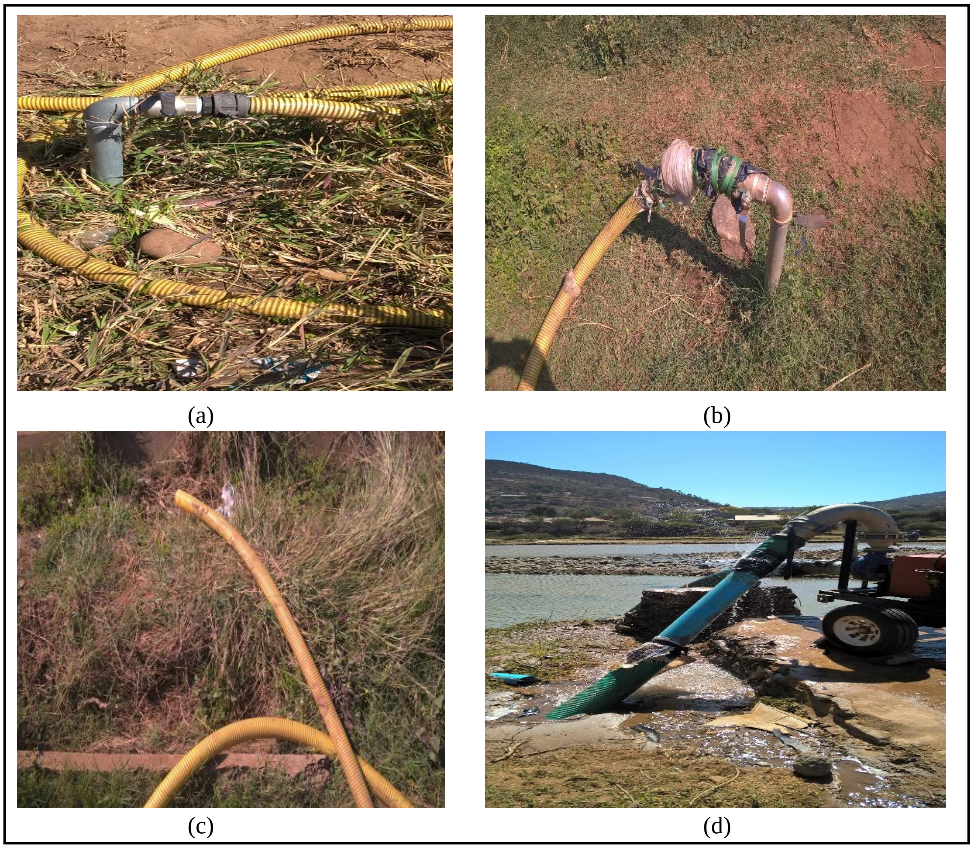
(a) (b) (c) (d)

Figure 3.16 (a) Hydrant and hosepipe in pristine condition, (b) An abused hydrant in TFIS, (c) An abandoned hosepipe in the sun and (d) Leaking secondary pipe abstracting from Thukela river supplying Block 4B

Figure 3.17 Vegetative growth invading canals in MRIS

3.7.1 **Diverging points**

The sharp difference were noted on Unaccountable institutions (RCI_{te} = 0.8 and RCI_{ew} = 03) for technical experts and extension workers respectively. The technical experts ranked highly the causal factor citing installation of scheme managers is not based on merit. The technical experts survey further revealed that incompetent individuals running organisations tend not to make informed decisions thus policy disarticulation and, more often than not, abuse of scheme funds that are meant for O&M. This finding is also consistent with Denby *et al.* (2017), who argued that irrigator participation and integration challenges were deeply aligned to flawed institutional accountability. Denby *et al.* (2017) further argue that newly installed governance models , e.g. creation of WUAs and IMCs, created a leadership vacuum, and they stated:

> *"In South Africa the creation of new decentralised institutions (WUAs and IMCs) parallel to existing governmental water institutions (DWA) brought up questions of who is ultimately in charge, who is accountable or holds the mandate to solve scheme challenges"*

Another point of divergence was on lack of compliance. The technical experts greatly attributed non-compliance as the major driver of irrigation infrastructure decay ($RCI_{te} = 0.9$) whereas the extension workers did not highly rank the factor ($RCI_{ew} = 0.3$). The survey revealed that water managers are mainly vulnerable and are scapegoats to scheme failures.

Policy issues were divergent between the extension workers and the technical experts. The technical experts ranked highly policy issues, i.e. ineffective irrigation policies and ineffective irrigation water laws. According to technical experts the ineffective irrigation policies and water laws both had $RCI_{te} = 0.7$ and $RCI_{te} = 0.3$ respectively. It appeared the extension workers would acknowledge policy disarticulation. Furthermore, the technical experts cited the lack of adherence to policy if it exists at all. The experts' notion is consistent with a study by North (1995) who argued that informal policy is dominant in schemes as it is embedded in the particular history and social fabric of the irrigators hence, promoting discordancy between the formal and the informal. The extension workers position can be justified since skills are passed from one generation to the next generation (inherited) thus the failure of policy implementation in the schemes. This is in line with the study by Denby *et al.* (2017) who argued that policy formulation is not inclusive hence discrepancies exist between the policy designers and the end user as such the formal way of handling infrastructure conflicts with the informal methods embedded in the irrigation schemes.

3.8 Conclusion

The infrastructure in Mooi-River Irrigation Scheme (MRIS) and Tugela Ferry Irrigation Scheme (TFIS) requires maintenance and major components require replacement. The canals for both schemes had serious cracks and the expansion joints were dislocated. Hydrants in TFIS were missing components and makeshift elastics bands were used to clip the hose to the hydrant. The hosepipes leaked showing signs of neglect. The farmers would also leave hoses lying in the field and the PVC material is subjected continuous heating and cooling due to day and night time temperature, thus accelerating rapid expansion and cooling and hence cracks. For both schemes canal lining had holes because people drilled holes to illegally abstract water. Furthermore, sluices abstraction valves had missing handles, and vegetative growth invaded the water conveyance channels.

The stakeholders i.e., technical experts and extension workers converged on perceptions regarding certain institutional arrangements such as WUAs assessment and support and how they affected infrastructure. They also converged on the sub-factor “lack of education” as a lowly ranking contributor to infrastructure deterioration. This conflicted with literature as it suggests that a formal education aids irrigators to make informed decisions. The study revealed many diverging points between stakeholders and a follow-up questionnaire revealed how there was discordancy amongst institutions i.e., the water users association, irrigation management committees and government. Stakeholder intervention ranked highly according to the technical experts perception. The technical experts pointed out that a lack of a training programme, combined with scheme design, rehabilitation and revitalization left farmers with knowledge gaps as per the operation and management (O&M) action plan. Disharmony amongst stakeholders facilitates omission made by policy-makers when concepts and strategies are transformed to policy.

3.9 Recommendations

It is highly recommended that government employs extra hands to aid scheme managers in MRIS since the predominant problems were somehow labour/manpower related. In addition, a participatory irrigation design approach is highly encouraged, as this will include the intended beneficiary of the infrastructure. Farmers and farmer organisations require training for effective and enhanced scheme functionality. Also irrigation and water management training improves the farmers appreciation of the schemes strategic goals which are for example, ensuring proper handling and maintenance of CPRs such as water conveyance infrastructure will improve water access and conveyance efficiency which, subsequently improves crop production. The shortage of water bailiffs led to poor scheme monitoring and hence increased infrastructure abuse. For both irrigation schemes institutional accountability was necessary and appointing scheme managers at farm level based on merit would ensure proper policy articulation. Financial autonomy would go a long way to ensure proper financial management system, .i.e. farmers will self-organise to collect water fees that will augment the O&M budget. In addition, if WUAs and IMCs are given financial autonomy they will freely set targets and strategies meant to realise scheme goals. Hiring external agencies to take over O&M will facilitate transparency and consistency in maintenance of infrastructure. Institutional accountability can be enhanced by financial autonomy, as farmers will be much involved in scheme affairs. A further enquiry is needed in investigating the enforcement mechanisms involved in the two study sites and to asses their impact on scheme governance.

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4 ASSESSING THE FUNCTIONAL AND OPERATIONAL RELATIONSHIPS BETWEEN WATER CONTROL INFRASTRUCTURE AND WATER GOVERNANCE: A CASE OF TUGELA FERRY IRRIGATION SCHEME AND MOOI RIVER IRRIGATION SCHEME.

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Abstract

Water governance is a multi-level and multi-actor decision-making process. The multi-actors are grouped under formal and informal institutions, and they collectively determine how irrigation scheme infrastructure is operated or managed. Infrastructure and governance interactions are precursors to a fully functional irrigation scheme, consequently enhancing agricultural productivity, which subsequently boosts rural economies. Water control infrastructure is a critical component that determines management of canal operation and use, and therefore, has to be built within a water governance framework that considers multisector and multilevel actors. This paper sought to establish an operational and functional relationship between water control infrastructure and the existing water governance in Mooi River Irrigation Scheme (MRIS) and Tugela Ferry Irrigation Scheme (TFIS). The technology adopted was imposed rather than being setup in a participatory manner and only considered engineering and hydraulics and not human and institutional aspects. This study uses a fuzzy model to establish a link between water control infrastructure, i.e., its characteristics, operational requirements, on one hand, and the existing water governance frameworks in the respective irrigation schemes, on the other. The approach was based on Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Technique for Order of Preference by

Similarity to Ideal Solution (FTOPSIS). The FAHP techniques was used to determine the fuzzy weight of the water control infrastructure aspects and the FTOPSIS was used to rank the water governance aspects, i.e., institutions, processes, procedures, rules and regulations, with respect to the infrastructure weights. Due to the high uncertainty and vagueness, the linguistic variable were expressed, as triangular fuzzy numbers. Questionnaires were administered to five irrigation experts from each scheme. The Closeness Coefficient (CC_i) was used for ranking. The study revealed that TFIS had strong institutional setups ($CC_{TFIS} = 0.18$), as compared to MRIS ($CC_{MRIS} = 0.13$). However, TFIS showed a low ranking on rules and regulation ($CC_{TFIS} = 0.14$). Farmers unwillingness to pay water tariffs and contribute funds for operation and maintenance is illuminated under the rules and regulations governance pillar. A collective and participatory approach is required to improve on the water governance shortcomings. In consequent, this will improve the scheme performance.

Keywords: Fuzzy Analytical Hierarchy Process (FAHP), Fuzzy Technique for Order of Preference by Similarity to ideal Solution (FTOPSIS), Linguistic Variables, **Triangular fuzzy number (TFN)**

4.1 Introduction

Water control infrastructure in Smallholder Irrigation Schemes (SISs) is supposed to be engineered for resilience. Resilience can be defined as the ability of the water control infrastructure to absorb natural and man-made disturbances while retaining functionality. Infrastructure remains constant in the face of scheme dynamic social changes and changes in self-organization and the capacity to adapt to stress. Irrigation schemes are an indispensable component of economic growth, and poverty reduction in SISs across Africa (Tortajada, 2016). Although infrastructure in SISs is critical for water conveyance, it needs to closely relate to policies, institutions (both formal and informal), laws, regulations, management practices, and participation models for the efficient management of water resources and water-related services (Molden et al., 2014). A resilient irrigation scheme exists when there is a strong functional and operational relationship between the water control infrastructure and the prevailing governance. Governance is anticipated to result in better managed water resources (Pittock, 2016). Typical water control infrastructure includes water canals, weirs, sluice gates and siphons. A typical canal layout in a scheme is depicted (Figure 4.1) and shows how the system branches into lower order canals.

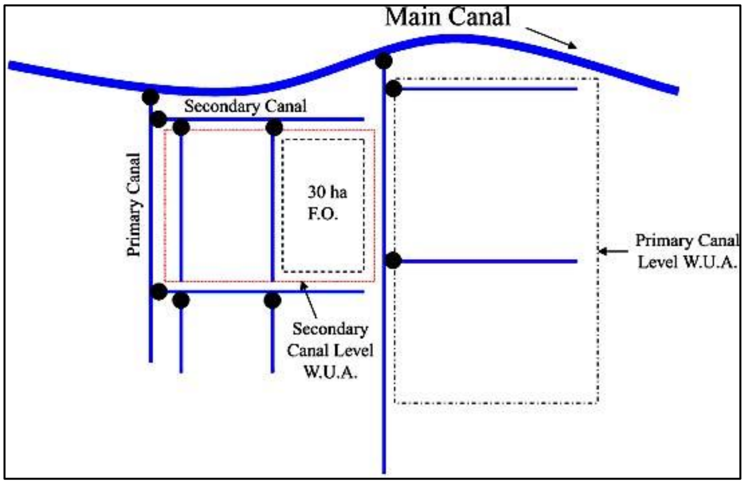


Figure 4.1 Typical bifurcating system (Plusquellec, 2002)

The bifurcating points are characterised by various water control infrastructures such as sluice gates, valves (Figure 4.2) (Horst, 1998). Gates and abstraction valves allow water abstraction from the main canal to the secondary canals (Figure 4.2). Water is diverted to the tertiary canals and it is the farmers' responsibility to get water to his or her plot.

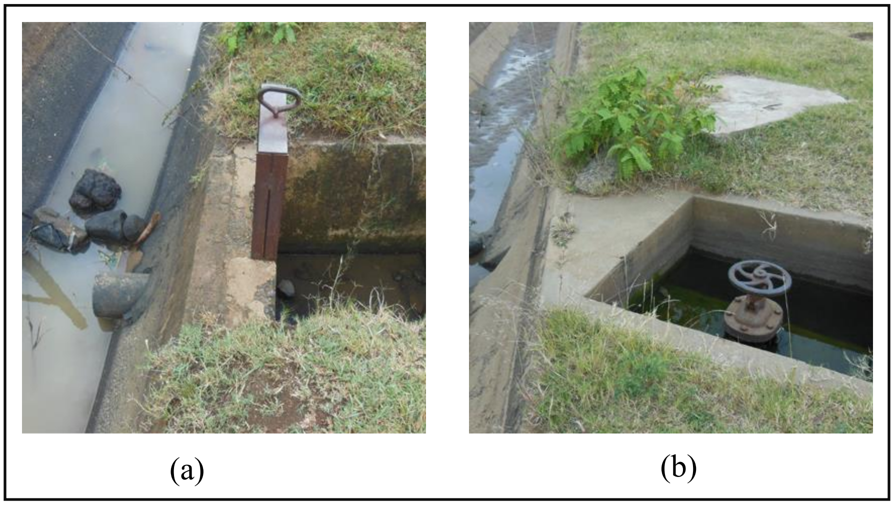

(a) (b)

Figure 4.2 Typical hydraulic structures at abstraction points (a) valve and (b) sluice gate with a spindle

Letsoalo & Van Averbeke (2006) showed the dilapidated state of infrastructure in South Africa's SISs. The Irrigation Management Transfer (IMT) policy saw the transferal of responsibility of the scheme Operation and Maintenance (O&M) from government to farmers. However, poor participation and poor institutional arrangements in the irrigation schemes have accelerated infrastructure decay, consequently affecting scheme performance (Sharaunga & Mudhara, 2018). The next section of the article defines and contextualises water governance. The objective of the study was to asses the functional and operational relationship between water control infrastructure and the water governance systems in selected SISs The next section defines the tools used for data analysis. Furthermore, the conceptual water governance-infrastructure model is depicted. The paper finally presents results and discussion.

4.2 Water Governance

Water governance in smallholder irrigation schemes encompasses institutions, processes, procedures rules and regulations involved in water management (Rogers & Hall, 2003). Governance (Figure 4.3) is dynamic since it is greatly influenced by the human dimension, as such continuous revision of the water governance framework is needed so that it matches up to the dynamic needs of irrigators (Horst, 1998; Rogers & Hall, 2003). Institutions are primarily involved in policy design and putting into place processes and procedures that are socially acceptable. The institutions must mobilise resources to support the policies. The process followed in policy formulation and implementation ensures that scheme goals are met. The scheme goals encompass efficiently providing equitable water to irrigators (Rogers & Hall, 2003). A participatory approach in SISs management facilitates decentralized management units that boost participation and farmer interests in achieving optimal irrigation performance (Mwendera & Chilonda, 2013 as cited by ; Sharaunga & Mudhara, 2018). Huitema *et al.* (2009) also concurred that de-centralizing institutions facilitates active farmer participation.

Irrigation schemes do not exist in a vacuum, as such there can never be a one size fits all policy, strategy and processes in one irrigation scheme as diverse cultures and dietary needs exist (OECD, 2015). Improved interactions between governance aspects facilitates an improvement of the water governance cycle (see Figure 4.4) which seeks to bridge gaps in scheme governance and infrastructure, formulate policies for continued trust and engagement amongst water managers, water bailiffs and the water users (improved processes).

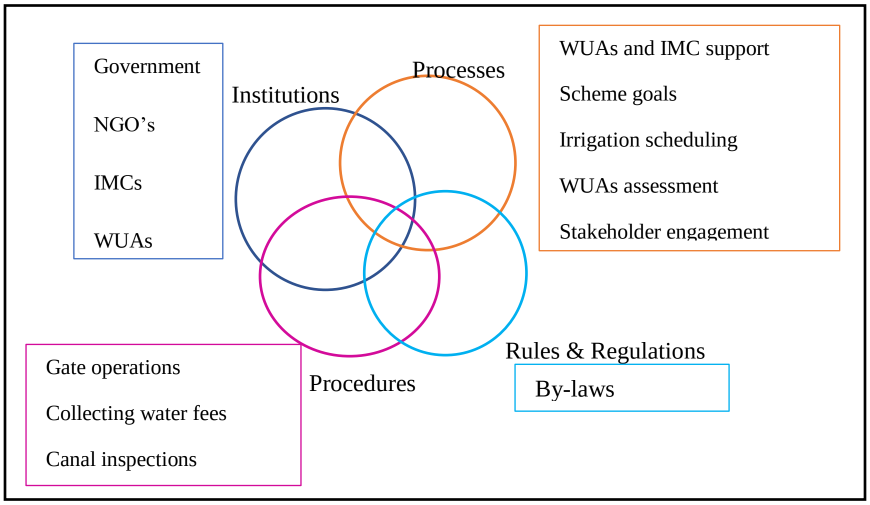


Figure 4.3 Water governance framework showing interactions amongst governance aspects in a typical smallholder irrigation scheme

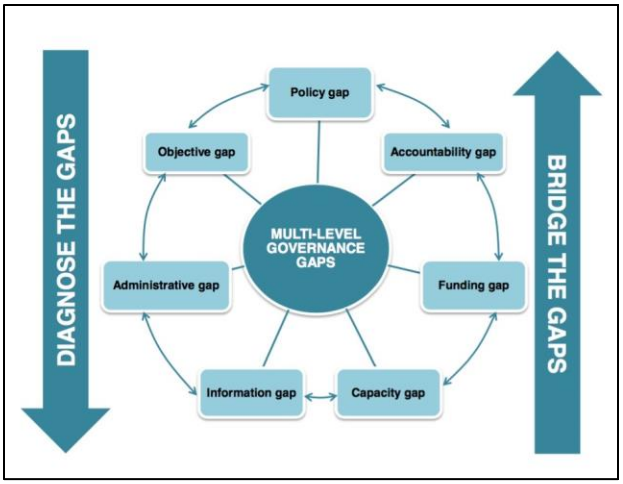


Figure 4.4 The water governance cycle (adopted from OECD, 2015)

To achieve optimal performance levels in the scheme the technology and the water governance framework have to interact. Matching management capability and operational flexibility to the level of technology leads to enhanced irrigation performance. However, the imposed technology and the operational reality more often than not do not match (Horst, 1998). The infrastructure or technology upgrades have cumbersome operational requirements that do not match the management capability of the irrigators. Unsustainable management in SISs stems from the disconnection between the physical and technical attributes of the irrigation scheme, socio-economic characteristics of the irrigators, local knowledge of the irrigators and irrigation governance structures (Marothia, 2002).

4.3 Basic concepts of fuzzy theory and their link to water governance

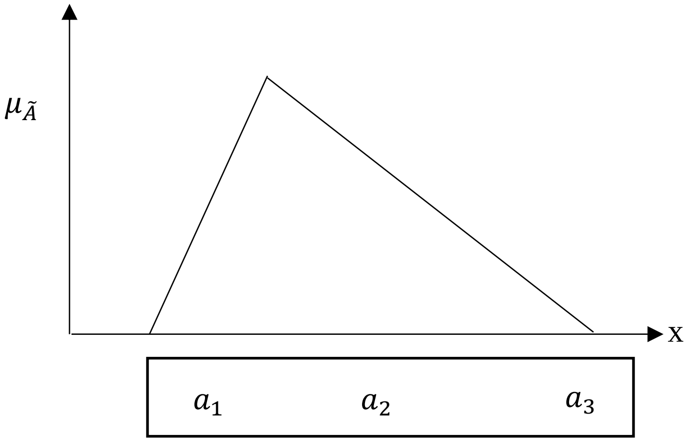
This section will define the fuzzy definitions according to Buckley (1985), Chen (2000) and Lee *et al.* (2012a).

Definition 1

A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates each element x in X a real number in the interval $[0,1]$. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$ (Zadeh, 1965).

Definition 2

Van Laarhoven & Pedrycz (1983) stated that a positive triangular fuzzy number (TFN) $\tilde{A}$ =(a_1, a_2, a_3); where a_1, a_2, a_3 are three real numbers satisfying $a_1 > 0$ and $a_1 \leq a_2 \leq a_3$ are defined by predetermined fuzzy number e.g.1, 3, 5 to mention a few. **Error! Reference source not found.** gives an illustration on how the upper and lower bounds are determined.



where:

a_1 - Lower bound, a_2 - Modal value and a_3 - Upper bound

Table 4.1 Membership function of a Fuzzy number after (after Yeh & Deng, 1997)

Fuzzy Number	Membership Function
$\tilde{1}$	(1, $\tilde{1}$, 3)
$\tilde{x}$	$(x-2, x, x+2)$ for $x = 3, 5, 7$
$\tilde{9}$	(7, $\tilde{9}$, 9)

In this study, the fuzzy numbers are a conversion of linguistic variables used by experts to assign fuzzy weights to water control infrastructure aspects. In addition, the fuzzy numbers are also used to define the linguistic variables used to rate water governance aspects w.r.t. water control infrastructure aspects.

Definition 3

Lee *et al.* (2012a) suggested that if $\widetilde{M} = (m_1, m_2,\ m_3)$ and $\widetilde{N} = (n_1, n_2,\ n_3)$ are two triangular numbers then the vertex method is defined to calculate the distance between them.

$$d(\widetilde{M}\ , \widetilde{N}) = \sqrt{\frac{1}{3}\ [(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \qquad 4.1$$

The underlying concept as used in this study is to compute Euclidean distances, which are contextualised as Positive Ideal Solutions (PIS) and Negative Ideal Solutions (NIS). The ideal state where farmers obtain a correct irrigation function is achieved by increasing PIS and minimising NIS.

Definition 4

A fuzzy linguistic variable is a variable whose domain is a collection of pre-specified fuzzy concepts (Ngan, 2011). Zadeh (1975) defined a linguistic variable as a variable whose values are non-numerical .i.e., they are words or sentences in a natural or artificial language The linguistic variables are converted to numerical fuzzy numbers for ease of computation (see Definition 2).

4.4 Study Area and Methodology

This section contains the location of the research sites, methods used for identifying experts and data collection tools used.

4.4.1 Study area

The study was carried out in Mooi-River irrigation Scheme and Tugela Ferry Irrigation Scheme. Mooi River is located in uMsinga Local Municipality in the Umzinyathi District of KwaZulu-Natal province (see Figure 4.5). The scheme is located between 28º 56` longitude, latitude 30º 22` (diversion point) and. 28º 56` S, 30º 29` (lower end of scheme) (Gomo, 2012). Tugela Ferry Irrigation Scheme is also located in uMsinga municipality between 28º 44`S and 30º 26`E. The irrigation scheme ranks as one of the largest in KZN with a land area of 840 ha (Cousins, 2013). Both schemes are located in former homelands that still exist as poverty nodes. Subsistence agriculture is central to the welfare of the poor farmers (Sinyolo et al., 2014).

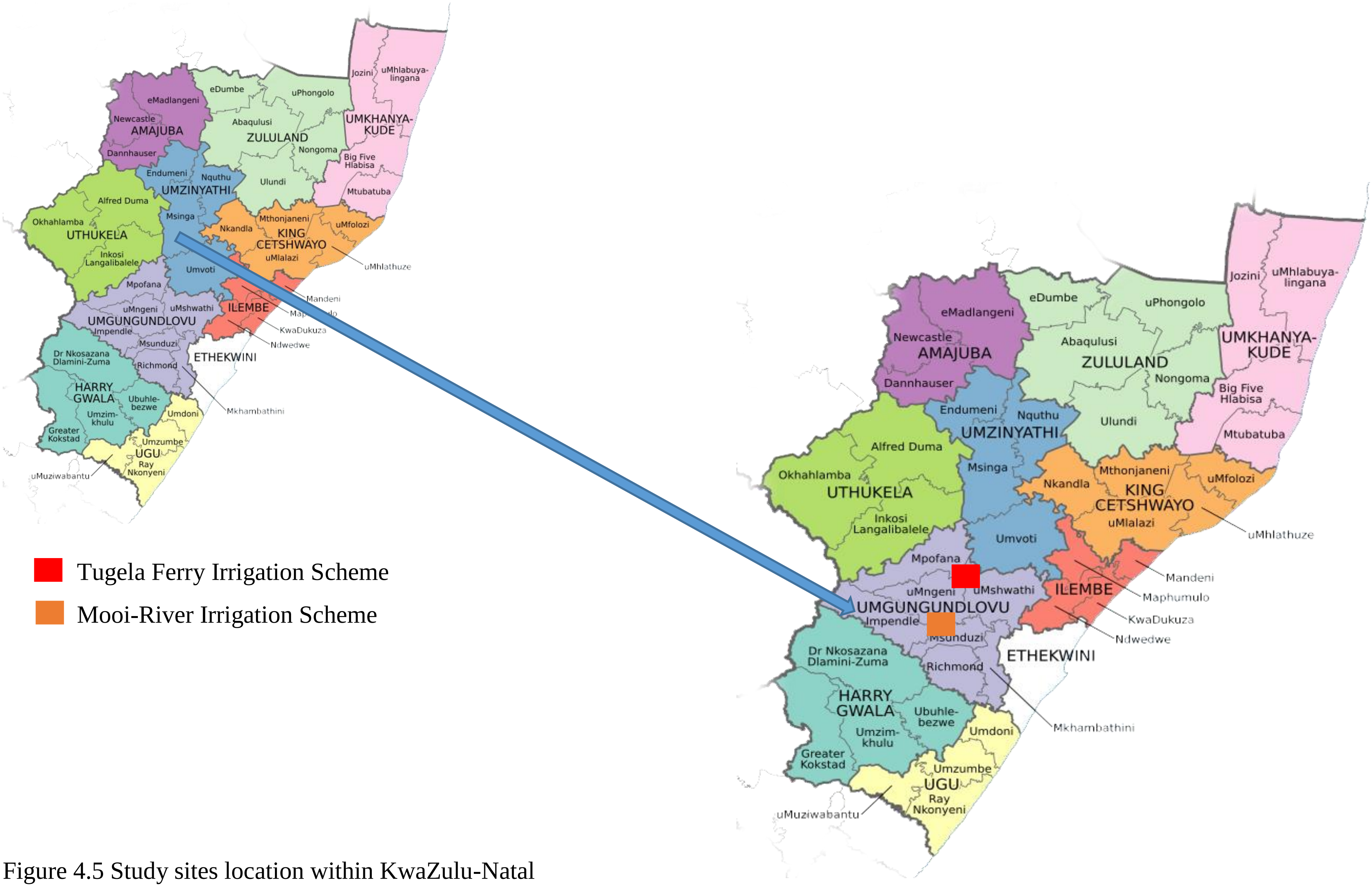


Figure 4.5 Study sites location within KwaZulu-Natal

4.4.2 Multi-criteria decision making

The study applied a Multi-Criteria Decision Making (MCDM) model based on fuzzy theory (Zadeh, 1996) to establish a functional and operational relationship between water control infrastructure and the water governance. Human judgement cannot be presented in crisp sets but can be defined by a fuzzy sets and fuzzy linguistic terms (Zadeh, 1965). A fuzzy linguistic variable is a variable whose domain is a collection of pre-specified fuzzy concepts (Ngan, 2011) and they collectively define the Saaty scale (Saaty, 1990). The MCDM based on the fuzzy analytical hierarchy process (FAHP) and the Fuzzy Technique for Order Preference by Ssimilarity to Ideal Solution (FTOPSIS), was employed to establish a link between infrastructural functionality and operational reality vs the schemes water governance aspects.

4.4.3 Data collection for FAHP and FTOPSIS

For data collection, a questionnairre survey was conducted. Five questionnaires were administered per scheme. The questionnaire targeted experts in the respective schemes since the FAHP depends on expert judgement rather than statistical conception for evaluation. Saaty & Vargas (1994) as cited by Lee *et al*. (2012a) suggested that three to seven experts are necessary for AHP. Lee *et al.* (2012a) used five experts, whereas Ertuğrul & Karakaşoğlu (2009) used 15 experts. For this study because of availability nine experts were used. The first section of the questionnaire asked experts to do a pairwise comparison amongst selected infrastructure aspect. Therafter, it asked experts to rate the performance of each infrastructure aspect with respect to the water governance aspects.

4.4.4 Expert selection

Lee *et al*. (2012a) defined experts as the people who are most likely to experience a service such that their responses to the questionnaire are representative and accurately reflect actual service qualities. In this case the experts are the people in the scheme that are most likely to experience the full irrigation service utility. Theoretically, expertise is closely related to the structure of individual differences in knowledge, representation, decision-making, and a range of other cognitive capabilities (Bolger & Wright, 1992) as cited by (Lee et al., 2012b). Thus, in this study the self-reporting parameters: level of education and the number of years one has been irrigating were used as bench-marks for expertise. The experts considered were agricultural engineers and extension workers directly involved with each respective scheme.

4.4.5 The Adopted Infrastructure-Governance Conceptual Model

The following sets describe the infrastructure-governance model shown in Figure 4.6:

- A set of m possible governance aspects denoted by $G = \left\{G_{1,}\ G_2, \dots \dots \dots . G_m\right\}$;
- A set of n infrastructure aspects called $P = \left\{P_1, P_2, \dots P_j, \dots . P_n\right\}$ and a set of S_j criteria with respect to aspect P_j measured by $\left\{P_{j1},\ P_{j2}, \dots \dots, P_{jS_j}\right\}$;
- A fuzzy performance ratings of governance aspects G_i $(i = 1, 2, \dots . . m)$ with respect to aspects $P_j (j = 1, 2, \dots \dots . n)$ called $\tilde{X}$=$\left\{\tilde{x}_{ij},\ i = 1, 2, . . m,\ j = 1, 2, \dots n\right\}$;
- A set of fuzzy importance weight of each infrastructure aspect called $\widetilde{w}$ =$\{w_1,\ w_2, \dots . w_n\}$ and fuzzy importance weight of each infrastructure criterion with respect to each aspect can be represented as; $w_{jS_j}, j = 1, 2, \dots . n$.

The hierarchy consists of four layers; the first layer is the ultimate goal and the second layer depicts aspects used to attain the goal the third and fourth layer represent the criteria (sub-aspects) and the governance pillars respectively.

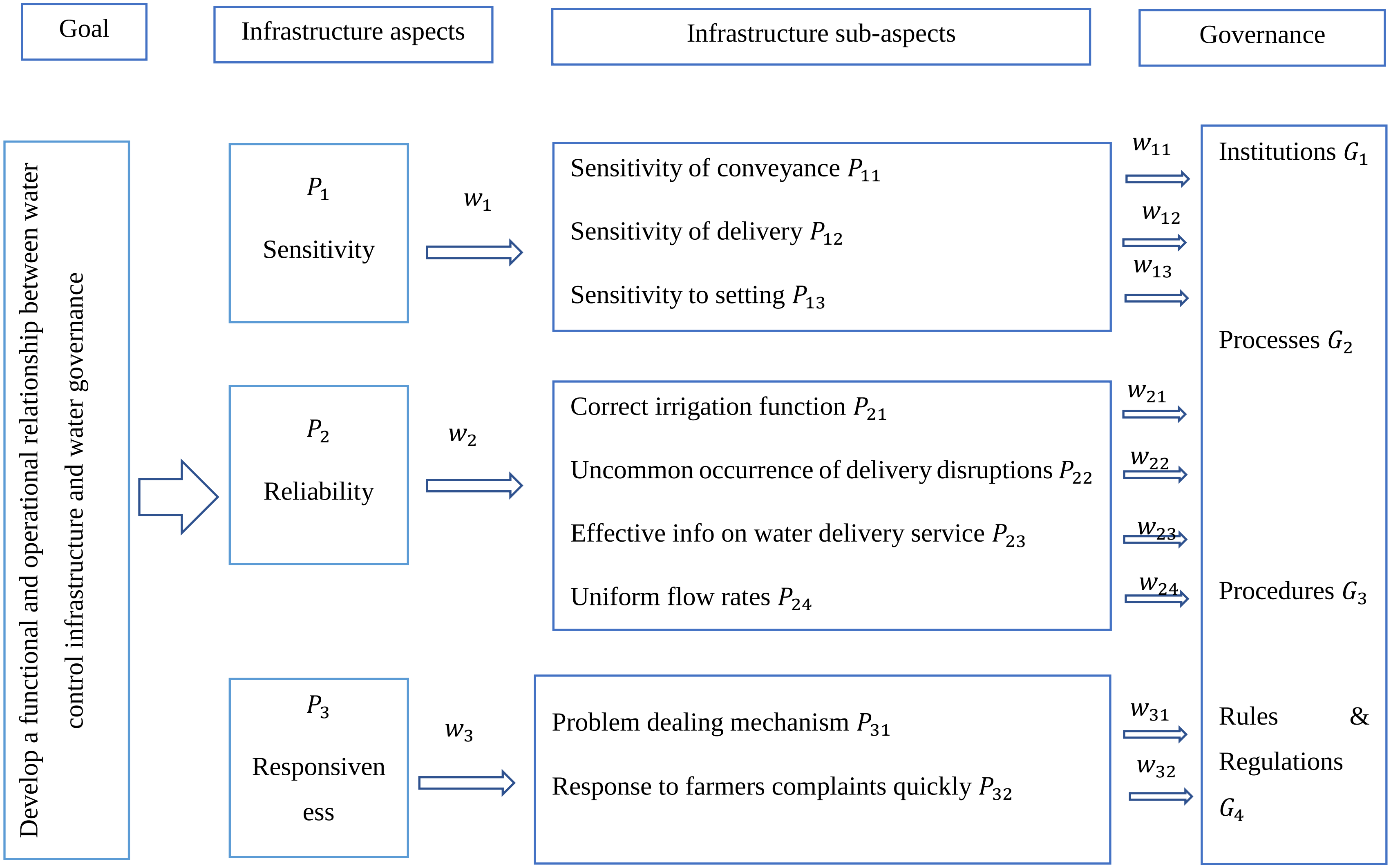


Figure 4.6 Infrastructure-Governance hierarchy (after Lee *et al.*, 2012a)

Kahraman & Kaya (2012) used the intelligence building system with the fuzzy AHP and TOPSIS. The aspect selection was based on five categories shown in **Error! Reference source not found.** below.

Table 4.2 Intelligent building assessment criteria used in the study

Category	Aspects
Engineering	Working efficiency, functionality and responsiveness
Socio-cultural	Functionality and usability
Technological	Work efficiency and intelligent systems

4.4.6 Fuzzy analytical hierarchy process

The orthodox AHP has limitations and tends to be imprecise when dealing with the vague nature of linguistic assessments. According to Erensal *et al.* (2006), triangular fuzzy numbers are used to represent common sense linguistic statements, which are the key premise of pair-wise comparison. In FAHP fuzzy numbers are used for the pairwise comparison and computing the corresponding fuzzy weights (Buckley, 1985; Boender *et al.*, 1989). Various methods deviated from Saaty's Hierarchical Analysis for obtaining weights (Csutora & Buckley, 2001). Van Laarhoven & Pedrycz (1983) applied a logarithmic regression model to compute the fuzzy weight estimates, and this model facilitated multiple estimates that solved the problems of missing data.

4.5 Applying the FAHP for weight determination

Linguistic variables (3) were used to assess the relative importance of the infrastructure aspects. The linguistic variables can be expressed by triangular fuzzy numbers (TFN). Experts were tasked to do a pairwise comparison of the infrastructure aspects using the linguistic variables in Table 2.

Table 4.3 Linguistic variables for fuzzy weights of each decision element (after Wu *et al.*, 2010; Zhou & Lu, 2012)

Intensity of importance (TFN)	TFN Reciprocal numbers	Definition	Explanation
$(1, \tilde{1}, 3)$	$(1, 1, \frac{1}{3})$	Equal importance	Two elements contribute equally to the objective
$(1, \tilde{3}, 5)$	$(\frac{1}{5}, \frac{1}{3}, 1)$	Moderate importance	Experience and judgment slightly favour one element over another
$(3, \tilde{5}, 7)$	$(\frac{1}{7}, \frac{1}{5}, \frac{1}{3})$	Strong Importance	Experience and judgment strongly favour one element over another
$(5, \tilde{7}, 9)$	$(\frac{1}{9}, \frac{1}{7}, \frac{1}{5})$	Very strong importance	One element is favoured very strongly over another, it dominance is demonstrated in practice
$(7, \tilde{9}, 9)$	$(\frac{1}{9}, \frac{1}{9}, \frac{1}{7})$	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values			

For each expert k a fuzzy positive reciprocal matrix is deduced i.e.,

$$\tilde{T}^k = \left[\tilde{t}^k_{ij}\right] \qquad 4.2$$

Where:

$\tilde{T}^k$ = the fuzzy positive reciprocal matrix of expert k,

$\tilde{t}^k_{ij}$ = the relative importance between the i-th decision element and the j-th decision element;

$\tilde{t}_{ij=1}, \vee\, i = j$ and $\left(\tilde{t}^k_{ij}\right)^{-1}, \vee\, i, j = 1, 2, 3 \ldots., n$

Aggregating experts' opinions as shown by Equation 4.3:

$$\widetilde{w}_i = \frac{w_1^k + w_2^k + \cdots + w_i^k}{k} \qquad 4.3$$

Where:

$\widetilde{w}_i$= aggregated fuzzy weight of total number of experts,

w_i^k = fuzzy weight of infrastructure aspect from the k^{th} expert, and

k = Number of experts.

4.6 Fuzzy technique for order preference by similarity to ideal solution

The FTOPSIS method developed by Yoon & Hwang (1995) is a very useful tool in MCDM. FTOPSIS is a practical and useful technique for ranking and selecting a number of possible alternatives by measuring Euclidean distances. The underlying logic of this technique is there are two solutions: the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). The PIS should be increased and NIS are those which need to be decreased so that farmers get the most out of the irrigation service utility (Benitez *et al*., 2007). The FTOPSIS is an extension of the TOPSIS method as used in fuzzy environments (Chen, 2000; Chen *et al.*, 2006; Yong, 2006), and this deals with the inherent vagueness and of the decision makers data. The resultant Euclidean distances are not to be weighed (Deng *et al*., 2000). The goal of this technique is to determine PIS and the NIS, and then find the closeness coefficient CC_i. Linguistic variables are used to define the aspects as shown in Table 4.4. The best performing governance aspect should have the shortest distance from the PIS and the farthest distance from the NIS. In order to determine the distances Euclidean distances, for each governance constituent are computed.

Table 4.4 Linguistic variables for FTOPSIS

Linguistic Variable	TFN
Very Poor	(1, 1, 3)
Poor	(1, 3, 5)
Fair	(3, 5, 7)
Good	(5, 7, 9)
Very Good	(7, 9, 9)

4.6.1 Using the FTOPSIS method to rank governance aspects

This method was employed after the fuzzy weights of the infrastructure aspects were computed. The FTOPSIS would then compute the closeness coefficients (CC_i) for each governance aspect. The step by step method for calculating the CC_i is listed below.

Step1: The experts' opinions are integrated, the fuzzy ratings of the k evaluators is aggregated by equation 4.3. Hence, the original fuzzy rating $\tilde{x}_{ijp}$ of governance aspect G_i with respect to the pth criterion under the jth aspect is calculated as:

$$\tilde{x}_{ijp} = \left(a_{ijp}, b_{ijp}, c_{ijp}\right) \qquad 4.3$$

where:

$$a_{ijp} = min_k\{\tilde{x}^k_{ijp}\}, \; b_{\;ijp} = \frac{1}{k}\sum_{k=1}^{k}\tilde{x}^k_{ijp}, \qquad c_{ijp} = max_k\{\tilde{x}^k_{ijp}\}$$

Step 2: Aggregate the experts' fuzzy ratings $\tilde{x}_{ij}$ $(i = 1,\ 2, .., m,\ j = 1,\ 2m, \dots, n)$ of Governance aspects G_i $(i = 1,\ 2,\ 3,\ 4)$ under aspects P_j $(1,\ 2,\ 3)$ and employ equation 4.4.

$$\tilde{x}_{ij} = \frac{1}{S_j}\left(\sum_{p=1}^{S_j}\tilde{x}_{ijp} * \tilde{w}_{jp}\right) \qquad 4.4$$

Where:

$\tilde{w}_{jp}$ = the fuzzy importance weight of criteria p in aspect j, and

S_j = the number of criteria in aspect j.

The MCDM model can be represented as an aggregated matrix as shown in equation 5.

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} = [\tilde{x}_{ij}]_{m*n} \qquad 4.5$$

Where:

$\tilde{x}_{ij}$ $(i = 1, \dots, m; j = 1, \dots, n)$ is the fuzzy ratings of the Governance aspects G_i $(i = 1,\ 2,\ 3,\ 4)$ with respect to aspects C_j $(j = 1, \dots., n)$

The weight vector $\tilde{w}$ of aspects C_j $(j = 1, \dots, n)$ is given by equation 4.6

$$\tilde{w} = \{\tilde{w}_1, \tilde{w}_2, \dots.., \tilde{w}_n\}, \text{ i.e., } \tilde{w}_j \; (j = 1, \dots, n) \qquad 4.6$$

Step 3: After obtaining $\tilde{X} = [\tilde{x}_{ij}]_{m*n}$ determine the FPIS (A^+) and FNIS (A^-) then the CC_i. The elements v_{ij} are normalized positive fuzzy numbers and their ranges belong to the closed interval [0, 1]. Thus, the fuzzy positive ideal solution (FPIS A^+) and the fuzzy negative ideal solution (FNIS, A^-) can be defined as: $v_j = (1, 1, 1)$, $v_j = (0, 0, 0)$, $j = 1, 2, 3 \dots \dots .., n$.

Where:

$$A^+ = \{v_1^*, v_2^*, \dots .., v_n^*\} \text{ maximum values} \qquad 4.7$$

$$A^- = \{v_1^-, v_2^-, \dots .., v_n^-\} \text{ minimum values} \qquad 4.8$$

The distances of each governance aspect from FPIS and FNIS is calculated as follows:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \ , j = 1, 2, \dots .., J \qquad 4.9$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \ , i = 1, 2, \dots .., J \qquad 4.10$$

Where:

v_j^+ are the positive maximum values

v_j^- are the minimum values

The closeness coefficient (CC_i) is then computed as follows:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \qquad 11$$

The CC_i has values ranging from 0 to 1 (0 not inclusive). The higher the CC_i the better performing the aspect is with respect to infrastructure characteristics and requirements.

4.7 Results and Discussion

The experts' aggregated matrices for weights are given in Table 4.5 and Table 4.6. The respective tables show how the fuzzy weights for infrastructure attributes performed against one another. The infrastructure aspects were compared with respect to the modal fuzzy weight (see definitions). The results of the geometric mean method used to compute the aggregated fuzzy weights for the decision makers from the respective irrigation schemes show that reliability ranks high in TFIS whereas responsiveness takes priority in MRIS. Sensitivity for both schemes ranked low, with the lowest in TFIS. The uniform flow rate ranked high on the priority of the evaluators (Appendix I) however, the occurrence of delivery disruptions had the least effect in the opinion of the evaluators. Mechanism for dealing with problems (Appendix I) took priority for the MRIS whilst response to farmers' complaints ranked high in TFIS (see Appendix I).

The sensitivity aspects allow one to understand the operation characteristics of the hydraulic structures. By comparison, the sensitivity weight for TFIS was higher than that for MRIS. The infrastructure at MRIS is mostly gated hence precision is needed in its operation to avoid discharge deviations at block level. Downstream farmers tend to suffer the most deviations between the targeted and the actual delivered discharge (Renault & Hemakumara, 1997). The finding concurs with Shahrokhnia et al. (2009) who argued that poor water equity is attributed to inaccurate and lack of understanding of the water control infrastructure. Renault (2000b) also argued that optimal operational measures stem from the water managers' adequate understanding of water control infrastructure.

The sensitivity to delivery weights are similar for both schemes because, according to the experts, the distributary canal that feeds the tertiary unit plays an important role in the scheme as irrigators can easily manipulate it. Irrigators use artificial regulators, e.g., piling trash and stones to increase head in the distribution canal (Renault & Hemakumara, 1997). Consequently, less water will be available in the main canal (conveyance). Shahrokhnia et al. (2009) also pointed to the artificial regulators constructed along the distribution canal to gain head, so farmers ultimately are concerned with delivery than they are with conveyance in the main canal.

By taking the modal value, the Eigen vectors for the reliability aspect under MRIS and TFIS show that farmers value uniform flow rate and a correct irrigation function. Uniform flow rate follows a correct irrigation function. The manner in which hydraulic structures are operated facilitate a proper flow rate and subsequently improved water access. Dejen (2015) argued that a lack of good understanding of the canal system and of adequate understating of the operation leads to a compromised performance.

Table 4.5 Aggregated decision matrix for Mooi River Irrigation Scheme evaluators

	Sensitivity	Reliability	Responsiveness
Sensitivity	0.00, 0.24, 0.30	0.31, 0.36, 0.59	0.14, 0.16, 0.46
Reliability	0.26, 0.28, 0.37	0.00, 0.45, 0.52	0.46, 0.50, 0.54
Responsiveness	0.44, 0.48, 0.63	0.16, 0.18, 0.42	0.00, 0.40, 0.40

Table 4.6 Aggregated decision matrix for Tugela Ferry Irrigation Scheme evaluators

	Sensitivity	Reliability	Responsiveness
Sensitivity	0.00, 0.28, 0.34	0.26, 0.31, 0.59	0.19, 0.20, 0.23
Reliability	0.29, 0.31, 0.42	0.00, 0.59, 0.61	0.60,0.66, 0.78
Responsiveness	0.37, 0.41, 0.57	0.13, 0.16, 0.41	0.00, 0.14, 0.21

4.7.1 Euclidean distances

This section presents the FPIS and the FNIS. The elements v_{ij} are normalized positive fuzzy numbers and their ranges belong to the closed interval [0, 1]. Thus, the fuzzy positive ideal solution (FPIS, A^*) and the fuzzy negative ideal solution (FNIS, A^-) can be defined as: $v_j = (1, 1, 1)$, $v_j = (0, 0, 0)$, respectively $j = 1, 2, 3 \dots \dots .., n$. Table 4.7 and Table 4.8 show the relative closeness of each governance aspect to the ideal solution. Rules and regulations ranked higher in MRIS followed by processes, procedures and then institutions, based on the Closeness Coefficients (CC_i). In the case of TFIS institutions and processes ranked higher followed by procedures, rules and regulations. The ranking was according to CC_i.

Table 4.7 Relative closeness for TFIS

	d^*	d^-	d^*+d^-	CC_i
Institutions	2.49	0.54	3.03	0.18
Processes	2.56	0.53	3.09	0.18
Procedures	2.61	0.52	3.13	0.17
Rules & Regulations	2.66	0.44	3.10	0.14

Table 4.8 Relative closeness for MRIS

	d^*	d^-	d^*+d^-	CC_i
Institutions	2.68	0.42	3.09	0.13
Processes	2.56	0.52	3.08	0.17
Procedures	2.53	0.48	3.01	0.16
Rules& Regulations	2.43	0.59	3.02	0.20

4.7.2 Managerial implications

The ranking in TFIS based on CC_i followed the order: Institutions, Processes, Procedures, Rules and regulations. The institution here are the Department of Agriculture Forestry and Fisheries (DAFF), Department of Water and Sanitation, Department of Rural Development and Land Reform (DRDLR), Water Users Associations (WUAs) and Irrigation Management Committees (IMCs) at irrigation scheme level. The government departments are actively involved in irrigation scheme rehabilitation and water appropriation at provincial and district level. The WUAs, which comprise of selected farmer committees, are the established institutions at farm level. WUAs are involved in enforcing rules, setting up operational and maintenance procedures.

Institutions

Institutions have been defined as "complexes of norms and behaviours that persist over time by serving collectively valued purposes"(Uphoff *et al.*, 1991). In TFIS, high levels of institutional involvement at scheme level and at farm level exist. Systems in place facilitate uniform flow rates, effective information dissemination, avoiding delivery disruptions (reliability). On the contrary, MRIS institutions ranked low amongst the governance aspects. This showed that despite massive institutional investments in water conveyance and distribution structures, the institutional arrangements and organisation was low. Improper institutional arrangements have a bearing on water allocation and subsequently on water availability. The institutional arrangements in MRIS are as follows: the DAFF, which vests powers to scheme organisations (WUAs and tribal authorities). The poor institutional mechanism for harmonising the players tend to lead to unaccountability in infrastructure O&M. This consequently leads to a poor performing scheme with deteriorating infrastructure.

Taylor (2002) also observed that poor institutional mechanisms that harmonise the active players in the irrigation scheme leads to a domino effect were there is lack of maintenance of water control infrastructure and subsequently poor conveyance and water scarcity. This finding also concurs with Afrasiabikia *et al*. (2017) who argued that institutional investments are countered by the traditional operation of the water control structures- thus there is zero regard of scientific modes of operation e.g. factoring issues to do with sensitivity in canal reaches. Water shortages have been cited in MRIS and the scheme is currently undergoing rehabilitation. The low level of organization can be attributed to the failure of agencies to break down and simplify the levels of operation. Creating low levels of operation harmonises the various levels of management by the organization (Yang *et al.* (2003). Many activities are handled informally in the scheme, which could be another reason as to why institutions are ranking low in Mooi-River Irrigation Scheme. However, the case be it formally or informally there is some degree of organization at each level (farm level, sub-farm level and village level).

Procedures

The procedures extend to selection of operational methods and this translates to the processes, as discussed. From the findings, the level of interaction of procedures and infrastructure are low, and this is attributed to complex operation methods and the misunderstanding of the consequences involved in setting out or adopting a selected operation method. Ankum (1996) stated that the role of institutions is to systematically plan and select operational procedures that lead to identifying how water control infrastructure is operated, maintained and how water is distributed through the main irrigation canal.

The set-out protocols for on-demand water delivery must be responsive, and the relative responsiveness at the Tugela Ferry Irrigation Scheme is low comparing to sensitivity and reliability. Sensitive points within an irrigation canal are points were water flow regimes frequently deviate from the normal flow, and having key knowledge of these points allows targeted actions for frequent inspection and operational decisions than others. Procedures in place for both schemes ranked third meaning low farmer participation in operation and maintenance (O&M) programs. An ongoing O&M exercise improves on canal sensitivity and system operability. The findings in this study resonate with Renault (2000a) who argued that the lack of procedural systems that monitor the irrigation schemes status for enhanced infrastructure operations and maintenance contribute to poor understanding of the water control infrastructure.

Upon construction and installation, the water control infrastructure has its operational requirement, however; it is poorly assimilated by the irrigators. This resonates with study by Horst (1998) and North (1995) cited by Denby et al. (2017) who argued that there exists a margin between design assumptions and operational realities where by designers stipulate operational procedures for improved irrigation functions whilst the irrigators "naturally" shift back to adopted traditional norms and knowledge. The procedures involved herewith also include information gathering by water users. The information is essential in formulating smart information systems that facilitate easy canal operation and management. The gated systems in MRIS present a challenge, as they require day-to-day operation; hence, the low ranking for both MRIS and TFIS can also be attributed to lack of procedures for participation and farmers coordination.

Processes

The $d_i^* = 0.90$ and $d_i^* = 0.93$ for MRIS and TFIS under sensitivity respectively, (Table 4.9 and Table 4.10) indicate that the constituents of process e.g. WUAs and IMCs support were adequately capacitated. Regulator and sluice gate operation has a bearing on head changes and flow rates along the main conveyance canal, thus the high d_i^* value showed a proper design process regarding precision in gate and regulator handling to maintain uniform flow rates and avoid flow perturbations. A study by Ertsen (2010) argued as follows: irrigation as an agricultural practice should be formulated around resilient water governance processes that adequately understand flow manipulation in short periods of times rather than managing volumes. The high d_i^* also entails a high understanding by the water managers at scheme and farm levels of the complex water conveyance and distribution system. According to Renault & Hemakumara (1999) such high level of optimal canal operation are attributed to water governance processes that ensure accurate information and precision in the definition of targets with respect to the setting of structures. Another crucial advantage that aids the governance processes is the existence of fixed structures that require minimal on no human operation.

The d_i^* value for TFIS (0.85) (see Table 4.9) ranked higher than that of MRIS (0.80) (see Table 4.10) under reliability. This brings into question the effectiveness of the Processes constituent: Irrigation scheduling and water distribution plan. From descriptive 8% of TFIS irrigators were not satisfied with the irrigation schedule where 52% in MRIS were dissatisfied with the irrigation schedule. This meant that there was common occurrence in delivery disruptions; there was also ineffective information on water delivery service. On demand water delivery is based on understanding flow variations during seasons and adaptive management techniques have to be adopted. In MRIS, the process of diverting water flows from a river to the canals is relatively ineffective compared to that in Tugela Ferry. Ertsen & van der Spek (2009) also attributed the varying water distribution to the hydraulic behaviours for canal and gated structures under different management styles.

The responsive attribute show had a value of 0.77 for TFIS, typically lower than that of MRIS (0.86). The rate of responsiveness to farmers' complaints and the problem dealing mechanism was low because of the lack of resources such as availability of water bailiffs and lack of properly structured tariffs. Water payments varied across the scheme. Renault & Hemakumara (1999) cited that for manually operated schemes, the biggest resource inputs are transportation and man-power and both require financial resource from the water levies. Government and other related agencies ought to provide manpower in the form of water bailiffs.

Rules and Regulations

The schemes have a set of modulated rules for canal operation. These rules facilitate the achievement of performance no matter how low the water levels are. The relative closeness to the

ideal solution for the respective irrigation differs by a huge margin. Whilst the MRIS exhibits to almost ideal, TFIS is the opposite. For a value of 0.975 in MRIS there is 0.578 in TFIS (see Table 4.9 and
Table 4.10 respectively), this means that there is adherence to operational rules and regulatory procedures involved in monitoring sensitive points within the parent canal for MRIS. The water managers are better equipped with knowledge of where perturbations occur along the parent canal and they have proper regulatory measures that facilitate the readjustment to prevent deviation to the command area

Table 4.9 Governance-Infrastructure aspects and the Euclidean distances for TFIS

	Institutions d^*	Processes d^*	Procedures d^*	Rules & Regulations d^*
Sensitivity	0.93	0.93	0.91	0.92
Reliability	0.76	0.85	0.81	0.85
Responsiveness	0.80	0.77	0.76	0.89

Table 4.10 Governance-Infrastructure aspects and the Euclidean distances for MRIS

	Institutions d^*	Processes d^*	Procedures d^*	Rules & Regulations d^*
Sensitivity	0.91	0.90	0.87	0.85
Reliability	0.88	0.80	0.83	0.79
Responsiveness	0.89	0.86	0.83	0.79

Blocks 1, 2 and 3 in TFIS still use canals, and farmers at the tertiary units tend to block regulators with trash just so to increase upstream water levels (Shahrokhnia *et al.*, 2009). Operational rules determine functionality and operational consequence. Poor set of operational rules result in high sensitivity i.e. flow deviations, which subsequently leads to poor hydraulic performance. The study revealed that MRIS has a set of practical rules that govern water capture, conveyance and delivery at the three levels of conveyance, which are parent/main canal, secondary distribution canal and the tertiary canal. The sanction-based approaches for enforcement seem to work well for MRIS whereas compliance based approaches in TFIS are a cause for low adherence to stipulated rules for the scheme.

4.8 Conclusion

The FAHP and FTOPSIS model used in this study sought to establish a link between infrastructure aspect and water governance in smallholder irrigation schemes. The study determined most important criteria using weight determination for the infrastructure aspects and its criteria. The study showed that three out of four governance constituents were in harmony with infrastructure characteristics and requirements. The FTOPSIS method utilizes the Euclidean distance measurement to determine the distance of each governance constituent with respect to infrastructure aspects and criteria from the ideal solution. The distance is closed within [0, 1] interval with the fuzzy distance of (1, 1, 1) being ideal. Therefore, the study concluded that TFIS had better institutional arrangements than MRIS. It was also found out that MRIS had better enforcement approaches of rules and regulations.

The overall rankings with respect to closeness coefficients CC_i, in descending order, showed that institutions, processes, procedures, rules and regulations for TFIS whilst the overall ranking in descending order at Mooi-River Irrigation Scheme was rules and regulations, processes, procedures, institutions. This has differing managerial implications. The processes involved in achieving a correct irrigation function for TFIS rank high because of infrastructure upgrades. The infrastructure upgrade from canal system to piped network requires less handling thus, the human dimension is minimised. Institutional setup in MRIS are weak, i.e., the multi-stakeholders at multi-levels need to engage to aid in improved irrigation performance. The farmers in MRIS follow rules, but informal rules are predominant in the scheme. TFIS has a strong institutional setup as they enjoy positive and active stakeholder engagement. This consequently leads to enhanced processes that lead to dependable and reliable water supply.

Adaptive management is key in ensuring that the level of technology is at par with the water governance framework in a place, particularly by the water managers. Poor management fails to reconcile the relationship between hydraulic infrastructure and its intended function of providing equitable water supply efficiently. The lack of harmony between stakeholders (WUAs, government, traditional leaders) is not the only reason for varying governance performance in the schemes. Omission by policy makers to consult and engage the grassroots often leads to non-commitment by stakeholders to the developed policies.

4.9 Recommendations

The results showed rules and regulation were lacking in TFIS. It is recommended that irrigation water users and their institutions focus more time and resources in ensuring compliance. The processes required for attaining a correct irrigation function were close to the desired levels. The study findings can be used for equipping water managers and policy makers at various levels to address the shortcomings in SIS governance for enhanced irrigation system and scheme performance. In future studies other MCDM methods like ELECTRE, or PROMETHUS can be used to establish a functional relationship between irrigation infrastructure and irrigation water governance.

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5 EVALUATION OF WATER GOVERNANCE IMPACTS ON WATER ADEQUACY IN SELECTED SMALLHOLDER IRRIGATION SCHEMES IN KWAZULU-NATAL, SOUTH AFRICA

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Abstract

Water adequacy is central to maximized agricultural production in irrigation schemes. Smallholder irrigation schemes (SISs) are designed to distribute water efficiently, adequately and equitably. Water governance defined as the institutions, processes, procedures, rules and regulations involved in water management plays an important role in water allocation and subsequently water adequacy. Poor crop production and consequently poverty in Smallholder Irrigation Schemes (SIS) can be partly attributed to water inadequacy of. This research aimed at investigating the impacts water governance had on adequacy of water in irrigation schemes and it was premised on the hypothesis that governance had no effect on water adequacy. Water adequacy describes water supply relative to demand. Adequacy indicates whether the water delivery system supplies the demand to a section in the irrigation scheme over a period of time (daily, monthly or seasonally). Two irrigation schemes, Mooi River (MRIS) and Tugela Ferry Irrigation Schemes (TFIS) were used as case studies. A descriptive analysis showed that 86% of the farmers in TFIS had adequate water, whereas 24% in MRIS had water adequacy. A Binary Logit model was employed to investigate the factors that influence water adequacy among irrigators. The regression model identified eight statistically significant factors that influenced water adequacy, and these were irrigation scheme, location of plot within the scheme, training in water management, training in irrigation, irrigators' knowledge about the government's aims in SISs, availability of water licenses, payment of water fees and satisfaction with the irrigation schedule. The study concluded that governance factors influenced water adequacy in the selected SISs. The study recommended that the schemes put procedures and protocols in place to support and aid irrigators to enhance scheme governance.

Keywords: Binary Logit, Governance, Hypothesis, Regression, Water adequacy

5.1 Introduction

Agricultural water withdrawals account for 72% of the global surface and groundwater, and the abstraction is about 90% in developing countries (Wisser *et al.*, 2008). Erratic rainfalls occur in South Africa affect crop production, and irrigation is the best alternative to augment the water deficit (Van Averbeke et al., 2011). Developing countries have invested heavily in irrigation infrastructure as a means to mitigate rural poverty. Such investments coupled with improved crop production technologies and fertiliser application processes, plant breeding has contributed to countries attaining food security (Gorantiwar & Smout, 2005). An irrigation system is a physical water delivery network comprising of subsystems that supply water to land by means of artificial canals and ditches, and the system also has a socio-economic dimension that operates and derive benefits from the infrastructure. Hence, it is set to attain farm level agricultural production goals such as maximizing net economic and social welfare benefits (Molden & Gates, 1990). Performance indicators to evaluate irrigation service utility need to be coupled with an assessment of the social aspects in the Smallholder Irrigation Schemes (SISs).

Despite massive investments, the performance of SISs has remained below expectations (Shah *et al.*, 2002a; Van Averbeke *et al.*, 2011; Sinyolo *et al.*, 2014; van Koppen *et al.*, 2018). Indicators (both static and dynamic) such as institutional framework, water resource use, irrigation area, irrigation technology, agricultural productivity, and poverty and food security have been used to assess the performance of SISs and are centered on water adequacy criterion (Svendsen et al., 2009). Water adequacy is the capacity of a supply source to meet the demand for multi- purposes such as irrigation and domestic uses (Frederick, 2013). According to Mehta *et al*. (2017) adequacy can be defined as the availability of water for food, energy, domestic supply and irrigation. Water adequacy is dependent on the dynamic parameters such as water resource use and institutional frameworks, and both technical/physical and socio-economic factors (institutional, gender, age).

Irrigation scheme performance is judged by the adequacy characteristic. Adequate supply and good governance will yield the desired irrigation scheme goals (Abernethy, 1990). Water adequacy entails delivery of the required amount of water at the right time and is a function of the condition of the hydraulic infrastructure and the governance structures in place (Figure 5.1). The human dimension encompasses design of delivery schedules, operation and maintenance of water control infrastructure (Molden & Gates, 1990; Horst, 1998). Water Users Associations (WUAs) distribute and manage water resource to improve on adequacy and equity (Kuşçu et al., 2008).

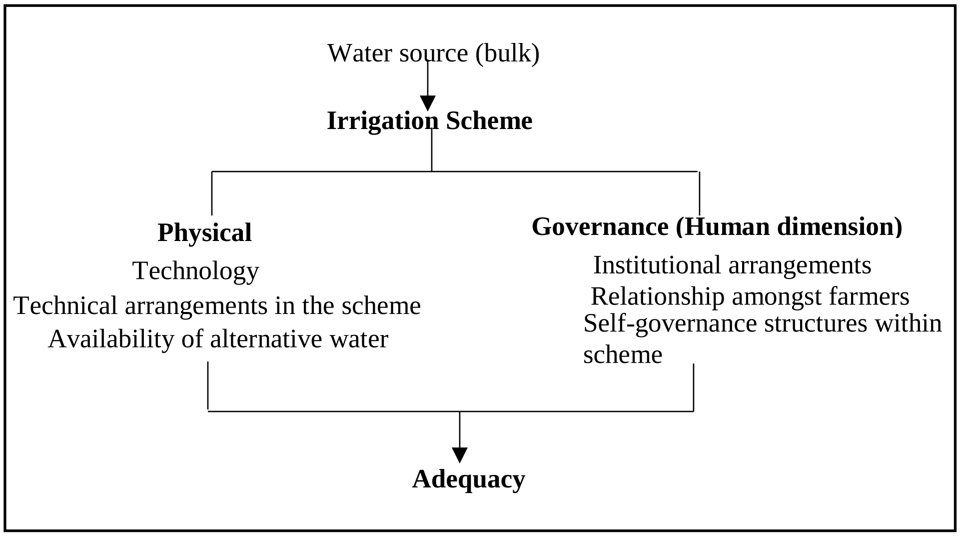

Figure 5.1 Relationship between physical and governance attributes that influence water adequacy (adopted from Taylor, 2002)

Various studies have been undertaken that investigate farmer perception of water security and water use efficiency (Gomo *et al.*, 2014; Sharaunga & Mudhara, 2016; Alcon *et al.*, 2017). However, not much investigation has been done on assessing the impacts of water governance on water adequacy .The management of Common Pool Resources (CPRs) such as availing adequate canal irrigation water and the maintenance of hydraulic infrastructure are key to improved crop production and poverty alleviation. However, SISs still remain poverty nodes despite the potential benefits of irrigation water and the conveyance system (Van Averbeke et al., 2011). This study investigated infrastructural and socio-economic factors that influenced water adequacy for the irrigators in MRIS and TFIS. The objective of the study was to assess the influence of water governance on adequacy of water for crop production.

5.2 Model Specification

There is not much literature on the use of empirical models in trying to investigate governance issues that influence water adequacy. Speelman *et al.* (2008) applied a Tobit regression model from data generated by the Data Envelopment Analysis (DEA) to investigate water use efficiency in smallholder irrigation schemes in North-West Province, South Africa. Various statistical tools allow data processing and the most common are the generalized linear models and the Logit and Probit models (Cakmakyapan & Goktas, 2013). Both Logit and Probit can be used to investigate the influence of governance on adequacy because the dependent variable is a binary variable. Careful consideration has to be taken in order to select the best performing model between the two. Supporting literature used the logit as it is stable for a large population size (Amemiya, 1981; Maddala, 1986; Cakmakyapan & Goktas, 2013; Sharaunga & Mudhara, 2016). According to Gomo *et al.* (2014) and Damisa *et al*. (2008) the advantages of using the Logit model are its ease to compute and interpret than the Probit models, it eliminates heteroskedasticity, i.e., the probability does not increase linearly with a unit change in the value of the independent variable and the computation of the logistic distribution guarantees the rate of the probabilities to always lie between the interval 0 and 1.

5.3 Materials and Methods

This section contains the study site description, data collection and analysis methods.

5.3.1 Study site

The study was carried out in Mooi-River Irrigation Scheme (MRIS) and Tugela Ferry Irrigation Schemes (TFIS). The two irrigation schemes are located in the Msinga District of KwaZulu-Natal, South Africa. The map (Figure 5.2) shows the location of the two irrigation schemes

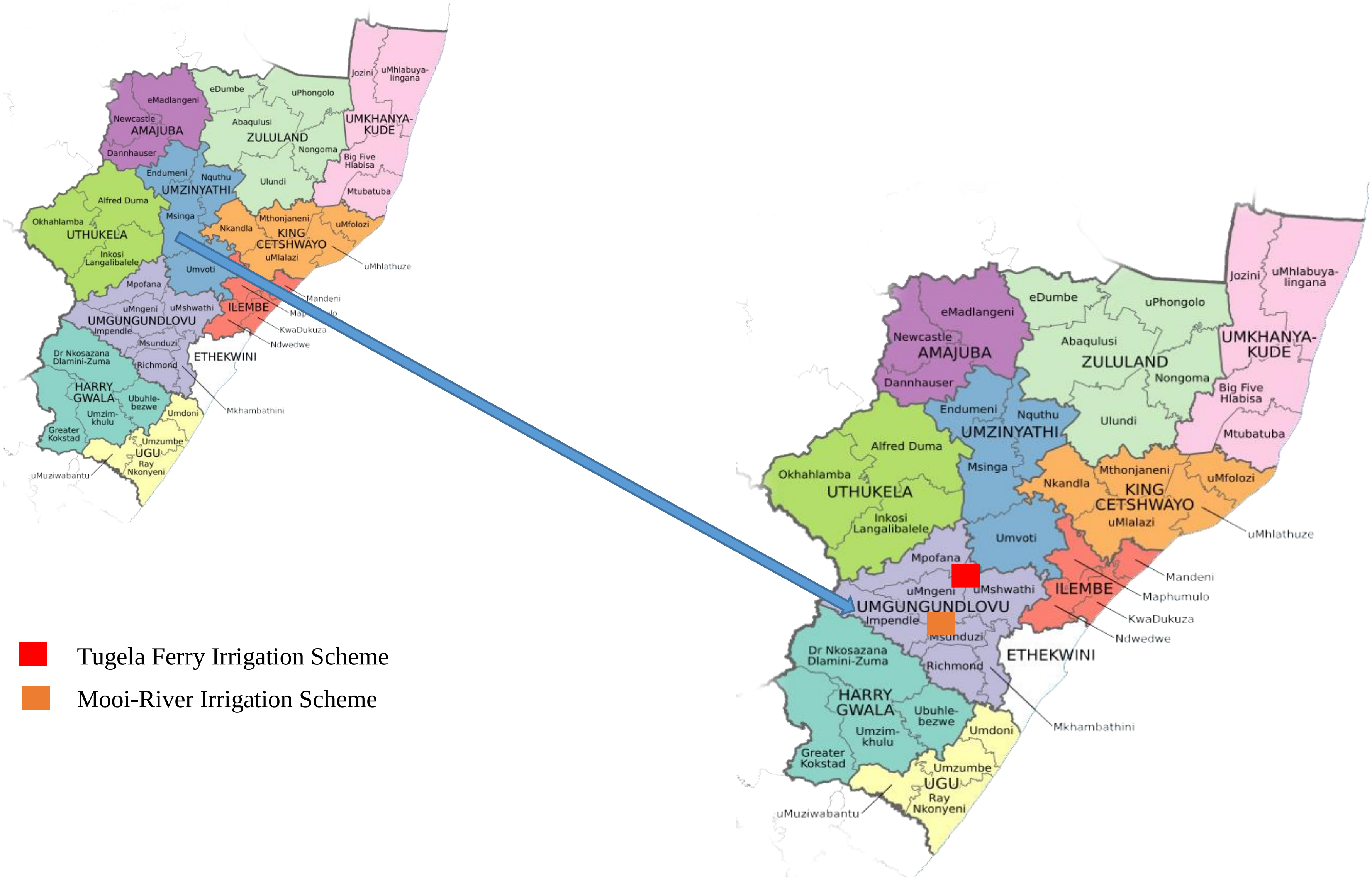

Figure 5.2 Location of study sites within KwaZulu-Natal

5.3.1.1 Mooi-River Irrigation Scheme (MRIS)

The scheme is located along the floodplains of the Mooi-River in Midlands region in KwaZulu-Natal province (Gomo, 2012). The scheme accommodates 842 farmers over 600 hectares of land. Land units are 0.1 ha in size but farmers tend to have more than one plot (Sharaunga & Mudhara, 2016). For ease of management and water distribution the scheme is divided into 15 blocks and each block has its own water management and allocation committee (Gomo, 2012). The upper section has Blocks 1-5, the mid-section has Blocks 6 – 11 and the tail section comprises of irrigators in Blocks 12 – 15 (Muchara *et al.,* 2014).

Water is diverted from a weir constructed across the Mooi-River into a parabolic canal, which runs for 20.8 km from the diversion point to the end of the scheme (DAEA, 2001). The concrete lined canal with a top width of 2.0 m and a depth of 1 m is designed to convey approximately 0.36 m^3s^{-1} (DAEA, 2001). The canal either feeds directly into the field or into night-storage/balancing dams. Distribution canals are used to convey water from the balancing dams to the fields as per the irrigation schedule. A diesel pump is used by tail-end user to abstract water from the Mooi-River to the canal. The diesel pump augments the irrigation canal water (Muchara *et al.,* 2014).

The scheme (see Figure 5.3) is said to have been constructed by the South African National Army in the early 20th century as a goodwill gesture to the locals. Initially the scheme had earthen lined canals which were later upgraded to concrete-lining (Gomo, 2012).

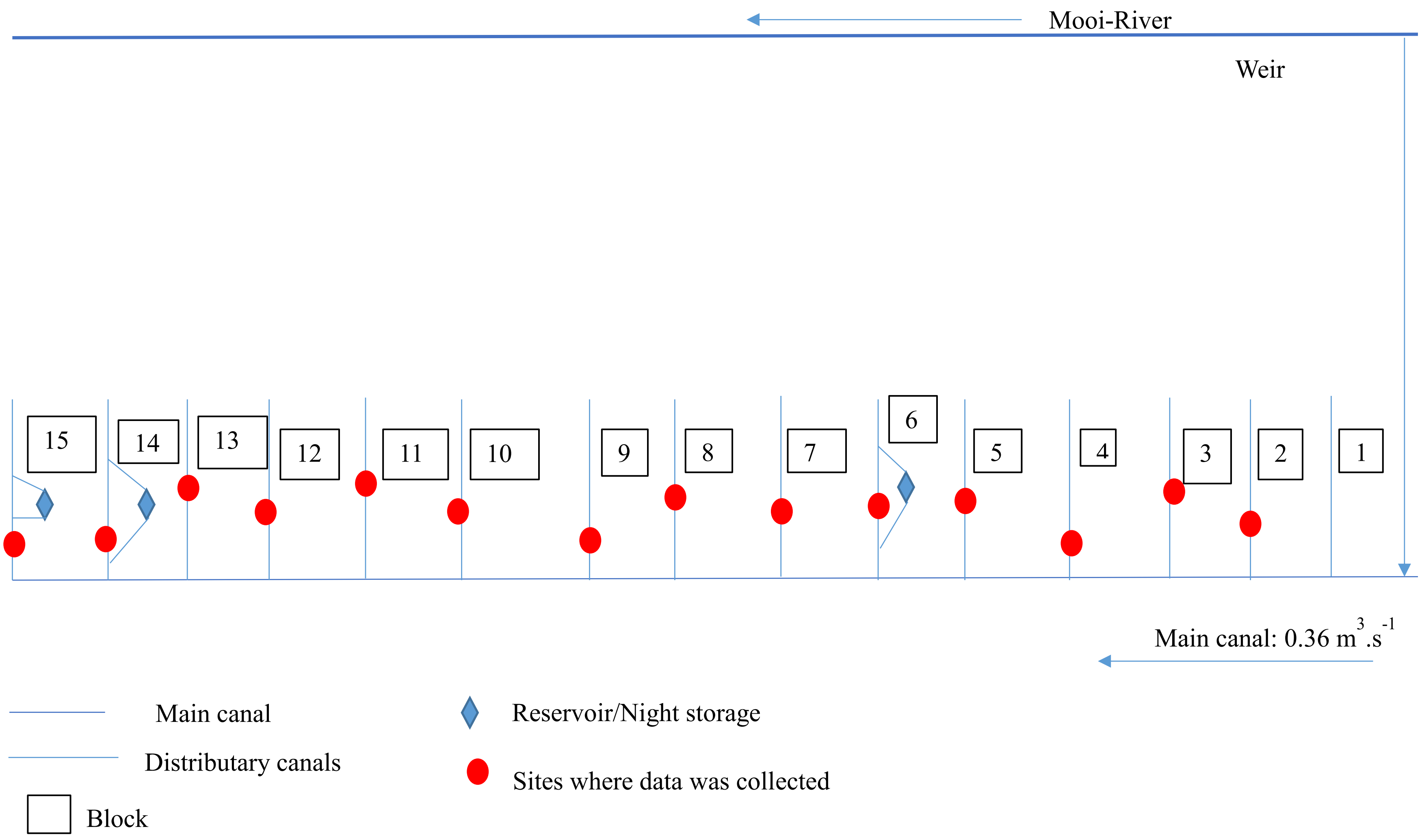

Figure 5.3 Schematic of Mooi-River Irrigation Scheme lay out

5.3.1.2 Tugela Ferry Irrigation Scheme (TFIS)

The scheme is located on both banks of the Thukela River near Tugela Ferry town, in the Msinga Local Municipality. The approximate co-ordinates of the scheme entrance are: S 28° 45” 46.5’ E 30° 26” 33.2’ (Mnkeni *et al.*, 2010; UWP_Consulting, 2012). With a land area of 800 hectares, an estimated area of 500 hectares is cultivated by approximately 1500 producers (Cousins, 2012; Sharaunga & Mudhara, 2016).

Blocks 1 – 3 are on the right bank of the Thukela River (Figure 5.4). The scheme abstracts water from the Thukela River at a weir approximately 4 km upstream of Block 1. Water is transported under gravity to the scheme through a parabolic canal pipeline to Block 1. Block 1 is the first block to receive water from the main canal. The main canal at this point is 2.1 m across the top and has a capacity of 0.4 $m^3.s^{-1}$ (UWP_Consulting, 2012).

Block 4 is on the right bank of the Thukela River downstream of Block 3. It is separated from Block 3 by a headland that protrudes towards the river. Due to failure of the connecting pipeline between Block 3 and Block 4, it is no longer connected to the main canal supply. The installed pump station provides water for irrigation; the water is pumped into a night storage dam where it is conveyed to the fields through existing concrete lined canals. The canal section is an estimated 1.1 m across the top and the average carrying capacity is 0.1 $m^3.s^{-1}$and reduced to 0.014 $m^3.s^{-1}$ towards the tail end.

Block 5 lies on the left bank of the river and water supply is from the main canal via an inverted siphon across the Thukela River. Block 6 is not functional due to tribal politics. Block 7 has two divisions namely Block 7A and Block 7B. The block has been cut off from the main supply canal due to the failure of the Sampofu River aqueduct and the siphons through the town of Tugela Ferry. Both blocks are supplied by an electricity powered pump (UWP_Consulting, 2012).

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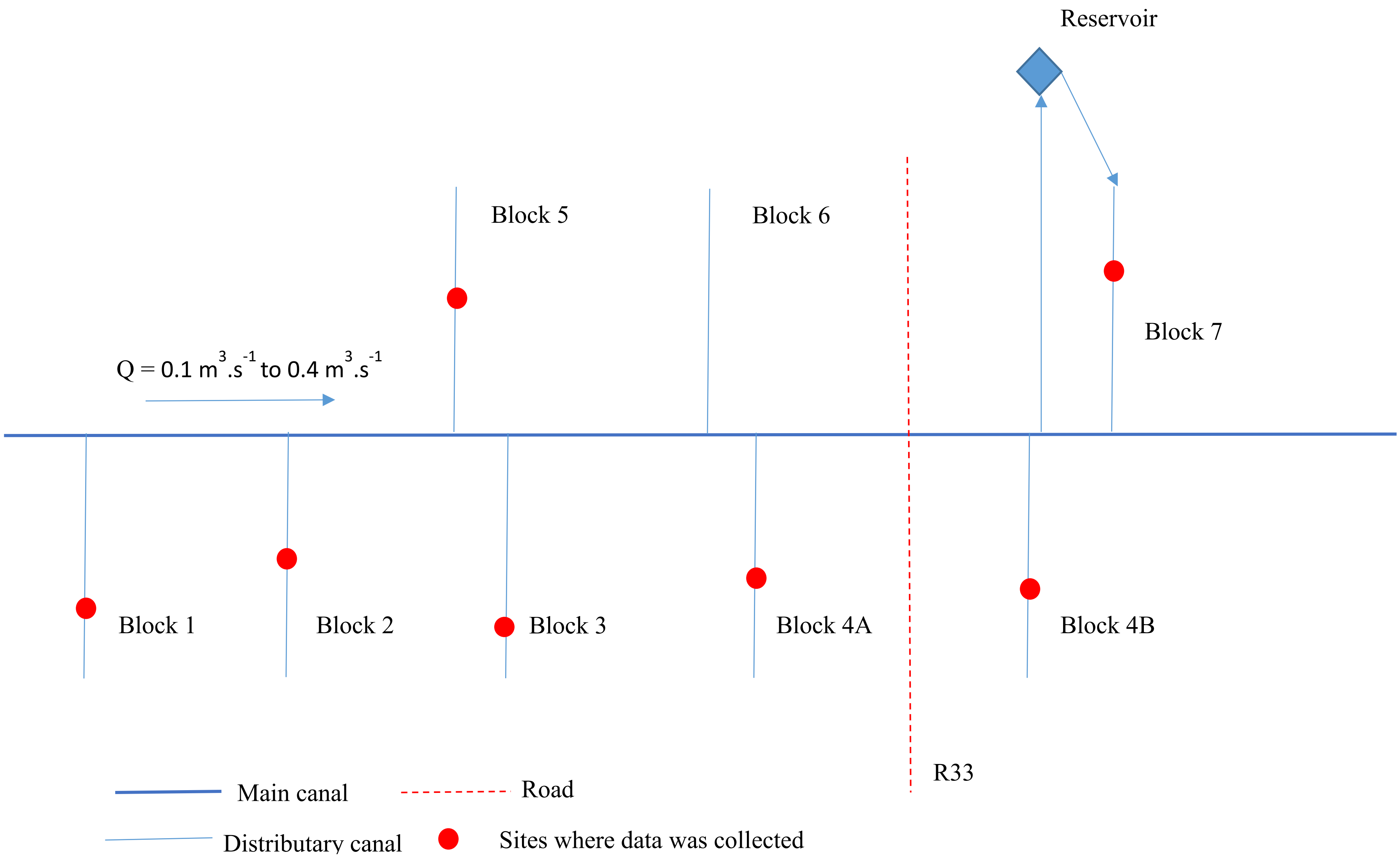


Figure 5.4 Schematic of Tugela Ferry Irrigation Scheme lay out

5.4 **Data collection**

Data was collected from the two irrigation schemes (TFIS and MRIS). Table 5.1 shows the detailed stratification of the irrigation schemes.

Table 5.1 Stratification of TFIS and MRIS

		Irrigation scheme			
		MRIS		TFIS	
Stratum	Water availability	Blocks	SP	Blocks	SP
Head section	Always available	1 - 4	40	1-3	37
Mid-section	Intermittently available	5 -11	52	5 & 4A	52
Tail- section	Limited availability	12 - 15	28	4B & 7	31

*SP = Sampled population

Each scheme was divided into 3 sections, where each exhibited similar characteristics in terms of water availability and irrigation days. Each stratum was further divided into 3 sections from which the sample was taken i.e., Upper, Middle, and Tail for farmers located closer to the water source,in the middle and further away respectively. The sample size was 240 for both schemes and was determined by Raosoft® (Incorporation, 2010) sample calculator at 95% confidence level.

A structured questionnaire was administered to 240 randomly selected farmers from both schemes. Five local isiZulu speakers acted as enumerators to administer the questionnaire. Age, gender, irrigation training and adequacy were among the recorded variables by the questionnaire. The description and coding for the variables assumed to influence adequacy of water are shown in Table 5.2. The model processed 15 selected independent variables.

Variable	Code	Description	Hypothesis
Location in block	BLCK	Location of plot in relation to main supply line Dummy; 1 if located at tail and 0 otherwise	Farmers closer to the main supply line have adequate water
Location in district (MRIS vs TFIS)	LOC_DISTRCT	Methods used for water abstraction, conveyance and application in the respective schemes Area dummy: 1 if household is from Mooi-River and 0 Tugela Ferry	Revitalisation improves water adequacy
Water management training	WAMTR	Determination of farmers who have received water management training Dummy; 1 if farmer had training and 0 otherwise	Training improves water adequacy
Irrigation training	IRRTR	Determination of farmers who have received irrigation training Dummy; 1 if farmer had training and 0 otherwise	Training improves water adequacy
Agricultural training	AGRTR	Determination of farmers who have received training in agriculture Dummy; 1 if farmer had training and 0 otherwise	Training improves water adequacy
Knowledge of government aims in SISs	KGOVAIMS	Measures farmers awareness of governments agenda for the SIS Likert; 1= strongly disagree, 2= disagree, 3= neutral 4= agree, 5= strongly agree	Awareness of the governments agenda for SISs improves water adequacy
Election process fair	FAIRELECTPRCSS	Allows determination of farmers in election participation Likert; 1= strongly disagree, 2= disagree, 3= neutral 4= agree, 5= strongly agree	Representation of all interest groups improves water adequacy
Available water license	AVWALIC	Determination of farmers who have water licenses Dummy; 1 if farmer cites yes and 0 otherwise	Farmers with water permits have water adequacy
Available water rights	AVWATRGHT	measure farmer perception on water rights Dummy; 1 if farmer cites yes and 0 otherwise	Farmers citing availability of water rights have adequate water

Table 5.2 Variables defining water adequacy status for the various farmers in the schemes and their respective coding as used in STATA 15

Variable	Code	Description	Hypothesis
Water conflicts between farmers	WACONFLFRM	Allows for the determination of conflicts at farm/village level Dummy; 1 yes and 0 otherwise	Less conflicts improves water adequacy
Water conflicts between blocks	WATCONFLBLK	Allows for the determination of conflicts at block level Dummy; 1 yes and 0 otherwise	Less conflicts improves water adequacy
Water fees	WATFEES	Determination of farmers that pay for water Dummy; 1 if farmer cites yes and 0 otherwise	Farmers that pay water fees have access to water hence are water adequate
Satisfied with irrigation schedule	SATIRRSCHDL	Measures timeliness in water delivery Likert; 1= strongly disagree, 2= disagree, 3= neutral 4= agree, 5= strongly agree	Farmers receiving water on time and irrigating for a long time are likely to be cite water adequacy
Attending water related training	ATTWTRLDTRA	Determination of farmers who participate actively in water related training exercises Likert; 1= sometimes, 2= always, 0= otherwise	Farmers who actively participate in such exercises are more likely to report water adequacy
Attending irrigation meetings	ATTIRRMTNGS	Determination of farmers who participate actively in irrigation meetings Likert; 1= sometimes, 2= always, 0= otherwise	Farmers who actively participate in such meetings are more likely to report water adequacy

5.4.1 Variable selection

For this study, 15 governance related factors were identified and run in the regression model. Location in block (BLCK) is a determinant factor when it comes to water access. Literature indicates that farmers located at upper reaches of the scheme have unlimited access to water and this subsequently impacts on adequacy (Bruns, 2007; Sharaunga & Mudhara, 2016). Another governance related factor Location of irrigation scheme within the district (LOC_DISTRICT) was identified as a contributor to water adequacy. The methods used to abstract, convey and apply water determines how successful scheme goals can be met. Literature suggests that farmers using advanced methods e.g. electric and diesel pumps, for water abstraction, conveyance and application are more likely to have adequate water to their plots. (Sinyolo *et al.*, 2014).

Water management training (WAMTR), irrigation training (IRRTR) and agricultural training (AGRTR) were also identified as probable factors that influence water adequacy in irrigation schemes. Water adequacy perception is centred on the farmers ability to utilise acquired skills. van Koppen *et al.* (2018) stated that investing in soft skills, i.e. farmer training, yields improved production which stems from improved water use efficiency and subsequently improved water adequacy. Allouche (2016) stated that farmers with knowledge about governments aim in SISs (KGOVAIMS) were most likely to have adequate water. Government designs policy and it is diffused and translated by the decentralised institutions (WUAs and IMCs) to the farmers. Farmers with a clear understanding of the policies and strategies are more likely inclined to effectively manage the water resource.

Fair election process (FAIRELECTPRCSS), attending water related training and irrigation meetings (ATTWTRLDTRA and ATTIRRMTNGS), water conflicts amongst blocks and farmers (WATCONFLBLK and WACONFLFRM) respectively were identified as water governance related factors that could potentially influence water adequacy. A fair election process is a participatory approach that ensures all interest groups are properly represented, as such properly represented interest groups averts conflict. Studies have revealed that a participatory approach harmonises irrigation scheme dynamics, hence water equity, delivery and adequacy are met (Groenfeldt & Svendsen, 2000; Yildirim & Çakmak, 2004; Uysal & Atış, 2010). Water licensing

(AVWALIC) and water fees (WATFEES) were also identified as water governance related factors that potentially influenced water adequacy. Literature reveals that for a farmer to have "wet water" they have to make the necessary payment to acquire permits ("paper water") (Denby *et al.*, 2017). The variable available water rights (AVWATRGHT) was considered to be a potentially water adequacy influencing governance factor. Studies have shown that water rights contribute immensely to improved water access and subsequently crop production. Water rights allow farmers to protect their water from being stealthily taken away by other farmers which subsequently impacts on water adequacy (Bruns, 2007). Lastly, satisfaction with irrigation schedule (SATIRRSCHDL) was also deemed as influencing water adequacy.

5.5 Data analysis

The Binomial Logit (BNL) was applied to analyse the governance factors assumed to influence adequacy. The analysis was done using STATA 15 statistical software. According to Pindyck & Rubinfeld (1981), the Binary Logit model is defined as follows:

$$P_i = E\left(Y_i = \frac{1}{X_{ij}}\right) = \frac{1}{1+e^{-(\alpha 1+\sum_1^k \beta_i X_i)}} \qquad 5.1$$

where:

P_i is the probability of the farmer having high water adequacy,

Y_i is the observed variable for adequacy (i.e., 1= adequate and 0= not adequate),

X_{ij} are factors determining the water adequacy status for farmer i, and j stand for parameters to be estimated.

For ease of presentation Sharaunga & Mudhara (2016) substituted the variable $e^{-(\alpha 1+\sum_1^k \beta_i X_i)}$ with Z thus Equation 5.1 becomes:

$$P_i = E\left(Y_i = \frac{1}{X_{ij}}\right) = \frac{1}{1+e^{-Z_i}} \qquad 5.2$$

From Equation (5.1) the probability of a farmer citing water adequacy is given by $(1 - P_i)$ which gives Equation (5.3):

$$(1 - P_i) = \frac{1}{1+e^{Z_i}} \qquad 5.3$$

The odds ratio for asserting water adequacy $\frac{P_i}{(1-P_i)}$ is given by:

$$\left(\frac{P_i}{1-P_i}\right) = \frac{1+e^{Z_i}}{1+e^{-Z_i}} = e^{Z_i} \qquad 5.4$$

Taking natural logarithms of Equation (5.4)

$$Ln\left(\frac{P_i}{1-P_i}\right) = \alpha + \sum_{k=1}^{k=n} \beta_i X_i \qquad 5.5$$

Taking into consideration, the disturbance term ε_i the Binary Logit model (BNL) finally becomes:

$$Z_i = \alpha + \sum_{k=1}^{k=n} \beta_i X_i + \varepsilon_i \qquad 5.6$$

where:

α = the fixed component of the log odds,
β_i = explanatory (independent) variable(s), and
ε_i = error term.

Similar empirical models have been applied in various water cases. Gomo *et al.* (2014) used the Probit model, which is in the same family with Logit generalized of linear models, to investigate farmer satisfaction with smallholder irrigation scheme performance. Sharaunga & Mudhara (2016) used the BNL model to investigate factors that influence water use security in smallholder irrigation farming.

5.6 Results and Discussions

5.6.1 Descriptive statistics for MRIS and TFIS

The variable IRRWTADQCY was a dummy variable with 1 indicating water adequacy and 0 otherwise (Table 5.3). Table 5.3 shows significant differences in water adequacy between some variables across farmers from TFIS and MRIS. It reveals that 87% of TFIS farmers are water adequate compared to 23% in MRIS. A high proportion of farmers did not receive training in agriculture, irrigation and water management, which is contrary to expectation. Table 5.3 reveals that 54% of farmers who do not pay for water (PAYMNTWAT) are not water adequate. Some 94% of farmers who were satisfied with the irrigation schedule (SATIRRSCHDL) were water adequate whilst all those who expressed dissatisfaction did not have water adequate. Farmers that did not experience water conflicts were more likely to be water adequate compared to their counterparts. Farmers' participation in irrigation and water management training increased the chances of experiencing water adequacy. This was evident as 64% who participated in water related training and subsequently indicated water adequacy. Farmers' who paid water fees indicate water adequacy. This is evident as 79% who paid water fees expressed water adequacy. On the contrary, 54% of those who did not pay water fees indicated water inadequacy. Farmer location across the canal reach was a significant factor. 65% of farmers at the head end indicated water adequacy, whereas 24% of those at the tail end indicated water adequacy. 58% of farmers' who agreed to a fair election process within the scheme indicated water adequacy whilst 54% of water adequate farmers' neither agreed nor disagreed.

Table 5.3 Independent variables behaviour with respect to water adequacy

		Water adequacy		
Variable name	All sample (n=239)	No (%)	Yes (%)	$p - value$
BLCK	Tail ($n = 59$)	76	24	0.000***
	Head($n = 180$)	35	65	
IRRG_SCHEME	TFIS ($n = 119$)	13	87	0.000***
	MRIS ($n = 120$)	77	23	
WAMTR	Yes ($n = 56$)	43	57	0.689
	No ($n = 183$)	46	54	
IRRTR	Yes ($n = 56$)	36	64	0.104
	No ($n = 183$)	48	52	
AGRTR	Yes ($n = 112$)	43	57	0.496
	No ($n = 127$)	47	53	
KGOVAIMS	Agree ($n = 11$)	36	64	0.394
	Neutral ($n = 44$)	34	66	

	Disagree ($n = 55$)	47	53	
FAIRELECTPRCSS	Agree ($n = 101$)	42	58	0.091*
	Neutral ($n = 28$)	46	54	
	Disagree ($n = 5$)	80	20	
AVWALIC	Agree ($n = 6$)	50	50	0.985
	Neutral ($n = 54$)	46	54	
	Disagree ($n = 66$)	47	53	
AVWATRGHT	Yes ($n = 111$)	13	87	0.954
	Not sure ($n = 38$)	47	53	
	No ($n = 90$)	12	88	
WACONFLFRM	Yes ($n = 61$)	70	30	
	No ($n = 177$)	36	64	0.000***
WATCONFLBLK	Yes ($n = 43$)	91	9	0.000***
	No ($n = 195$)	35	65	
PAYMNTWAT	Yes ($n = 62$)	21	79	0.000***
	No ($n = 177$)	54	46	
SATIRRSCHDL	Agree ($n = 52$)	6	94	0.000***
	Neutral ($n = 19$)	68	32	
	Disagree($n = 28$)	100	0	
ATTWTRLDTRA	Always ($n = 127$)	39	61	0.091*
	Sometimes ($n = 62$)	53	47	
	Never ($n = 50$)	52	48	
ATTIRRMTNGS	Always ($n = 167$)	42	58	0.300
	Sometimes ($n = 68$)	53	47	
	Never ($n = 4$)	50	50	

Notes: ***, **, * means statistically significant at 1%, 5% and 10% levels respectively.

Source: Survey data 2017

5.6.2 Binary logit analysis

This section shows the results of the Binary Logit model (BNL) run using STATA 15. The BNL had two levels of responses based on water adequacy (IRRWTADQCY). A frequencies table was generated and it indicated that 28 irrigators in MRIS had adequate water and 92 had inadequate water. In TFIS 104 irrigators had adequate water and 16 had inadequate water. The data is summarised in Table 5.4 below.

Table 5.4 Frequency table with respect to water adequacy for TFIS and MRIS

Response	TFIS		MRIS	
	Frequency	Percent (%)	Frequency	Percent (%)
Yes	104	87	28	23
No	16	13	92	77
Total	120	100	120	100

5.7 Regression Model Diagnostics

The model results are presented in Table 5.5. Multi-collinearity diagnostics showed no significant correlation between the explanatory variables. The Variance Inflation Factors (VIF) averaged 1.698 which is within the acceptable range of below 10 (Rogerson, 2001; Hounsome *et al.*, 2006). The standard error estimates were low, i.e., below 10, which indicated that micro-numericity was not a problem. The model revealed an overall classification accuracy of 89.12%, which illustrates that it successfully predicted irrigation water adequacy. The Chi-square test was significant ($p < 0.01$) indicating a good predictive capacity of the model. The results show that irrigation scheme infrastructure characteristics (IRRG_SCHEME) have a bearing on water adequacy ($p = 0.001$). In addition, other statistically significant variables are location of plot in scheme (BLCK) ($p = 0.001$), water management training (WAMTR) ($p = 0.012$), irrigation training (IRRTR) ($p = 0.088$), knowledge of government aims in the SISs (KGOVAIMS) ($p = 0.026$), availability of water license (AVWALIC) ($p = 0.002$), paying water fees (PAYMNTWAT) ($p = 0.093$), and satisfaction with irrigation schedule (SATIRRSCHDL) ($p = 0.001$).

Table 5.5 Estimates of the Binary Logit Model for TFIS and MRIS

IRRWTADQCY	Coef	Std Err	$p > \|z\|$	Marginal Effects (dy/dx)
BLCK	-2.383	0.656	0.001	-0.176
IRRG_SCHEME	-4.581***	1.141	0.000	-0.338
WAMTR	2.190**	0.874	0.012	0.162
IRRTR	-1.440*	0.843	0.088	-0.106
AGRTR	-0.634	0.634	0.317	-0.047
KGOVAIMS	0.517**	0.232	0.026	0.038
FAIRELECTPRCSS	0.204	0.269	0.447	0.015
AVWALIC	0.799***	0.252	0.002	0.059
AVWATRGHT	0.309	0.532	0.561	0.023
WATCONFLBLK	-1.055	1.025	0.303	-0.052
WATCONFLFRM	-0.709	0.774	0.360	-0.078
PAYMNTWAT	-1.728**	1.028	0.093	-0.128
SATIRRSCHDL	1.601***	0.297	0.000	0.118
ATTWTRLDTRA	-0.296	0.404	0.465	-0.022
ATTIRRMTNGS	0.795	0.551	0.149	0.059
_cons	-6.658	2.325	0.004	-

Number of observation	239
LR Chi-square (Prob > Chi-square)	214.52 ($p = 0.000$)
Pseudo R^2	0.6518
% correct prediction	89.12%

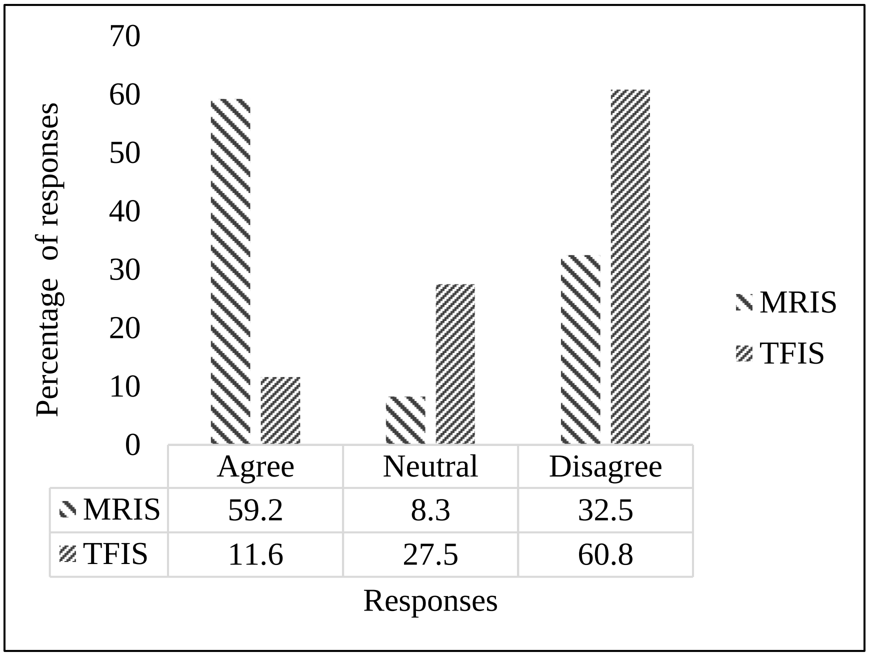
****, **, * means statistically significant at 1%, 5% and 10% respectively.*

Source: Survey data (2017).

Irrigation scheme and farmer location in scheme

The variable for location of farmer within the district (LOC_DISTRICT) was negative and statistically significantly influenced water adequacy ($p = 0.000$). This revealed that being located in MRIS is associated with an increase in probability of citing water inadequacy by 0.3. The farmers in TFIS are more likely to have adequate water than those in MRIS. The scheme infrastructure characteristics contribute to the positive attribute on TFIS. TFIS adopted an underground-piped water conveyance system, whereas MRIS has the canal system that needs repair and is old. The upgraded technology in TFIS has minimal human interaction and interference, i.e., operability of the water control infrastructure, whilst Mooi River farmers use manually operated canal and gated systems that can be tampered with. Horst (1998) highlighted that a system that is user friendly and requires minimal human interaction during operation tends to serve the purpose better and offer farmers/irrigators a correct irrigation function.

MRIS is characterized by many gated structures that are illegally accessed and easily vandalized. The variable (BLCK) which signifies the farmers' location within the scheme statistically significantly had a bearing on water adequacy ($p = 0.001$). Farmers located at the tail end were approximately 18% more likely to indicate water inadequacy than those at the head. Sharaunga & Mudhara (2016) established that farmers at the tail-end in MRIS were water deficient. Gomo (2012) revealed that the average conveyance efficiency for the canal systems in MRIS was 40% instead of the design 85% for the concrete lined canals. This was attributed to leakages along the canals where maintenance was over-due. Illegal water abstractions (Figure 5.5), amplified by leaking canals and silt accumulation (Figure 5.6), are amongst the major factors that impact on water conveyance and subsequently influence water adequacy negatively in MRIS.



	Agree	Neutral	Disagree
▧ MRIS	59.2	8.3	32.5
▨ TFIS	11.6	27.5	60.8

Figure 5.5 A comparison of illegal water abstractions between MRIS and TFIS.

According to Letsoalo & Van Averbeke (2006) poor infrastructural maintenance leads to weeds growing in canals so that when water carries the silt it enhances increases subsequently reducing the cross-sectional area and thus the canal carrying capacity.


(a)

(b)

Figure 5.6 (a) Silted canal and (b) cracks and failed concrete lining

Water management training

The variable for training in water management (WAMTR) was statistically significant ($p = 0.012$) suggesting that it influenced water adequacy. Training in water management is associated with an increase in probability of indicating water adequacy by 16%. Water management is defined as determining and controlling the rate, amount and timing of irrigation water in a planned and efficient manner. Farmers with knowledge in Crop Water Requirement (CWR) and the irrigation schedule were most likely to have adequate water for cropping requirements. Pereira *et al.* (2002) also argued that for water supplied on a demand-scheduled, farmers with knowledge in irrigation scheduling and CWR were more likely to be water efficient, which subsequently means they had adequate water to meet their cropping needs. Langyintuo & Mekuria (2000) revealed that educating farmers in adopting technologies increased their adaptive capacities, which improves natural resource usage.

Irrigation training

The negative and statistically significant variable irrigation training (IRRTR)$(p = 0.088)$ showed that its lack increased the probability of indicating water adequacy by 11%. This finding was not expected. The anticipated outcome was exposure to irrigation training would increase the probability of a farmer citing water adequacy. The finding resonates with the notion that farmers are comfortable with their inherited irrigation knowledge (Mehta *et al.*, 2017). Furthermore, Mehta *et al.* (2017) point out the complexity of the African system of water resource management, as one that has a web of customary beliefs.

Knowledge of government aims

The variable for “farmers had knowledge of the government’s aims" (KGOVAIMS) was positively statistically significant $(p = 0.026)$. Farmers who had knowledge of the government’s aims in SISs were likely to experience water adequacy, i.e., a knowledgeable farmer was more likely to increase the probability of water adequacy by 4%. Government as over-seer of the irrigation schemes, formulates policy and strategies that trickle down from basin scale to village level irrigation schemes, thus proper policy articulation and implementation of the strategies improve the handling of the water resource, which subsequently increases water adequacy. De-centralisation, which saw the creation of WUAs and IMCs has been the driver for improved policy and information dissemination. Local institutions and organisations have promoted participation. The finding concurs with Denby *et al.* (2017) who argued that the 1998 National Water Act facilitated decentralising participatory institutions that articulate and reconcile the divergent goal between government and the farmers. In addition, Alba & Bolding (2016) also argued that the creation of local level institutions that articulate policy and implement government strategy allow policy movement through various channels where it gains more transformative perspective and thus generating new ideas.

Availability of water license

The positive and statistically significant parameter estimate for possessing a water license (AVWALIC) means that farmers who possessed water licenses were more likely to experience water adequacy. The positive impact for possessing a water license increased the probability of citing water adequacy by 59%. Water permits allow equitable water appropriation. Denby *et al.* (2017) argued that in order to obtain “wet water” there has to be “paper water” first. In addition, Alba *et al.* (2016) argued that water licensing presented a robust accountability system that improve water allocation amongst users, where the underlying concept being that proper volumes are specifically allocated to a user thus preventing conflicts.

Water fees

The coefficient estimate for concurring to paying water fees (PAYMNTWAT) was negative and statistically significant $(p = 0.093)$. The finding did not concur with the anticipated outcome. It is expected that farmers who pay water fees are more likely to indicate water adequacy since water payments secure water abstraction rights. Access to water can be blocked when no payments has been made. In addition, water payments facilitate infrastructure maintenance, which subsequently improves water conveyance, and water adequacy. The anticipated finding concurred with Gulati & Narayanan (2002) who argued that the absence of water payments hindered improved water service quality and such inefficiencies that negatively impact on water adequacy.

Satisfaction with the irrigation schedule

Irrigation scheduling is primarily related to technological and operational factors (Horst, 1998). The variable called satisfaction with irrigation scheduling (SATIRRSCHDL), was statistically significant ($p = 0.001$) and positively influenced water adequacy. According to Table 5.5 farmers who were content with the irrigation schedule were more likely to have adequate water for their operations. A farmer satisfied with the irrigation schedule increased the probability of indicating water adequacy by 0.12. This phenomenon may be attributable to effective information dissemination on the delivery schedule to the farmers. A satisfactory irrigation schedule is one that is flexible in supply, timing and rate. A flexible irrigation schedule facilitates easy agronomic planning and decision-making. Palmer *et al.* (1989) cites a flexible irrigation schedule promotes satisfaction amongst irrigators thus giving them more freedom in economic and agronomic decision-making.

5.8 Conclusion

This study assessed the factors that influenced water adequacy in smallholder irrigation schemes in KwaZulu-Natal, South Africa. Eight factors were statistically significant. In addition, poor infrastructure maintenance procedures in place have had a negative impact on the carrying capacity of the concrete lined canals. Investing in water management training improves access to water. In addition, conflicts impacted negatively on water adequacy for crop production. A flexible irrigation i.e., one designed to operate in a timely and accurate manner, empowers farmers to make informed agronomic and economic decisions.

The study also assessed the implication of technology upgrade on water adequacy. TFIS farmers were more likely to be water adequate as compared to the MRIS farmers partly due to the scheme upgrade done in TFIS. TIFS moved from wholly canal systems to piped networks across the blocks. Through this, it was established that the human dimension, as effected by operability and canal structure handling, has a bearing on water adequacy. Flow sensitivity is common in canals , and due to lack of knowledge scheme managers and bailiffs are less likely to identify such point. This consequently leads to poor flow regimes and water inadequacy.

Farmers who received water management training were highly likely to have adequate water to meet their cropping needs. Illegal abstractions were taxing compliant farmers. The rule breakers seem to reap the benefits of accessing water at any given time at the expense of the other farmers. Water conflicts between blocks were also another factor that negatively influenced water adequacy. Policy incoherence and lack of coordination amongst blocks were the primary cause for water conflicts. In addition, institutions showed poor capacity in rule enforcement and reining in delinquent water users in the block.

5.9 Recommendations

It is recommended that the farmers properly organize themselves and re-align thoughts and attitudes towards the scheme infrastructure and be aware of the consequences of their actions to other tail-end users.

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6 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Background

Scheme performance is influenced by water governance structures. IMT transferred scheme management from government agencies to Water User Associations (WUAs) and Irrigation Management Committees (IMCs). These WUA and IMCs are legal entities whose scope of responsibility varies across the scheme. The WUAs and IMCs are "supposedly" concerned and vested with the authority to among, other things, organize the operation and maintenance (O&M) of the scheme, conflict resolution and collecting water fees. The self-governance approach varies across the world with irrigation schemes in Asia reporting a success whilst those in Africa exhibited the opposite. Despite massive investment by the South Africa government in irrigation schemes performance has been low. Irrigation is a priority on the budget, the government is on record of spending ZAR40,000.00 per hectare in irrigation (Sinyolo *et al.*, 2014). Scheme rehabilitation and revitalization has been recurrent however the level of performance exhibited by the irrigation schemes is not commensurate with invested funds. Canal irrigation management is besieged by poor institutional arrangements and poor and degraded water control infrastructure.

The study sought to establish a link between water control infrastructure and the existing water governance frameworks in Mooi-River Irrigation Scheme (MRIS) and Tugela Ferry Irrigation Scheme (TFIS). Questionnaires were administered to key players and irrigators to capture their perceptions on the interactions of water governance and water control infrastructure.

6.2 Findings and Conclusions

6.2.1 Infrastructure condition

Infrastructure in MRIS was badly dilapidated and was due for maintenance. The canals in the sampled blocks 5, 89, 11 and 15 were critically damaged needing immediate repair. Some components of the sluice gates had exceeded their service life. The regulators in blocks 9 and 11 had also exceeded the service life. Distribution canals in TFIS exhibited signs of deterioration i.e., the components of the infrastructure were due maintenance. The infield watering hoses were critically damaged and needed immediate replacement. The hoses had cracks that caused a lot of leaks. The investigative study concluded that various components of infrastructure in both irrigation schemes (MRIS and TFIS) was in bad condition. A root cause analysis revealed that both stakeholders (extension workers and designers) converged on certain governance casual factors for infrastructure deterioration. The common causal factors were maintenance related, institutional related, people related and environmental related. The study concluded that the irrigation schemes lacked an O&M programme. In addition, infrastructure dilapidation was exacerbated by uncooperative irrigators, and the irrigators were unwilling to contribute financially towards the scheme. It was revealed that the schemes had non-existent WUAs and IMCs. The institutional causal factors was a result of poor policy articulation by extension workers which then trickles to the irrigators. The infrastructure needed maintenance to avoid water losses.

6.2.2 Functional and operational relationships between water control infrastructure and water governance

MRIS had poor institutional arrangements as compared to TFIS. However, MRIS had high compliance levels as compared to TFIS. MRIS had solid rule enforcement compared to TFIS. Both schemes exhibited similar characteristics under processes (defining scheme goals, stakeholder engagement just to mention a few) and procedures (collecting water fees and gate operations). It was concluded that MRIS improve its institutional arrangement whilst TFIs improved on its rule enforcement and compliance. It was concluded that both schemes needed to improve on their procedures when it comes to infrastructure handling and understanding its requirements and characteristics. It was also concluded that farmers were unaware of institutions that are supposed to foster participation and improve self-governance.

6.2.3 Governance impacts on water adequacy

The governance factors which were significant in impacting on water adequacy were five variables; irrigation scheme, location of plot within the scheme, training in water management, satisfaction with irrigation schedule and water conflicts between block. It was established that irrigators that had water management training were more likely to cite water adequacy. The study concluded that farmers at the top end were always water adequate and this created an “artificial” water inadequacy for downstream users. A continuous supply of water for the upstream users disrupted the irrigation schedule and created erratic delivery disruption for the downstream users, thus the factor irrigation schedule impacted on water adequacy.

6.3 Recommendations

It is recommended that findings from this study be implemented for improved water management in TFIS and MRIS. Routine canal inspections and financial contributions towards the scheme are essential. Transaction costs associated with O&M are too large a cost for the local irrigators’ since the inhabitants are in previously poverty nodes or homelands, hence external stakeholder intervention is required for financial assistance. Farmers are encouraged to report unlawful behavior and desist from vandalism. This will preserve the integrity of the infrastructure thus reducing water losses. Training in water management is warranted, as this will improve crop production and water security for other domestic uses.

6.4 Future Research Needs

Extending the diagnosis to other irrigation schemes in South Africa will aid in designing a decision support tool for stakeholders involved in sharing and managing common pool resources. Artificial intelligence can be incorporated in the fuzzy theory to design a physical and socioeconomic model that can be predict farmer behaviour and the consequences on scheme performance.

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APPENDIX I

Integrated decision matrix for Mooi-River Irrigation Scheme (MRIS)

Aspect P_i	Aspect weight P_i	Criteria P_{ij}	Criteria weight P_{ij}	$P_{ij}\ w.r.t.P_i$
Sensitivity	0.25, 0.25, 0.34	Sensitivity of conveyance	0.38, 0.42, 0.42	0.11, 0.11, 0.13
		Sensitivity of delivery	0.35, 0.37, 0.40	0.09, 0.10, 0.12
		Sensitivity to setting	0.20, 0.21, 0.22	0.05, 0.06, 0.07
Reliability	0.31, 0.41, 0.42	Correct irrigation function	0.28, 0.29, 0.32	0.10, 0.12, 0.12
		Uncommon occurrence	0.11, 0.11, 0.18	0.05, 0.05, 0.06
		Effective info	0.22, 0.30, 0.30	0.07, 0.12, 0.13
		Uniform flow rate	0.32, 0.32, 0.38	0.12, 0.13, 0.13
Responsiveness	0.33, 0.35, 0.35	Problem dealing mechanism	0.50, 0.70, 0.71	0.18, 0.23, 0.25
		Response to farmers complaints	0.30, 0.31, 0.50	0.10, 0.11, 0.18

Integrated decision matrix for Tugela Ferry Irrigation Scheme (TFIS)

Aspect P_i	Aspect weight P_i	Criteria P_{ij}	Criteria weight P_{ij}	$P_{ij}\ w.r.t.P_i$
Sensitivity	0.15, 0.15, 0.24	Sensitivity of conveyance	0.35, 0.40, 0.42	0.05, 0.06, 0.06
		Sensitivity of delivery	0.26, 0.32, 0.32	0.03, 0.05, 0.08
		Sensitivity to setting	0.15, 0.17, 0.25	0.02, 0.03, 0.06
Reliability	0.37, 0.37, 0.39	Correct irrigation function	0.19, 0.19, 0.24	0.07, 0.07, 0.09
		Uncommon occurrence	0.15, 0.15, 0.20	0.05, 0.06, 0.08
		Effective info	0.18, 0.18, 0.21	0.07, 0.07, 0.08
		Uniform flow rate	0.22, 0.26, 0.27	0.08, 0.10, 0.10
Responsiveness	0.23, 0.32, 0.37	Problem dealing mechanism	0.00, 0.23, 0.25	0.00, 0.07, 0.09
		Response to farmers complaints	0.00, 0.55, 0.56	0.00, 0.18, 0.21