Adaptive Co-management of Small Tank Cascade Systems in Sri Lanka in a Changing Climate

By
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Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, *Bhathiya Kekulandala,* declare that this thesis, is submitted in fulfilment of the requirements for the award of *Doctor of Philosophy*, in the *Institute of Sustainable Futures* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Contribution	5% Assistance for conceptual design, guidance for literature review, assistance in data analysis, reviewing and editing the manuscript

List Of Abbreviations

ACM - Adaptive Co-management
CA - Comprehensive Assessment of Water Management in Agriculture
DAD - Department of Agrarian Development
ENSO - ElNino, Southern Oscillation
FAO - Food and Agricultural Organization of the United Nations
GCF - Green Climate Fund
GIAHS - Globally Important Agricultural Heritage System
GIS - Geographical Information Systems
IOD - Indian Ocean Dipole
ID - Irrigation Department
IPCC - Inter-Governmental Panel on Climate Change
IUCN - International Union for Conservation of Nature and Natural Resources
IWMI - International Water Management Institute
MJO - Madden Julian Oscillation
NAPS - National Adaptation Plan for Climate Change
NGO's - Non Governmental Organizations
QBO - Quasi-Biennial Oscillation
RCM - Regional Climate Models
SNA - Social Network Analysis
SRES - Special Report on Emission Scenarios
SSI - Semi-structured Interviews
STCS - Small Tank Cascade Systems
UN - United Nations
UNDP - United Nations Development Programme
UNFCCC - United Nations Framework Convention on Climate Change

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Abstract

Sri Lanka produces nearly 80% of its food requirement, and most produced in the country's dry zone. The seasonality of rainfall and undulating geomorphology of the dry zone led to the development of small tanks to store water, and over time these evolved into complex, multi-purpose small tank cascade systems (STCS). A community-led process governed STCS, but the British colonial administration abandoned community-led management favouring centralised bureaucracy. Centralisation continued in the post-colonial period leading to the degradation and deterioration of STCS. Recent research indicates that STCS can improve rural communities' food and livelihood securities and buffer the risks of climate change. The Sri Lankan Government and the United Nations Development Program (UNDP) are implementing a Green Climate Fund[1] project in Sri Lanka to rehabilitate STCS and introduce cascade-based adaptive governance systems.

This thesis investigates the potential to incorporate adaptive governance for managing STCS in a globally recognised agricultural heritage system (Palugaswewa STCS) in Northcentral Sri Lanka and its implications for ongoing climate adaptation. I used a diagnostic framework for adaptive co-management (ACM) (Plummer et al., 2017) to look for evidence of ACM that could support STCS adaptive governance and climate adaptation using a three-step methodology: 1. document and policy analysis to assess the evolution of STCS governance, 2. social network analysis (SNA) to identify key actors, and governance structures, and 3. semi-structured interviews to reveal governance processes, roles of key actors, and enablers and barriers of changes in governance. At each stage, implications for adaptive governance and climate change adaptation were considered.

My findings showed the governance of STCS as primarily community-led, flexible and robust, but centralised, formal institutional mechanisms led to governance inadequacies. A previously undocumented, informal decision process (pre-cultivation meeting) employed farmer experience of past weather/climate patterns to drive the formal decision process (cultivation meeting) and compensates for lack of timely meteorological information, allows stakeholder collaboration and knowledge co-development, and facilitates ACM. However, SNA-derived structures and measures showed significant vulnerabilities in STCS knowledge sharing around existing close social and family relationships, community norms, and values that need to be considered in efforts to enhance STCS governance.

[1] https://www.greenclimate.fund/project/fp124

I conclude that strengthening adaptive governance for climate change adaptation needs further research in a broader range of STCS, provision of user-centred meteorological information, recognition of existing informal governance processes and information flows among actors, and recasting legal frameworks at local and national scales to enable diversification of agricultural practices.

CHAPTER ONE

1.1 Introduction

Agriculture accounts for 70% of global water use (Boretti & Rosa, 2019; Pokhrel et al., 2021). The demand for water in agriculture will escalate with the increasing population, rising incomes and changing dietary requirements (de Fraiture & Wichelns, 2010; Rosa et al., 2020). However, global estimates and projections of water availability and usage are still uncertain (Boretti & Rosa, 2019).

Globally, 23% of croplands are irrigated. Approximately 68% of these irrigated lands experience water scarcity for at least one month per year and 37% for up to 5 months per year. Such agricultural water scarcity is experienced in mostly drought-prone areas in low-income countries (Rosa et al., 2020). Around three-quarters of global agricultural lands (454 million hectares) experienced drought-induced yield losses equivalent to US$166 billion between 1983 and 2009 (Leng & Hall, 2020). Globally, a 25% yield loss occurred between 1961 and 2006, with yield loss increasing by 22% for maize, 9% for rice, and 22% for soybean under drought conditions (Leng & Hall, 2020).

Water governance to meet competing demands of industrial, urban and rural water users, provide water for the environment and address water scarcity will be challenging (Boretti & Rosa, 2019; Rosa et al., 2020). The complexities associated with political, economic, and social institutions are essential for managing and developing water resources. Furthermore, equitable, efficient, and sustainable water management requires the participation of all actors who use and are affected by the resource (Boretti & Rosa, 2019; Caretta et al., 2022; de Fraiture & Wichelns, 2010). Water governance is undertaken through a variety of processes across the globe. Although water is often regarded as a common property resource, related rights and entitlements are generally vested in the state or its agencies (Gari et al., 2017; Ostrom, 2005)

Rainfed agriculture (including small irrigation systems) meets about 60% of the food and nutritional needs of the world's population, and it is a significant livelihood for marginal or subsistence farmers (Biradar et al., 2009; Boretti & Rosa, 2019; Caretta et al., 2022). Small water storage and irrigation systems have the potential to provide higher returns for local communities than larger projects, and effective management of local water storage is a critical factor for the food and livelihood security of rural farming communities (Gari et al., 2017; Ostrom, 1993; Ostrom & Gardner, 1993; Ricart et al., 2018). In a global context, the shift in governance from local resource users to centralised government agencies has led to the exploitation of the resource base by individual actors depending on their social status and wealth (Gain et al., 2020; Gari et al., 2017; Ostrom, 1993). Furthermore, such exploitation may lead to conflicts and abandonment of collective responsibility to maintain the resource base (Di Baldassarre et al., 2019; Ostrom & Gardner, 1993). Successful governance of small irrigation systems has several common characteristics: local-level governance and associated institutional structures, community-derived laws, rules and customs, stakeholder participation, and high social capital (Dietz et al., 2003; Ostrom, 1993, 2005).

In Sri Lanka, a bimodal rainfall pattern corresponding to two alternating monsoons (southwest and northeast), a central highland located perpendicular to the alternating monsoons, and landform diversity contributed to the heterogenous rainfall distribution pattern (Jayawardena et al., 2022; Marambe et al., 2015). Sri Lanka is divided into three major climatic zones (wet, intermediate and dry) based on rainfall's spatial/temporal variation (Climate Change Secretariat, 2016; Marambe et al., 2015). The northwest, north, northeast, east and southeast of Sri Lanka in the lowest elevation zone is described as the dry zone of Sri Lanka. The dry zone is characterised by a prominent dry season from May to September (Marambe et al., 2015), undulating land surface with numerous inland valleys, underlying highly impervious basement rock, overlying weathered rock, and shallow to moderately deep soil (Panabokke et al., 2002).

The seasonality of rainfall required early settlers to construct small water storages to collect water in the wet season. The topography and soil conditions are very conducive to the construction and storage of water for use in the dry season (Panabokke et al., 2002). The earliest evidence for the construction of small local water storage extends to 300 BC (Abeywardana et al., 2018; Dharmasena, 2010; Panabokke, 2009). These storages evolved into interconnected large complex tanks by the 3rd Century AD (Panabokke et al., 2002). Connected series of tanks that store, convey and utilise water from an ephemeral rivulet within a meso-catchment are described as Small Tank Cascade Systems (STCS) (Madduma Bandara, 1985; Panabokke, 2009). STCS governance has changed since the pre-colonial period from traditional community institutions managing STCS on a set of commonly agreed norms and rules (Kekulandala et al., 2021; Wijekoon et al., 2016). The local communities had various property rights that enabled them to adapt and manage water and adjacent land resources. The British colonial administrators declared land and water as Crown property, leading to the degradation and deterioration of local institutions as local users, as they were marginalised from the decision-making processes (Abeywardana et al., 2018; Kekulandala et al., 2021). The Sri Lankan governments in the post-independence period have contributed to the deterioration and degradation of STCS by shifting STCS governance into several agencies, continuous changes in the regulatory framework and deprioritising STCS in favour of large-scale irrigation schemes for investments. These have contributed to treating STCS as irrigation entities rather than multifunctional ecosystems supporting food and livelihood securities of smallholder farmers in the dry zone of Sri Lanka (Kekulandala et al., 2021).

Sri Lanka is investing more than $50m (USD) through a Green Climate Fund grant to enhance the resilience of dry zone farmers by upgrading and improving small irrigation systems (including STCS) (UNDP Sri Lanka, 2016). This project will develop cascade/catchment-level governance strategies that can contribute toward climate change adaptation, resilience building and adaptive capacity improvements in farming communities. These contributions are expected to enhance smallholder farming communities' food and livelihood security.

Climate change adaptation reduces climate risks and vulnerability by adjusting the functioning of existing systems. There are various adaptation options, but their implementation is determined by capacity and effectiveness of governance and decision-making processes (IPCC, 2022). IPCC WG 2's contribution to the 6th assessment report notes that adaptation planning and implementation across all sectors and regions delivered multiple benefits, but progress is uneven. Many adaptation actions have prioritised immediate short-term action rather than long-term transformation (IPCC, 2022). Current climate adaptation actions show that current adaptation levels are insufficient to meet the levels needed for managing future climate risks (IPCC, 2022). There is conjecture about the effectiveness of current adaptation, which includes discussion of the inadequacies and limitations in adaptation policy tools (Ulibarri et al., 2022), multiple perspectives on the effectiveness of climate adaptation (Singh et al., 2022) and a dearth of knowledge on addressing barriers to climate adaptation policy (Lee et al., 2022). Climate adaptation has long implementation times and requires long-term planning. Therefore, accelerated implementation, particularly in the next decade, is vital to close adaptation gaps (IPCC, 2022).

Climate change adaption in a water governance context requires recognising the complex interplay of physical, social, ecological and environmental considerations (Baird et al., 2021; Gotgelf et al., 2020; Quealy & Yates, 2021). Climate adaptation in water governance involves multiple actors and processes. Therefore, water governance in a changing and variable climate needs a holistic approach that ensure the participation of all actors, their roles and responsibilities in decision-making processes (Baird et al., 2021). Adaptive co-management (ACM) is receiving attention as an approach to governance that reconciles complex natural resources management issues. ACM combines adaptive management (focusing on learning by doing through learning and adaptation over medium to long time scales) with co-management (focusing on linkages across institutions and resource users to build relationships and promote participation and engagement) (Berkes et al., 2007; Olsson et al., 2004; Plummer et al., 2012). ACM supports the process of seeking solutions for complex social-ecological problems because it advocates flexible community-based resource management systems tailored to specific places and situations and supported by organisations working at different levels or scales (Armitage et al., 2009; Feist et al., 2020; Folke et al., 2002; Plummer et al., 2012). ACM can enhance the capacity of water users and institutions to deal with uncertainty and change (Olsson et al., 2007). ACM can be considered as a tool in a suite of governance options that might include conventional institutional mechanisms, rigid institutional structures, and social and marketing incentives (Armitage et al., 2009). Trust-building, institutional development, and collaborative and social learning are essential elements in ACM that facilitate inclusive and sustainable governance (Armitage et al., 2009; Baird et al., 2019) .

My research intends to investigate whether improved governance can contribute towards climate change adaptation in STCS in Sri Lanka. My research is designed to seek evidence for ACM in a water governance context. To that end, Plummer et al. (2017) provide a framework for diagnosing ACM in four steps:

1. Identifying antecedents (actors, their roles and responsibilities and practices)

2. Consideration of decision processes

3. Establishment of connections to various outcomes (both desirable and potentially undesirable)

4. Conducting parts 1-3 within a considered setting.

1.2 Rationale for the research

Sri Lanka's agricultural sector produces around 85% of its annual food requirements and contributes significantly to the economy (Esham & Garforth, 2013). Small farming systems contribute to 80% of this agricultural production, and 66% of the cultivable land is rainfed (Biradar et al., 2009; Esham & Garforth 2013). Therefore, seasonal rainfall is a critical factor for these small farming systems, and two distinct cultivation seasons correspond to the monsoonal and inter-monsoonal climatic patterns of Sri Lanka. Furthermore, the spatial and temporal distribution of rainfall results in a highly localised rainfall regime (Amarnath et al., 2017; Eriyagama et al., 2010; Marambe et al., 2015). Therefore, reliable, precise, localised seasonal weather and climate forecasts become imperative as they help farmers adapt and improve food production systems (Esham et al., 2017; Ziervogel & Calder, 2003). The existing literature suggests that farmers have certain expectations about the climate pattern for a given season and plan their cultivation accordingly. Farming is affected when this expected pattern does not materialise (de la Poterie et al., 2018; Gunda et al., 2017; Senaratne, 2013). There is a significant gap in research on how farmers' local/tacit knowledge is generated and used for cultivation decisions within the formal governance systems in STCS (i.e. cultivation meeting).

Furthermore, there is a dearth of research on how Sri Lankan farmers use climate information (derived from climate forecast, information bulletins, experiential knowledge or social learning) in cultivation decisions throughout the cultivation cycle (from initial land preparation to harvesting).

The Department of Agrarian Development (DAD) is the legally mandated agency that manages small irrigation systems, including STCS. DAD has tried to transfer some management rights to communities by organising them into farmer organisations and contracting them to maintain, repair and monitor irrigation infrastructure (Wijekoon et al., 2016). A 'cultivation meeting' is the primary decision-making platform at each small tank. Farmers that cultivate under each tank participate in the cultivation meeting to decide water allocation dates, crop types or mix, irrigation infrastructure rehabilitation, repair and maintenance schedules. The issues canvassed in the decision-making process (including the cultivation meeting) have been documented by various authors (Abeyratne, 1985; Dayaratne, 1991; Kekulandala et al., 2021; Merrey, 1988; Moore, n.d.; Panabokke et al., 2002). However, there is a significant knowledge gap about how decisions are made at the cultivation meeting, including the roles, responsibilities, actions and accountabilities of participating state/non-state actors.

State actors have distributed their management responsibilities across central, provincial and local government agencies. These hierarchical institutional structures could either facilitate or complicate the decision-making process at the village level. Sri Lanka's twin streams of government consist of decentralised administrative functions represented by district secretariats and divisional secretariats and a devolved political system represented by provincial councils and local government agencies (Figure 1).A myriad of local-level institutions and officials represent these national-level actors.

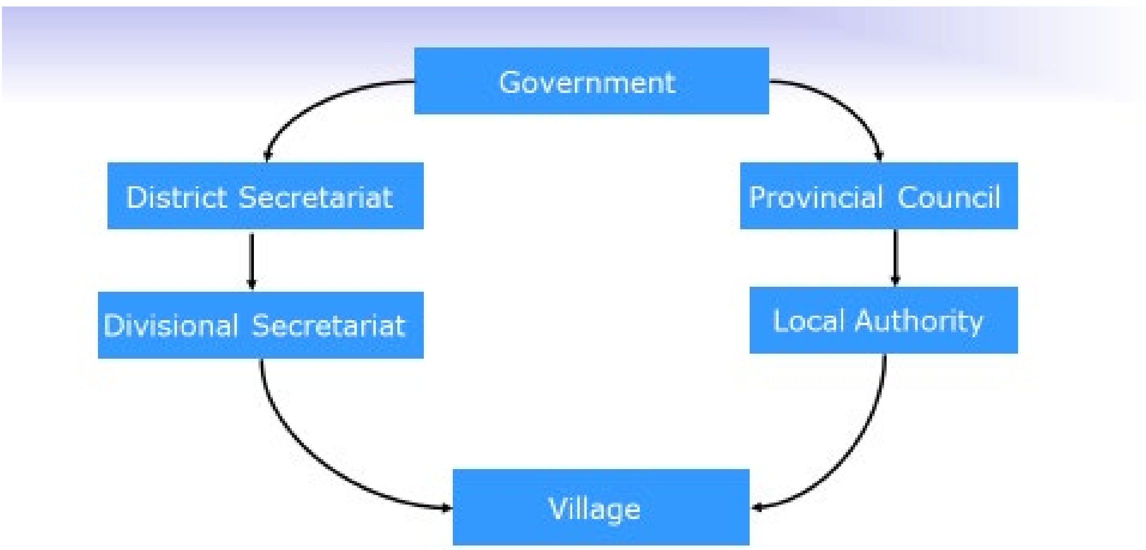

Figure 1 - Decentralised and devolved streams of government in Sri Lanka (Source: Training manual on decentralised disaster risk management, Practical Action Sri Lanka).

The literature indicates that cultivation meetings are generally organised around individual tanks (Abeywardana et al., 2019; Aheeyar, 2000; Kekulandala et al., 2021). However, the tanks in a cascade are hydrologically connected to upstream and downstream tanks, and decisions made in one tank affect other water users in the STCS. Therefore, management interventions at wider scales than a single tank are best suited to improve water and cultivation planning (Tennakoon, 2002). Catchment or sub-catchment level management interventions can improve the efficiency of use and reduce conflicts over water resources (Gari et al., 2017; Ostrom & Gardner, 1993; Ricart et al., 2018). Recent research on STCS indicates that they provide multiple ecological, social and economic services and that management intervention needs to capture the value of irrigation and these other services holistically (Bebermeier et al., 2017; Goonatilake et al., 2015; Mendis, 2008; Schütt et al., 2013; Vidanage, 2019). Therefore cascade level management planning has been envisaged as an approach to address these issues (Vidanage et al., 2005). However, published literature on governance interventions to promote cascade level management is scarce and remains a significant research gap.

STCS and associated agricultural systems are a significant contributor to the food and livelihood security of the dry zone farmers. These agricultural livelihoods in the dry zone of Sri Lanka are increasingly vulnerable to a changing and variable climate. (Esham et al., 2017; Köpke et al., 2019; Marambe et al., 2015).

1.3 Aim and Research Questions

STCS have the potential to help ensure food security and livelihoods for communities in Sri Lanka's dry zone affected by climate-induced changes in local social-ecological systems (Abeywardana, et al., 2019; Bebermeier et al., 2017). Various studies from many parts of the world have shown the benefits of integrating adaptation planning into cultivation planning and decision-making processes for food production (Alexander & Block, 2022; Davidson, 2016; Gunda et al., 2017; Šūmane et al., 2018). In Sri Lanka, NGOs have carried out several interventions to integrate climate change concerns into cultivation planning and introduce adaptive measures to projected or perceived changes in climate. The outcomes of these interventions are largely absent in the peer-reviewed literature (Senaratne, 2013). Therefore, identifying the agricultural decision-making process and associated governance environment, how farmers access and share climate information, and analysing enablers and barriers for integrating climate information in the agricultural decision process and learning from successful adaptation strategies for STCS are important for designing future governance.

There has been significant policy support for developing and rehabilitating STCS in Sri Lanka over the last decade. The Sector Vulnerability Profile: Agriculture and Fisheries 2010 (a supplementary document to the National Climate Change Adaptation Strategy 2010-2016), National Adaptation Plan for Climate Change 2016-2025, National Agricultural Policy and National Climate Change Policy highlight the importance of developing and rehabilitating small tank systems to reduce vulnerabilities posed by climate change[2]. In 2017, Green Climate Fund approved a joint project proposal by the Government of Sri Lanka and UNDP Sri Lanka to explore the resilience of smallholder farmers in Sri Lanka's dry zone to climate variability and extreme events through an integrated approach to water management. This multi-year project is co-funded by the Green Climate Fund and the Government of Sri Lanka[3]. The project started in late 2017 aims to establish STCS-based watershed management strategies to enhance the resilience of rural farming communities against climate change and will be implemented from 2017 to 2024.

Conventional hierarchical governance systems often fail to capture the uncertainty associated with complex social-ecological systems. But, my review of the literature (see Chapter 3) indicates that ACM provides a mechanism to address these uncertainties and complexities through collaborative learning, experimentation, and the participation of all actors that have a stake in the resource (Feist et al., 2020; Olsson, Folke, & Berkes, 2004; Panditharatne, 2016; Plummer et al., 2012). ACM scholarship emphasises that further evidence is needed to provide conceptual and definitional clarity, expand the evidence base and advance learning through relevant case studies. This literature highlights that most of the evidence for ACM has been generated in Europe and North America, while evidence from the developing world is limited (Plummer et al., 2012).

In summary, the research described in this thesis was inspired by:

- Firstly, the literature on STCS that indicates they display the characteristics of a complex social-ecological system.
- Secondly, evidence from academic literature that indicates the local level decision process at cultivation meetings is critical to plan the cultivation season. Therefore, identifying the decision-making process, key actors involved, their roles and responsibilities, and factors that facilitate or complicate the decision processes are vital to design governance improvements.

[2] For details on these policies see http://www.climatechange.lk/ccs_index.html
[3] Green Climate Fund Sri Lanka Project - https://tinyurl.com/ybs4go6u

- Thirdly, evidence indicates that there is significant scope for integrating adaptive governance mechanisms that incorporate participation, collaboration, experimentation and climate change adaptation into the management of STCS and influence relevant policy mechanisms. ACM presents as an appropriate alternative to the existing governance of STCS.
- Lastly, priorities identified in the literature on ACM indicate a need to develop and expand the existing evidence base to cover a wider range of contexts (e.g. developing country).

I have indicated in this introduction that climate change adaptation is multi-faceted and needs to account for physical risks of climate change as well as social, ecological and economic risks. IPCC WG 2 report on impacts, adaptation and vulnerability notes that adaptation actions are mainly concerned with physical interventions rather than social, ecological and economic aspects of climate change (IPCC, 2022) and my thesis will explore the social context for climate adaptation in STCS in Sri Lanka. The ACM diagnostic framework (Plummer et al., 2017) provides an opportunity to look at these social contexts. The research will focus on the first and second steps of the ACM framework (antecedents and processes) to identify key actors, their roles and responsibilities and decision processes to ascertain enablers and barriers for climate adaptation in a water governance context, and how governance improvements can enhance climate adaptation. Therefore, my research aims to explore how improved governance of STCS in the dry zone of Sri Lanka can contribute to climate change adaptation.

My research questions are:

1. What is the current decision making process for managing water and cultivations associated with small tank cascade systems?
    a. Whom are the main actors involved in the decision-making process
    b. What are their roles and responsibilities
    c. What are the advantages and disadvantages of the process (in terms of livelihood and food security of communities)
2. How is climate information accessed and used in managing water and cultivations associated with small tank cascade systems?
    a. How do farmers access and use climate information?
    b. What are the enablers and barriers to integrating climate information into the decision-making process?
3. Can adaptive co-management strategies be adopted for managing small tank cascade systems to derive better livelihood and food security outcomes?
    a. What are the enablers and barriers for integrating adaptive co-management strategies

Figure 2 provides an overview of the research questions, the methods employed to collect data, the actors or stakeholders targeted for data collection, and the data collection outcome. RQ1 explores the evolution of current STCS governance and compares it with the contemporary NRM practices and the implications for climate adaptation. RQ 2 explores the key actors involved in the governance process in an STCS, how they are organised to access and share cultivation/climate information, characterises the organisation of actors (networks), and what those elements mean for climate adaptation. RQ3 explores key actors' roles and responsibilities, characterises the agricultural decision-making process, and analyses enablers and barriers for ACM and climate adaptation.

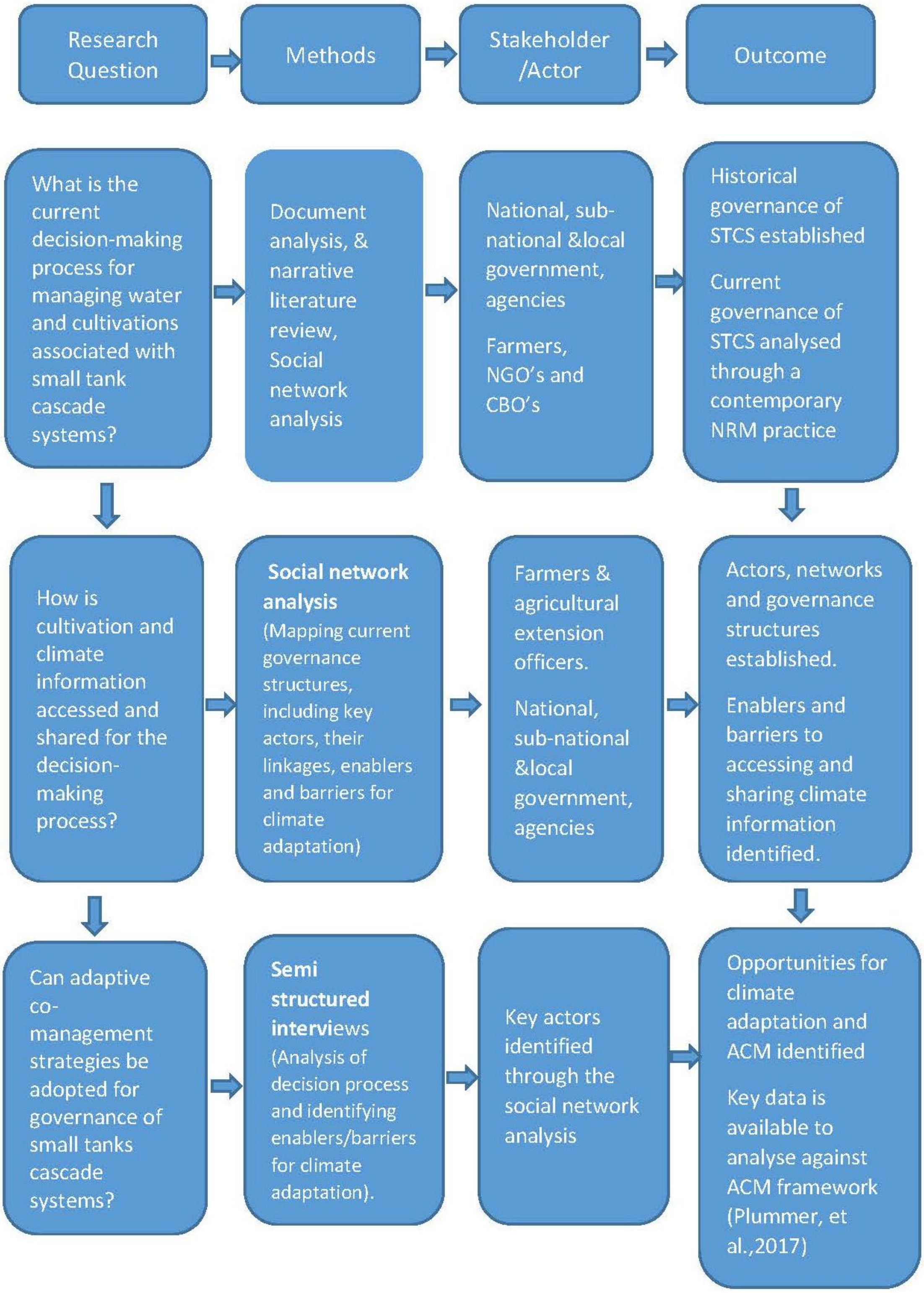

Figure 2 - An overview of research questions, methods, targeted actors and expected outcomes of data collection.

1.4 Thesis Structure

This is a thesis by compilation. The thesis is a combination of chapters and papers (published, submitted and finalised manuscripts) and complies with the rules set out for a thesis by compilation by The University of Technology Sydney (UTS). Overall, the thesis is organised into nine chapters as follows:

Chapter 1 provides the broader context that underpins my research, a quick overview of the research questions and explains the organisation of the thesis

Chapter 2 presents the background and the setting for the research. This chapter firstly (section 2.1) describes STCS, explores their history and evolution, analyses the current governance, and assesses the current and future challenges to STCS governance, secondly (section 2.2) explores the current status of understanding about climate change and its impacts on STCS and associated farming systems.

Chapter 3 explores the theoretical underpinnings of the main themes of my research. The chapter provides the status of knowledge on broader NRM governance, , climate adaptation in a social context , adaptive water governance with an emphasis on approaches that enhance food and livelihood securities, and adaptive co-management.

Chapter 4 describes the study site or the setting for my research and provides the research design and theoretical framework. Furthermore, the chapter discusses the methods used and ethical considerations of the research.

Chapter 5 is a published journal article presenting the setting for the research. It discusses the findings of a document/policy analysis on the evolution of STCS governance and its implications for enhancing adaptive governance and climate change adaptation.

Chapter 6 is a submitted manuscript that has undergone peer review. The chapter provides the results of a survey that underpins social network analysis (actors, network structure, structural perspective of governance, assessing and sharing information) and discusses its implication for adaptive governance and climate change adaptation.

Chapter 7 is a manuscript finalised for journal submission. The manuscript presents the findings and results of semi-structured interviews (about STCS actor roles and responsibilities, decision processes, practices, socio-cultural considerations) and discusses the implications of the results for adaptive governance and climate change adaptation.

Chapter 8 discusses the findings in the context of adaptive co-management (ACM), analysing evidence for ACM, discussing conditions that enable or disrupt ACM and climate change adaptation, and its implications for ongoing STCS development/rehabilitation in Sri Lanka. The chapter also discusses the contributions and limitations of this research.

Chapter 9 provides concluding remarks on implications of the findings for ACM scholarship, adaptive water governance, and the value of analysing water governance through a combination of social network analysis and semi-structured interviews. It also discusses future research opportunities to improve adaptive governance for climate change adaptation.

CHAPTER TWO

Background

This chapter will review the current knowledge and background information on the setting for my research and to identify research/knowledge gaps in keeping with three research themes (Figure 3).

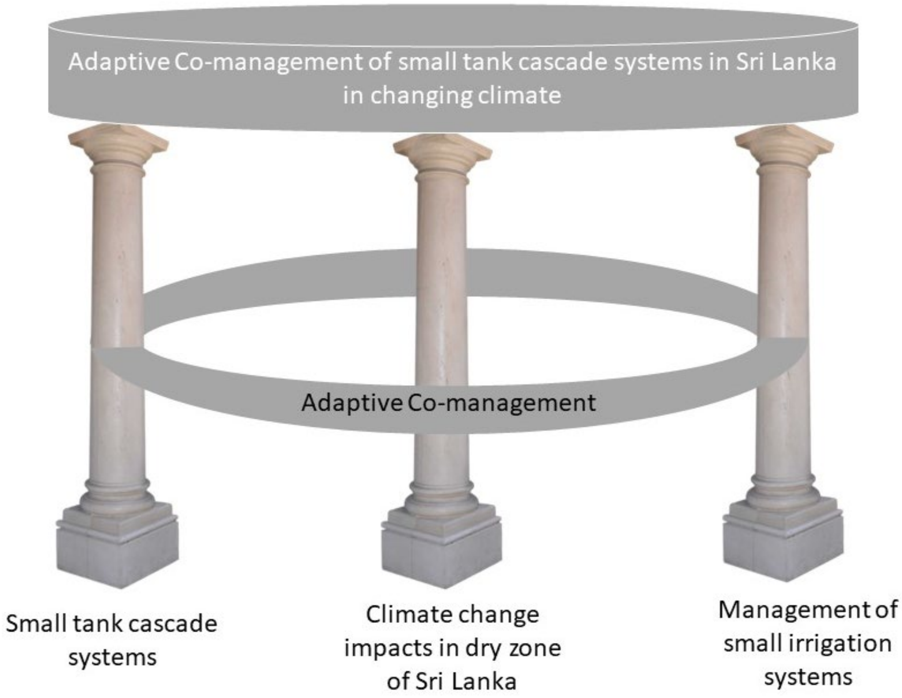

Figure 3 – Main themes for the research

The chapter is organised in two sections 2.1 Small Tank Cascade Systems of Sri Lanka and 2.2. Climate change impacts on rural agricultural and water storage systems in Sri Lanka. Management of small irrigation systems will be reviewed in Chapter 4.

Section 2.1 reviews the history and evolution of STCS, the current state of knowledge about their management, their social, cultural, and ecological significance, and the policy landscape influencing current and future challenges for these systems. Section 2.2 explores the current state of knowledge on climate change in Sri Lanka with emphasis on the dry zone and risks for managing STCS indicated by projected climate scenarios.

Introduction

Agriculture plays a key role globally in economic development and poverty alleviation. It is estimated that there are enough water resources to produce food for a growing global population (Boretti & Rosa, 2019; CA, 2007). However, trends in consumption, production and environmental patterns indicate the potential for a water crisis in many parts of the world (Caretta et al., 2022; de Fraiture et al., 2010). Agriculture consumes a large amount of freshwater compared to any other economic sector (Boretti & Rosa, 2019; de Fraiture et al., 2010). Scenario analysis has shown that the volume of water used in food production will increase to between 8,500 and 11,000 km^3 depending on the assumptions made on improvements in rainfed and irrigated agricultural systems. Therefore, water storage and control investments will be essential strategies in water resources management and rural development to meet ongoing demand (Boretti & Rosa, 2019; de Fraiture et al., 2010; Rosa et al., 2020).

The literature also indicates that poverty is highly regionalised. South Asia and Sub-Saharan Africa are the core areas for absolute poverty, with 70% of the world's poor and 510 million people in these regions considered food insecure (Caretta et al., 2022; de Fraiture et al., 2010; Namara et al., 2010). South Asia is one of the fastest-growing economies, with 23.7% of the poorest people in the world. Furthermore, South Asia shares only 4.6 % of the world's renewable water resources (Hirji et al., 2017; Shaw et al., 2022). Although the prevalence of poverty is not necessarily correlated with water availability, increasing scarcity and competition for water pose severe threats to poverty alleviation in many countries (Namara et al., 2010).

Water scarcity is a critical issue for agriculture in many parts of the world, especially in small farming systems, as physical and economical water scarcities affect nearly 2.7 billion people worldwide (de Fraiture et al., 2010). However, the low productivity of rainfed farming systems is associated with poor management practices rather than water availability per se (Rockström et al., 2003). CA indicates the potential to increase the agricultural yields of rainfed systems where most rural poor depend on these systems for their livelihoods. It further indicates that South Asia shows the highest potential for this improvement (Ensor et al., 2019; Li, 2022; Namara et al., 2010).

Crop yields in rainfed farming systems have increased through better rainwater management. The literature indicates that inefficient management of water, soils and crops is the major contributor to lower yields from rainfed farming systems (especially sub-Saharan Africa and South Asia), and significant improvements are necessary (Amarnath et al., 2017; Mukherji et al., 2009; Rockström et al., 2010). The literature further elaborates on major challenges for improving water and agricultural productivity in rainfed farming systems, and these include hydro-climatic (changes in rainfall and drought patterns, intensity, and duration), institutional, governance and capacity factors (Ahmed & Suphachalasai, 2014; Boretti & Rosa, 2019; Molden et al., 2013).

Water management in rainfed agricultural systems to improve water productivity and crop yields have received attention from researchers, multilateral development partners, UN agencies and respective governments. The literature shows that:

- Administrative and policy directives are often top-down, where government agencies hold significant power over the farmers or local communities that are directly benefited or impacted by the local water storage and management (Hassenforder & Barone, 2019; Pokhrel et al., 2021; Rockström et al., 2003).
- The water flows between blue water, and green water components are hard to assess in a landscape. There is a significant transfer of blue water into the green water during surface runoff (Barron et al., 2008; Hassenforder & Barone, 2019; Rosa et al., 2020).
- Climate change will exacerbate existing risks and vulnerabilities and will put a severe strain on local water resources. These strains will negatively affect local communities' food and livelihood securities (Bergkamp et al., 2003; Caretta et al., 2022; de Fraiture et al., 2010).

In this borader context, the next sections explore the the background and setting for the research by looking at STCS and the climate change context in Sri Lanka.

2.1 Small Tank Cascade Systems of Sri Lanka

2.1.1 Introduction

Sri Lanka is an island located in the Indian Ocean close to the Indian subcontinent. Sri Lanka is characterised by a tropical climate as it is situated close to the equator. Extensive geological faulting and erosion have led to a wide range of topographical features and three major elevation zones (peneplains): a coastal belt, plains, and central highlands with a peak elevation of 2524 m (Marambe et al., 2015). These geographical and topographical features influence the climate, especially the rainfall pattern (Marambe et al., 2015). Sri Lanka is divided into three climatic zones (see Figure 4) based on spatial and temporal variation in rainfall (Climate Change Secretariat, 2016a; Dharmasena, 2010a; Marambe et al., 2015).

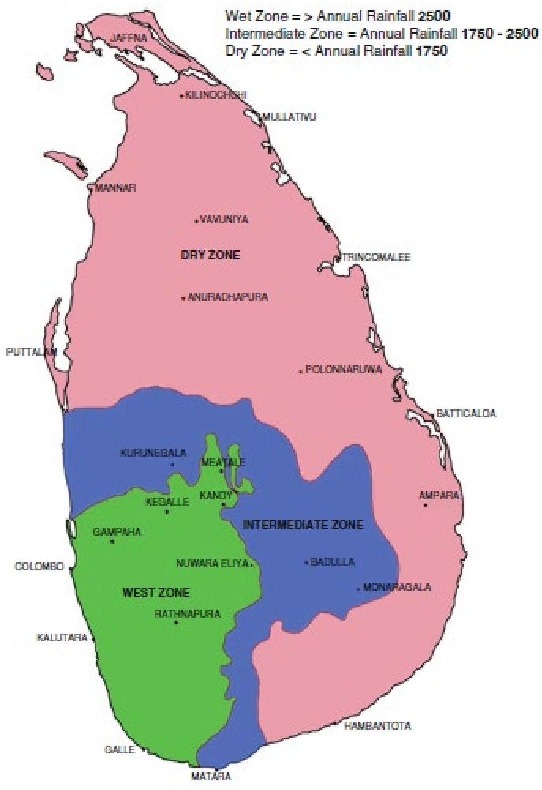

Figure 4 - Major climate zones of Sri Lanka (Punyawardena, 2007)

The dry zone extends northwest, north, northeast, east and southeast of Sri Lanka in the lowest peneplain. It receives a mean annual rainfall of less than 1750 mm with a prominent dry season from May to September (Marambe et al., 2015). The main rainfall season is from October to January. It shows high yearly variation with 800-1000 mm at a realistic rainfall expectancy (75% probability) for the dry zone (Panabokke et al., 2002). High evaporation and dry winds are characteristic features during May to October, with daily evaporation rates between 5-7 mm (Marambe et al., 2015; Panabokke et al., 2002). Furthermore, an extensive undulating land surface in the dry zone has resulted in a large number of small inland valleys (Panabokke et al., 2002). The dry zone's topography and geological characteristics (underlying highly impervious basement rock, overlying weathered rock and shallow to moderately deep soil) are very conducive to the construction of small reservoirs for water storage (Abeywardana et al., 2019; Panabokke, 2009).

The undulating terrain of the dry zone that comprises narrow valleys and ridges provided an opportunity for early settlers to divert or store water by constructing earthen dams (Abeywardana et al., 2019; Panabokke, 2009; Tennakoon, 2000). These early forms of small reservoirs (or Wewa in Sinhalese) are known as tanks. The term 'tank' evolved from the Portuguese term 'Tanque' that refers to small reservoirs (Dharmasena, 2010a). The literature identifies them as small or village tanks (tanks with an irrigated command area less than 80 hectares as per Agrarian Services Act No. 58 of 1979), and these terms are used interchangeably (Panabokke et al., 2002). The term small tank is used hereafter for consistency.

Early forms of small tanks constructed across narrow valleys served small communities/villages living adjacent to the tank. Subsequently, more tanks were built along these narrow valleys sequentially to accommodate expanding populations (Abeywardana et al., 2019; Mendis, 1981; Panabokke, 2009; Tennakoon, 2000). These sequences of tanks in a narrow valley enabled the ancient settlers to optimise a limited water resource by diverting, reusing and storing water (Mendis, 1981; Tennakoon, 2000). These sequentially constructed tanks are termed 'Tank Cascade Systems'. Tank cascade systems are defined as 'connected series of tanks organised within a micro-catchment of a dry zone landscape, storing, conveying and utilising water from an ephemeral rivulet (Madduma Bandara 1985). Several subsequent studies have introduced minor refinements to the definition by expanding it further and suggesting that micro-catchment is replaced by the more appropriate term ‘meso-catchment’ (Panabokke, 2009). There are several terms used to describe this sequential development of tanks: small tank cascade systems (STCS), tank cascade systems (TCS) or village tank cascade systems (VTCS). The term small tank cascade systems (STCS) is used hereafter for consistency.

The structure of an STCS (Figure 5) shows that the central axis of the ephemeral stream runs from top to bottom of the valley, and tributaries enter from side valleys. Small tanks in the upper areas in the central and side valleys collect the runoff from the surrounding landscape and transfer it to the downstream larger tank. Therefore, runoff from the surrounding landscape and discharge from small upstream tanks are used, reused and discharged to downstream reservoirs (Panabokke et al., 2002; Tennakoon, 2002). STCS are also described as stock-type irrigation systems where interconnected storage and regulating reservoirs serve multiple resource management functions, including irrigation, domestic supply, water for livestock and subsurface water for perennial cropping (Itakura & Abernethy, 1993). This multifunctional nature of the STCS transformed early settlements of Sri Lanka into an agricultural society by the 3rd to 5th century AD (Abeywardana et al., 2018; Panabokke, 2009; Tennakoon, 2000).

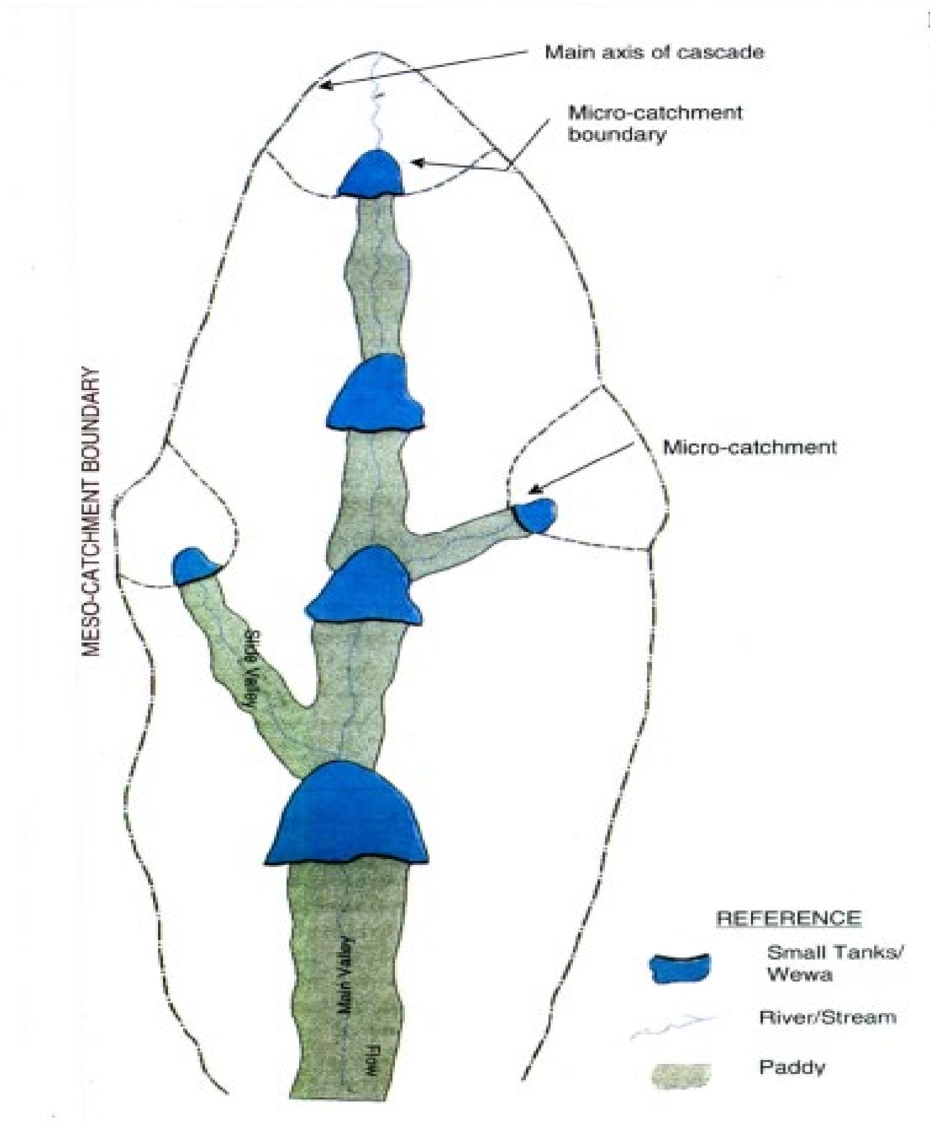

Figure 5 - Schematic representation of a typical small tank cascade system (Panabokke 2009, p.26) – Reproduced and adapted with permission (copyright owner IWMI)

2.1.2 History and evolution of small tank cascade systems

Irrigated wetland agriculture was firmly established in early settlements around 500 BC and concentrated in the dry zone of Sri Lanka (Panabokke, 2009). The transition from primarily rainfed upland cultivation (*chena*[4] or shifting or slash and burn cultivation) to a combination of wetland and upland cultivation enabled the small communities to build permanent settlements within narrow valleys of the dry zone (Panabokke, 2009). The literature indicates that irrigated agriculture was fundamental to Sri Lanka's civilisation and its expansion throughout the island. The sequential development of small village tanks around 300 BC culminated in the large, sophisticated irrigation works constructed in the 5th and 6th centuries AD (Abeywardana et al., 2019; Panabokke, 2009).

The early colonists must have used natural pools and ponds in the landscape to meet their water requirements. At some point in history, settlers learned to construct ponds to collect rainwater and local runoff (Jayawardana & Wijithadhamma, 2015; Panabokke, 2009; Tennakoon, 2000). These rudimentary ponds indicated the societal transition from hunter-gatherer to rainfed agriculture (Panabokke, 2009). The earliest forms of tanks were earthen bunds constructed across the small inland valleys of a micro/meso-catchment. These served the community to collect surface runoff for upland cultivation (chena), forming the earliest stages of wetland cultivation (paddy) or domestic use such as drinking, bathing and washing (Oka et al., 2015; Panabokke, 2009).

The construction of tanks has evolved with the invention of new technological features such as sluices and spillways. Hence the cascades of tanks were constructed to store, divert and reuse water in a micro-catchment to meet the needs of an expanding population (Panabokke, 2009). Early forms of small tanks were first built in Sri Lanka around 300 BC with the invention of the sluice systems (Jayawardana & Wijithadhamma, 2015; Kenyon et al., 2004; Mendis, 1981). Indirect and circumstantial evidence suggests that these small village tanks were the precursors to developing more extensive and complex irrigation works until 1200 AD (Mendis, 1981; Panabokke et al., 2002). The construction of small tanks continued concurrently with the construction of major irrigation works until the 1800s. Small communities throughout the dry zone of Sri Lanka continued to construct small tanks to fulfil their needs with little or no support from Sri Lanka's rulers (Jayawardana & Wijithadhamma, 2015; Mendis, 1981; Panabokke, 2009; Tennakoon, 2000). The majority of small tanks are hydrologically well endowed, less susceptible to breaching in a significant

[4] Chena is a form of traditional upland, slash/burn and shifting cultivation system, where plots of bushland adjacent to the village is cultivated rotationally over number of years

rainfall event and have been in continuous use (as per the local oral tradition) since 300 BC (Panabokke et al., 2002).

Communities adopted wetland agriculture as a primary livelihood when they acquired the skills to construct village tanks with extensive storage. Irrigation, therefore, became possible, and food production through irrigated agriculture expanded (Panabokke, 2009). Improved food security led to an expansion of population by 3rd Century BC, resulting in more small tank systems across small valleys in the dry zone (Panabokke, 2009). The literature also indicates similar patterns in Sanchi, Madhya Pradesh, India, where reservoirs were constructed across smaller tributaries of the Betwa River to support an expanding population (Shaw & Sutcliffe, 2003). The social, cultural and religious similarities between Sri Lanka and Sanchi in India also suggest that these two regions exchanged technical expertise on constructing tanks(Palanisami, 2006; Shaw & Sutcliffe, 2003).

A systematic study carried out by C. R. Panabokke in 1999 produced a methodology for nomenclature, distribution pattern and hydrography of STCS in the north-central province of Sri Lanka (Panabokke, 1999). The study identified 457 STCS distributed over 50 sub-watersheds in nine river basins. Almost 90% of small tanks were situated within 457 cascades in the north-central province (Panabokke, 1999). A subsequent study in 2002 provides statistical data on the distribution and density of small tanks based on a stereoscopic analysis of topographic maps and aerial photographs. The study revealed that the highest density of small tanks is found in north-western and north-central provinces. In contrast, most abandoned tanks were situated in the eastern segment of the southern, lower part of eastern provinces (Panabokke et al., 2002). Low annual rainfall, high yearly evaporation, small catchment areas and highly dispersible sodic soils are significant reasons for high tank abandonments in these areas (Panabokke et al., 2002).

The average density of small tanks is one tank per 2.6 km^2 in northern, north-central and southern provinces, and one tank per 1.2 km^2 in the north-western province (Panabokke, 2009). Many tanks do not have a sluice for water storage, and their primary purpose is to divert runoff to the central valley or increase the percolation into the groundwater table (Mendis, 1981; Tennakoon, 2000). These networks of small tanks constructed in a small valley come about through observation, understanding and analysis of local hydrology (de la Poterie et al., 2018; Shaw & Sutcliffe, 2003).

STCS supported the development of a body of knowledge by the dry zone communities of Sri Lanka that enabled them to adapt to an environment characterised by special geomorphological features and the seasonal nature of rainfall (Jayawardana & Wijithadhamma, 2015; Panabokke et al., 2002). The decline and abandonment of the STCS in the early 19th century has been attributed to many factors that include foreign invasions, extended drought periods, the spread of malaria, and most importantly to the abolition of the 'Rajakariya' system (Panabokke et al., 2002). Rajakariya, or 'king's duty', was an ancient custom of compulsory labour that contributed to the communal maintenance mode to manage tanks. Rajakariya and related customs that evolved through centuries ensured the successful management of small tank systems. However, these arrangements were prohibited by the British colonial administration in 1832, and without the introduction of an alternative method of governance these irrigation systems were neglected (Abeywardana et al., 2019; Kekulandala et al., 2021; Panabokke et al., 2002).

The literature shows significant interest in STCS since independence in Sri Lanka in 1948 (Dayaratne, 1991). A set of policy and legal instruments facilitated the rehabilitation and revitalisation of STCS over the last few decades. These include the introduction of the Agrarian Services Act No 58 of 1979, several donor-funded projects, the creation of research interests (through the National Science Foundation of Sri Lanka), and involvement of the non-government sector in their rehabilitation (Dayaratne, 1991; Panabokke et al., 2002; UNDP Sri Lanka, 2016). Table 1 lists the large scale STCS rehabilitation projects.

Table 1- Major projects that incorporated the rehabilitation of STCS (Dayaratne, 1991; UNDP Sri Lanka, 2014).

Project/program Name	**Implementing Agency/ Funding Agency**
Tank Rehabilitation Project – Time Frame: 1979 – 1989	National Freedom from Hunger Campaign/ World Food Programme
Village Irrigation and Rehabilitation Project (VIRP), Time Frame: 1980 -1987	Department of Irrigation, Department of Agrarian Services / World Bank
National Irrigation Rehabilitation Project (NIRP) Time Frame: 1980 -1987	Department of Irrigation, Department of Agrarian Services / World Bank
Dry Zone Agricultural Development Project, Time Frame: 2002 – 2005	Care International
Pro-poor Economic Advancement and Community Enhancement Project (PEACE), Time Frame: 2006- 2011	Japan Bank for International Corporation/JICA

Cascade based small tanks rehabilitation Project Time Frame: 2004 – 2010	Plan Sri Lanka
Restoring Traditional Cascading Tank Systems for Enhanced Rural Livelihoods and Environmental Services in Sri Lanka. Time Frame: 2013 – 2015	IUCN Sri Lanka/ HSBC Sri Lanka
Strengthening the resilience of smallholder farmers in the Dry Zone to climate variability and extreme events through an integrated approach to water management. Time Frame: 2017 - 2024	Government Of Sri Lanka and UNDP Sri Lanka

These initiatives created momentum in Sri Lanka to research, rehabilitate and develop STCS (Kekulandala et al., 2021). Furthermore, well-functioning STCS have been identified as an adaptation mechanism to ensure food and livelihood security at the local level (Climate Change Secretariat 2010). The National Adaptation Plan for Climate Change Impacts in Sri Lanka 2016 (NAPS) identified the development and rehabilitation of STCS as a critical adaptation strategy to improve watershed management and overcome the scarcities caused by climate change impacts (Climate Change Secretariat, 2016a). Furthermore, the Sri Lanka Ministry of Agriculture and the United Nations' Food and Agricultural Organization (FAO) proposed to designate STCS (with a representative system in the northcentral province of Sri Lanka) as a Globally Important Agricultural Heritage System (GIAHS) (Ministry of Agriculture & FAO, 2016). Subsequently, FAO designated[5] STCS in the dry zone of Sri Lanka in 2017.

2.1.3 Management of Small Tank Cascade Systems

Historically, the management of small irrigation systems was primarily the community's responsibility, and most literature suggests that the state did not control the management of these systems; communities took decisions locally to suit their needs (Begum, 1987; Jayawardana & Wijithadhamma, 2015; Wijekoon et al., 2016). An analysis of historical records comprising ancient chronicles, inscriptions and classical texts revealed very little information compared to more extensive irrigation works in ancient Sri Lanka (Abeywardana et al., 2019). This lack of knowledge in ancient chronicles indicates that small irrigation systems were mainly constructed and managed by local communities without patronage from the state (Abeywardana et al., 2018; Abeywardana et al., 2019; Leach, 1961). However, the land tenure and property rights issues would have dictated the

[5] https://www.fao.org/giahs/giahsaroundtheworld/designated-sites/asia-and-the-pacific/the-cascaded-tank-village-system-ctvs-in-the-dry-zone-of-sri-lanka/en/

management of these systems since local elites, who owned lands or invested (finance, labour) towards the construction of irrigation infrastructure, would have some rights in managing the system (Abeyratne, 1985; Abeywardanaet al., 2019). The King was the sole owner of the land. Therefore the King or his agents would have a role in management decisions taken at the local level (Abeyratne, 1985). Literature also suggests that some tanks were built for specific functions, such as providing flowers for religious ceremonies and serving monks in monasteries (Tennakoon, 2000). The literature further indicates two main traditions of water management in ancient Sri Lanka. The first is "Chulasammatha" or "Lesser Tradition", which refers to the construction and management of large-scale irrigation infrastructures such as reservoirs, large tanks, canals, and dams (anicuts). The ruling King or his agency was directly involved in the management of these large systems (Kenyon et al., 2004; Panabokke, 2009). The second tradition, the "Mahasammatha" or "Greater Tradition", refers to small village tanks and related irrigation infrastructure. This tradition also encompasses the oral traditions of customary rules, laws and rituals attached to small village irrigation systems and paddy cultivation (Jayawardana & Wijithadhamma, 2015; Kenyon et al., 2004; Panabokke, 2009).

The management of STCS transformed from community institutions into a state bureaucracy during the colonial period, and this continued in the post-independence period (Aheeyar, 2000; Kekulandala et al., 2021; Wijekoon et al., 2016). Since independence, frequent changes to institutional mechanisms (managing the STCS) were a common characteristic, leading to uncertainties in the governance environment (Kekulandala et al., 2021). The current management framework for STCS revolves around the cultivation meeting process. The cultivation or "Kanna" meeting is the most important event in the calendar for the small irrigation and paddy farming systems (Begum, 1987; Kekulandala et al., 2021; Wijekoon et al., 2016). Agrarian Services Act No 58 of 1979 introduced the legal provisions for cultivation meetings and subsequent revisions retained these provisions, including Agrarian Development Act 46 of 2011. The law requires that a cultivation (Kanna) meeting be held with the participation of all the cultivators of the system for planning and managing a cultivation cycle (from initial land preparation to harvesting). Furthermore, agricultural extension officials (Department of Agrarian Development) and farmer organisations convene the meeting. Other relevant government departments and line ministry representatives also attend (Begum, 1987; Kekulandala et al., 2021; Wijekoon et al., 2016). All parties participate and take decisions to plan the cultivation season. The Department of Agrarian Development certifies these decisions and authorises implementation (Kekulandala et al., 2021; Panabokke et al., 2002). The key decisions taken at the cultivation meeting include (Panabokke et al., 2002):

1) The extent of paddy lands to be cultivated
2) Date of the commencement of cultivation season
3) Dates for commencement and completion of:
    a) The first and last water issue
    b) Cleaning bunds and channels
    c) Cleaning and repairing sluice gates
    d) Ploughing and sowing
    e) Variety and age classes of paddy

The responsibilities are allocated to farmer organisation members to carry out agreed maintenance work before land preparation activities are allowed (Panabokke et al., 2002). The cultivation meeting is a critical event in the farming calendar for these small-scale, rainfed agricultural systems. The success of the process depends on many factors such as the type and availability of information for decision-making, level of community consensus, members accountability for decisions, power dynamics within different interest groups, and the effectiveness of government institutions in delivering services (Aheeyar, 2000; Panabokke et al., 2002; Wijekoon et al., 2016). Key actors in the relevant government and local administrative institutions determine the efficiency of the cultivation meeting process (Aheeyar, 2000; Wijekoon et al., 2016). The motivation, willingness and capacity of these actors influence the organisation, linking and facilitation of the decision-making process for relevant stakeholders (e.g., farmers, landowners, irrigation managers, local suppliers). The cultural and social dynamics such as relationships, cultural beliefs, political affiliations and social status affect the decision-making process and implementation of the decisions (Abeyratne, 1985; Panabokke et al., 2002; Paranage, 2018a; Perera, 1985).

2.1.4 Water and land management practices in small irrigation systems

Historically, the dry zone farming system is a mix of lowland paddy land, upland shifting cultivation (chena) and home gardens that sustained food and livelihood security of the villagers. The chena cultivation is often prioritised over others as it provides stable sustenance to the household (Panabokke et al., 2002). The chena cultivation comprises legumes, millets and other less water-intensive crops. Hence risks associated with water availability were low (Aheeyar, 2000; Dharmasena, 2010a). Lowland paddy cultivation depends heavily on the availability of water in the village tank. Therefore chena cultivation acts as insurance against failures in paddy cultivation (Aheeyar, 2000). Hence the land and water management practices associated with the STCS have evolved as risk aversion strategies rather than for yield maximisation (Panabokke et al., 2002; Ratnayake et al., 2021; Siriweera, 2000).

Land tenure often determine the farmer's ability to cultivate paddy under a village tank Literature suggests that complex tenure structures existed in these systems (Begum, 1987; Leach, 1961; Paranage, 2018a). Cultivable land under a small tank contains two land allocations: "Old Field" (Puranawela) and "New Field" (Akkarawela). "Old Field" refers to the original paddy tracts developed with the construction of the tank, and "New Field" refers to paddy tracts that developed over more recent years (Aheeyar, 2000; Begum, 1987; Paranage, 2018a). Farmers privately own old fields; whereas, the state owns the new areas. Furthermore, old fields enjoyed primary rights for water from the tank, with new areas securing only secondary rights (Begum, 1987). Also, the community maintained old field lands according to traditional rights and customs; whereas, new field rights were subjected to leasing and renting under the legal framework (Jayawardana & Wijithadhamma, 2015; Leach, 1961; Paranage, 2018a).

The complex tenure issues and entitlements also determined the access to water in water-stressed conditions, prioritisation of old field over the new area, allocation of cultivation plots within the old field (based on proximity to the tank), and water release for lands close to and away from the tank (Begum, 1987; Leach, 1961; Paranage, 2018a). Complex arrangements for land allocation, water release, cultivation and maintenance existed within the agricultural communities associated with small tanks. It is evident that these management practices changed and adapted to suit the evolving requirements of the community (Aheeyar, 2000; Begum, 1987).

Water management for the upcoming season is decided at the cultivation meeting and agreed upon by all parties. The major decisions were the selection of cultivators (farmers or farmer groups), the crop mix to be cultivated and the timing of water allocation. Also, the cultivation meeting provided a platform for scheduling repair and maintenance activities for the agricultural system concerned (e.g. rehabilitation of canal systems and drainages, clearing around canals, fencing). Farmer organisations allocated these responsibilities to farmers, and they carried out agreed maintenance work before land preparation activities were allowed (Panabokke et al., 2002). The literature also indicates several water conservation strategies adopted by communities, and these are:

1. Dry Sowing (Kekulam System)

Farmers practised dry sowing to save tank water during the cultivation season (primarily in Maha season associated with northeast monsoon). Farmers ploughed the land just before the onset of rains and used initial showers for planting. Tank water is used later to support and maintain the crop to maturity. This practice reduces the use of water stored in the tank. Farmers can use the water saved by this to cultivate an intermediate (inter-season) crop or dry season crop (Aheeyar, 2000; Begum, 1987; Dharmasena, 2010a).

2. Bethma Cultivation

Bethma cultivation (bethma) is a temporary practice in water-stressed conditions where plots of land situated near the tank were shared with farmers who own plots further away from the tank. The extent of land owned by farmer families in the upper and lower reaches of the command area determines this temporary redistribution of land (Begum, 1987; Leach, 1961; Paranage, 2018a). Bethma was a common practice in the traditional villages in the dry zone of Sri Lanka. However, bethma is rarely practised today as observation of traditional customs, practices, and values has declined (Jayawardana & Wijithadhamma, 2015; Ratnayake et al., 2022).

3. Crop Diversification

The government promoted the cultivation of non-paddy crops in water-stressed areas to encourage farmers to use limited water resources efficiently. However, the literature indicates that farmers prefer paddy cultivation over non-paddy crops as government subsidies, legislation, and other supporting mechanisms (e.g. fertiliser subsidy) that favor rice farming (Kumara, 2016). Furthermore, high costs, labour requirements, and lack of access to quality seeds have been issues that prevented the adoption of diversification over the long term (Aheeyar, 2000; Begum, 1987; Kumara, 2016).

2.1.5 Social, cultural and ecological dimensions of STCS

Small tanks have been an essential component of rural farming communities for centuries. The small tanks and associated socio-cultural landscape link agriculture, religion and habitation aspects of a rural community (Paranage, 2018b; Shannon & Manawadu, 2007). In his celebrated anthropological monograph "Pul Eliya, A Village in Ceylon: A Study of Land Tenure and Kinship", Leach describes rural communities' social and cultural dynamics associated with a small tank system (Leach, 1961). Leach's research emphasised the role of small tank systems in the lives and livelihoods of people in a rural Sri Lankan village where the topography of the land, availability of water, the status of the land and climate are the critical determinants of village life (Leach, 1961).

Research has identified common patterns in small tanks and the surrounding landscape that provide essential services and functions to communities. Figure 6 shows the standard features of a small tank system in the dry zone of Sri Lanka. These features or components (more than 15) described by

Dharmasena (2010, 2011) provide ecological and social functions and vary with location. These features play a specific function. These include water filtration, reduction of runoff of silt into water bodies, demarcation of an area of the tank for livestock, and designation of areas for cultivation of perennial fruiting trees, shrubland for collection of firewood, upland rainfed farming (chena) and irrigated areas for paddy cultivation (Dharmasena, 2010b, 2010a).

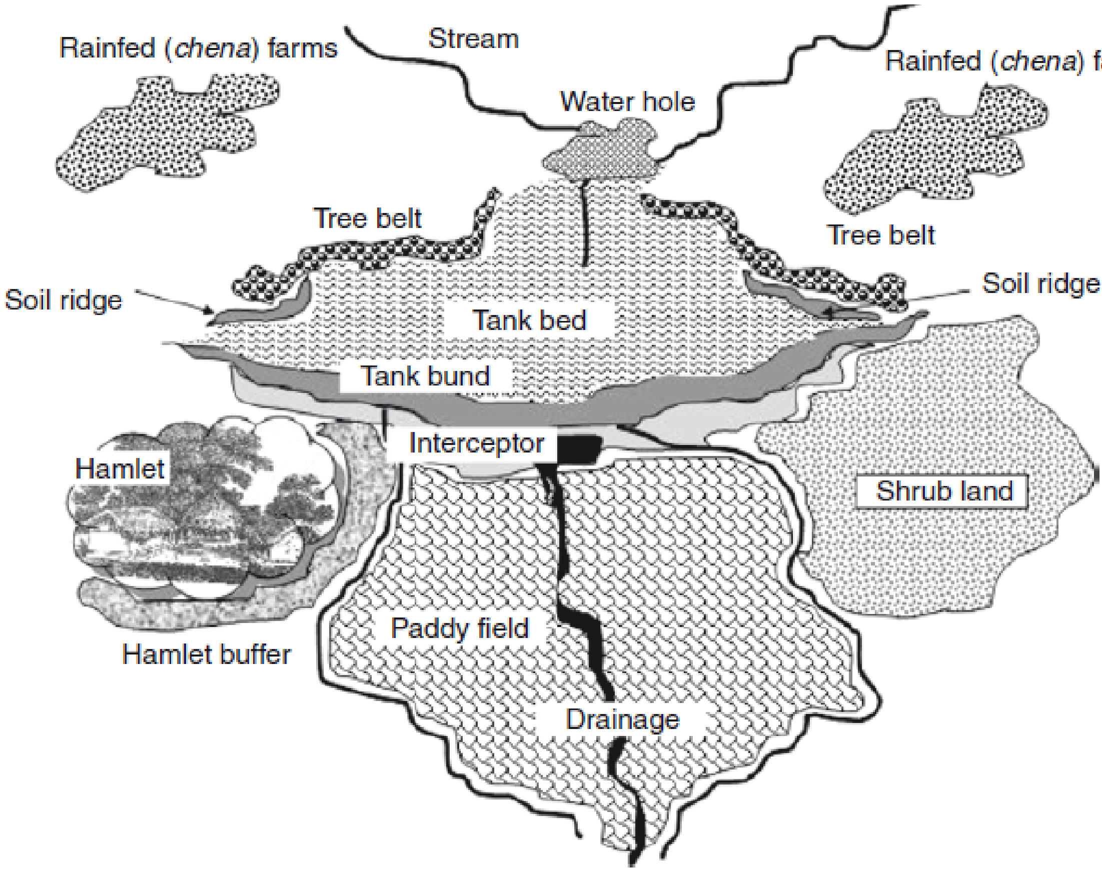

Figure 6 - Components of a traditional tank that provides various services (Dharmasena 2011, p.9)

British colonial administrators and the post-independence irrigation bureaucracy considered STCS as hydrological entities primarily designed for irrigation (Mendis, 1981). Emerging evidence shows that STCS are multifunctional landscape features that provide hydrological, ecological and social services to rural farming communities (Mendis, 1981; Panabokke et al., 2002; Tennakoon, 2000; Vidanage, 2019).

STCS are described as water conservation mechanisms adopted by early settlers to efficiently and effectively use a limited resource. STCS evolved over generations by adding new elements and features to enhance benefits and minimise any issues that emerged (Mendis, 1981; Tennakoon, 2000). There is increasing evidence that STCS were constructed primarily to manage water in a dry environment and systematically planned to maximise water use (Gangadhara & Jayasena, 2005; Jayasena et al., 2011; Kenyon et al., 2004; Shannon & Manawadu, 2007). Research demonstrates the ecological features of STCS and their importance (Geekiyanage & Pushpakumara, 2013; Marambe et al., 2012). These studies also identify various species assemblages associated with small tanks and related them to specific components (Dharmasena, 2011). A survey carried out by IUCN Sri Lanka inventoried the faunal and floral species in an STCS and compared them to natural systems. The study indicated that STCS and associated vegetation were comparable to natural dry zone forests. This study also identified threats and suggested strategies to improve ecological conditions (Goonatilake et al., 2015).

STCS resemble wetlands, as per the RAMSAR[6] definition. The benefits associated with tank goods and services underline their high economic and livelihood value to local communities. They also emphasise the importance of calculating direct values such as incomes from agriculture, fishery, plants collected as vegetables, livestock, and domestic use, as well as non-direct values such as aesthetics, tourism, flood attenuation, groundwater recharge, and nutrient and sediment retention. The value of these services has been estimated as USD 3,911 per hectare per year (Emerton & Kekulandala, 2003; Vidanage et al., 2005; Vidanage, 2019).

2.1.6 Current Status, Threats and Opportunities

The governance of small irrigation systems became gradually centralised since the middle of the 19th century (Abeyratne, 1985; Abeywardana et al., 2018; Panabokke, 2009). Some literature argues that farmer- or community-managed irrigation systems in Sri Lanka are a misnomer as the state or its agencies have authority over farmers or local communities (Abeyratne, 1985; Perera, 1985; Wijekoon et al., 2016). Policy and legal instruments related to irrigation management over the last two decades have not made significant changes to state authority despite provisions enacted to enhance farmer engagement (Paranage, 2018a; Perera, 1985)

Research highlights several contributory factors that led to the decline and degradation of STCS (Kekulandala et al., 2021; Shah et al., 2013; Vidanage, 2019). These factors include:

- Alienation of local communities from decision-making processes.
- Land fragmentation and complex tenure systems led to small landholding sizes.

[6] RAMSAR refers to the international convention on wetlands of international importance for migratory waterfowl. https://www.ramsar.org/about-the-ramsar-convention

- Prioritisation of large irrigation systems to cultivate and irrigate more extensive areas.
- Gradual abandonment due to silting, breaching of tank bunds, expansion of agro-well irrigation.
- Decreasing incomes from rice farming due to the high demand for non-paddy crops, private sector investments in commercial non-paddy agriculture, and low prices for paddy.

The institutional landscape for STCS has undergone significant changes over the last 74 years (since independence), where management responsibility has transferred from communities to a government bureaucracy (Panabokke et al., 2002; Shah et al., 2013). Government bureaucracy viewed STCS as inefficient irrigation entities, and the cost-benefit of rehabilitation was considered as low (Panabokke et al., 2000; Vidanage et al., 2005). The literature indicates that STCS are not merely irrigation systems but are multipurpose socio-cultural landscapes, where other services provided by STCS are arguably more critical than irrigation (Tennakoon, 2002; Vidanage et al., 2005). Small tanks show common property characteristics by providing many environmental goods and services to the community living in their vicinity that are often undervalued or neglected (Vidanage et al., 2005). STCS are viewed as a vital entity that facilitates the development of the rural economy in the dry zone of Sri Lanka to enhance social, cultural and economic advancement (Tennakoon, 2002). The literature also highlights several strategies that can be adapted to improve the productivity and sustainability of STCS. These include involving communities in decision-making processes, flexibility in land allocation for non-paddy crops, adoption of drought-tolerant crop varieties, crop diversification, support for rainfed upland cultivation (chena), cultivation of food crops in home gardens, improvements in fisheries, and improvements in land management (Panabokke et al., 2002; Tennakoon, 2002; Vidanage et al., 2005).

Currently, the development of STCS is considered a viable strategy to address emerging threats such as climate change, and literature suggests that STCS can buffer against climate variations and help sustain local communities. These indigenous agricultural systems encourage the incorporation of local knowledge, culture, values and norms into management and provide opportunities for local innovation (Abeywardana et al., 2019; Bebermeier et al., 2017; de la Poterie et al., 2018). Sri Lanka’s National Climate Adaptation Strategy 2016 recognises the importance of developing STCS to minimise future food security risks posed by climate change (Climate Change Secretariat, 2016a; Köpke et al., 2019; Ratnayake et al., 2021). The Green Climate Fund recently approved a joint project[7] proposed by the Government of Sri Lanka and UNDP Sri Lanka to explore the resilience of smallholder farmers in Sri Lanka's dry zone to climate variability and extreme events through an

[7] https://www.greenclimate.fund/project/fp016

integrated approach to water management (UNDP Sri Lanka, 2016). This large multi-year project is co-funded by the Green Climate Fund and the Government of Sri Lanka. The project started in 2017 and aims to establish STCS-based watershed management strategies to enhance the resilience of rural farming communities against climate change over 2017-2024.

2.1.7 Summary

Small tanks are an invention of the early settlers of the dry zone of Sri Lanka. The unique geomorphological characteristics of the landscape (narrow inland valleys and impervious soil conditions) and seasonality of rainfall led to the development of small tanks as reservoirs of water. Later, a series of tanks in narrow valleys were constructed to accommodate expanding populations enabling them to divert, use and re-use limited water resources. These are described as Small Tank Cascade Systems (STCS). STCS constructed and managed by local communities are based on the experience gathered over generations.

The knowledge on STCS has been growing steadily over the last 30 – 40 years due to renewed interest in these ancient irrigation systems. The established and emerging body of knowledge on STCS indicates that these are not merely irrigation entities but are integral components of the broader socio-cultural landscape that provide multiple social, ecological and cultural services to the communities. STCS are recognised as centres for developing the rural economy to improve the lives and livelihoods of local communities. Furthermore, rehabilitation and restoration of STCS could provide multiple economic and ecological benefits over the long term. The economic valuation of STCS indicates that indirect environmental, social and cultural values are much higher than the direct economic values from agricultural production, fisheries and recreation.

Recent research suggests that STCS are capable of buffering climate variations and reducing hydro-meteorological disasters. The restoration, rehabilitation and sustainable management of STCS are recognised as an adaptation strategy in key national policy documents in Sri Lanka. The government and multinational agencies have undertaken significant investments to rehabilitate STCS to improve the resilience of rural farming communities.

2.2 Climate Change impacts on rural agricultural and water storage systems in Sri Lanka

2.2.1 Introduction

Sri Lanka is a island situated at the southern tip of the Indian subcontinent between northern latitudes 5^0 55' - 9^0 5' and eastern longitudes 79^0 42' - 81^0 53'. The total land area is 65,610 km^2. As noted in Section 2.1.1, the island has three distinct elevational zones; a relatively flat coastal belt, undulating middle plain, and central highland (Jayawardena et al., 2022; Marambe et al., 2015). The central highland with the highest elevation of 2,514m creates mountain ranges, ridges and valleys that extend radially towards the coastal plains. Sri Lanka's position in the warm tropical Indian Ocean is associated with warm, humid air masses. Its proximity to the equator (intertropical convergence zone), central highlands aligned perpendicular to alternative tropical monsoons (southwest and northeast), and the large landmass of the Indian subcontinent are among the critical factors that govern its climate system (Marambe et al., 2015). Sri Lanka is divided into three climatic zones; dry, intermediate and wet (see Figure 4) based on the spatial distribution of rainfall, soil type, topography and vegetation (Marambe et al., 2015). Furthermore, Sri Lanka is divided into 46 agro-ecological zones based on monthly rainfall (75% probability) in addition to the variables used to define climatic zones (Marambe et al., 2015) (See Figure 7).

As Sri Lanka is a relatively small island situated close to the equator, there is little annual or seasonal temperature variation. However, there is a significant change in temperature with altitude. At lower elevations, temperature varies around 26.5^{0}C - 28.5^{0}C and around 15^{0}C at higher elevations of 1800m. Therefore, Sri Lanka's climate is predominantly determined by its rainfall regime. Furthermore, topography, elevation, seasonality and distribution of rain determine the spatial and temporal variability (see Figure 7) (Climate Change Secretariat, 2016a; Jayawardena et al., 2022; Marambe et al., 2015).

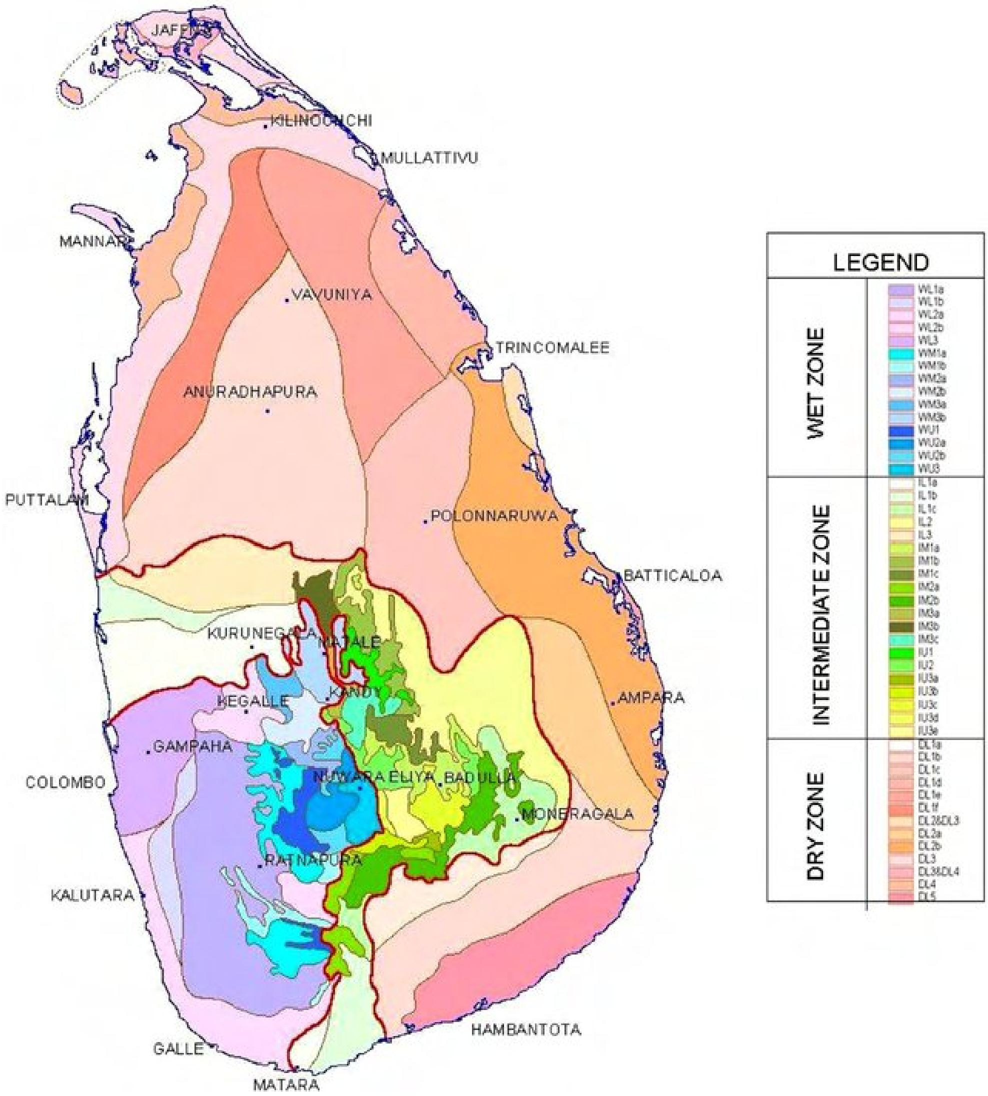

Figure 7 - Agroecological zones of Sri Lanka (Punyawardena, 2007)

Sri Lanka's mean annual rainfall ranges from 900 mm in the northwest to 5000 mm on the south-western slopes of the central highlands. There are three primary sources of rain; monsoonal, convection and synoptic weather formations (depressions) in the Bay of Bengal (Jayawardene et al., 2015; Marambe et al., 2015). The literature identifies four seasons based on the rainfall distribution (Eriyagama et al., 2010; Jayawardena et al., 2022; Marambe et al., 2015), and these are (see Figure 8 and Figure 9):

1. First Inter monsoon (FIM): March - April (convectional rains)

2. Southwest monsoon (SWM): May – September (monsoon rains)

3. Second Inter monsoon (SIM): October-November (depressional/convectional rains)

4. Northeast monsoon (NEM): December-February (monsoonal rains)

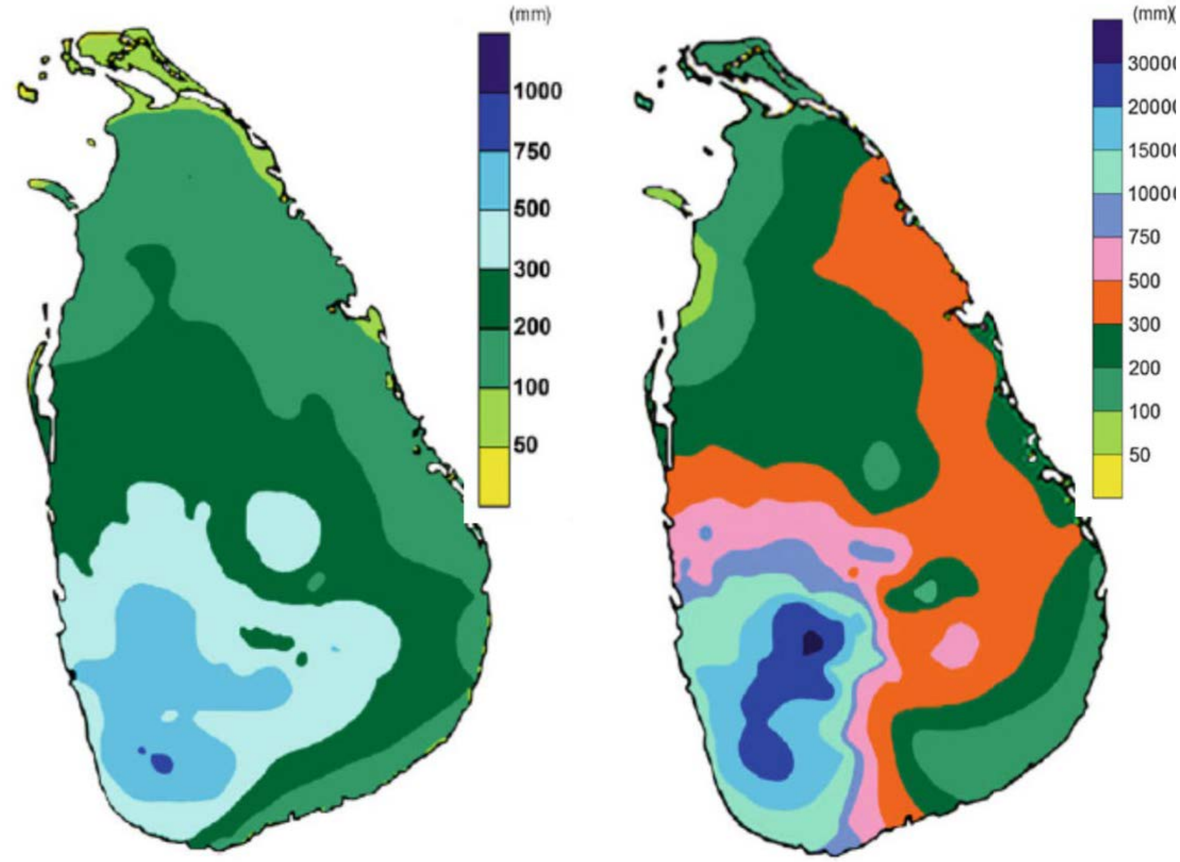

Figure 8 - Rainfall distribution during the first inter-monsoon (left) and the southwest monsoon (right) - (Marambe et al. 2015, p.1764-1765)

Sri Lanka's rainfall regime is bimodal cyclic and corresponds to two monsoons and two inter-monsoon events, cyclonic influences, orography (central highlands) and regionalisation of rainfall (Ahmed & Suphachalasai, 2014; Yahiya et al., 2009). The agroecological map of Sri Lanka (Figure 7) highlights the unique landscape diversity that has resulted from rainfall distribution and variation, elevational change, soil types and vegetation. The intermediate zone shows this high local diversity in the northeast, east and southeast slopes of the central highlands. The seasonal distribution of rainfall is the predominant factor that determines the agriculture pattern in the dry zone of Sri Lanka. Rainfall amount, distribution, and onset and the withdrawal of monsoon determine the cultivation seasons (Climate Change Secretariat, 2016a; Marambe et al., 2015).

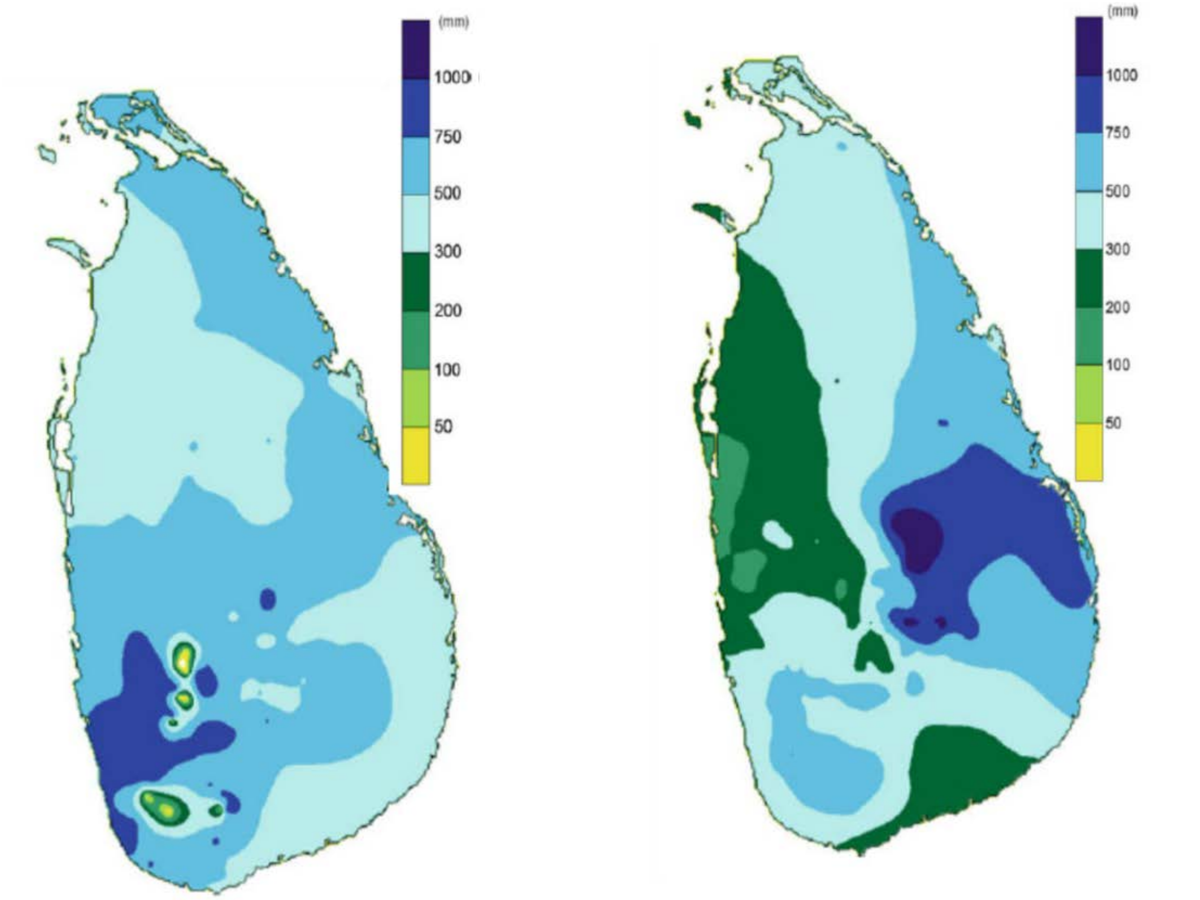

Figure 9 - Rainfall distribution during the second inter-monsoon (left) and northeast monsoon (right) (Marambe et al. 2015, p.1766-1767)

2.3.2 Observed and projected changes in the climate

A long series of historical weather records are available in Sri Lanka (since 1860 for some locations), especially for rainfall and temperature. These historical records have enabled several detailed analyses of trends observed in the climate record (Marambe et al., 2015). The literature also shows that various statistical methods and approaches, different periods and some weather stations (for data) were used in these studies. These diverse methods have led to divergent views on the historical trends for rainfall (Climate Change Secretariat, 2016a; Eriyagama et al., 2010). These divergent views are evident in the National Adaptation Plan for Sri Lanka 2016-2025 submitted to UNFCCC in 2016.

2.3.2.1 Temperature

There is a consensus among researchers on historical trends about temperature, and the ambient air temperature has increased gradually over the last century (Climate Change Secretariat, 2016a).

Long-term time-series data (1871-1990) indicate a significant warming trend throughout the country, especially towards the latter part of this period. The rate of increase has been observed as 0.016 ^{0}C per year from 1961 to 1990 (Ahmed & Suphachalasai, 2014; Eriyagama et al., 2010). It is interesting to note that Sri Lanka's 100-year warming trend 1896-1996 is 0.003 ^{0}C per year, and it is 0.025 ^{0}C per year in the last ten years (Eriyagama et al., 2010). Long term analysis of temperature data indicates strong evidence for warming in all climatic zones of Sri Lanka (De Costa, 2008; Selvarajah et al., 2021).

The future projections for temperature have been studied by three modelling approaches that include General Circulation Models (GCM), Regional Climate Models (RCM) and statistically downscaled GCM Projections (Eriyagama et al., 2010; Selvarajah et al., 2021). Coupled Modelled Intercomparison Project (CMIP) 5 data with Reconstructed Concentration Pathways (RCP) 4.5 and 8.5 emissions scenario shows that temperature projections for Sri Lanka s indicate a gradual increase in temperature towards the year 2100 (Ahmed & Suphachalasai, 2014; Selvarajah et al., 2021)

Regional climate model projections for Sri Lanka indicate consistent warming of 2^{O}C- 3^{O}C by the end of the century with a high degree of confidence (Ahmed & Suphachalasai, 2014). A temperature projections under RCP 4.5 and 8.5 scenarios indicate temperature increases from 2^{0}C to 4^{0}C These projections are consistant with the latest IPCC projections for South Asia (IPCC, 2021). However, the rate of change differs across studies (Jayawardena et al., 2022; Selvarajah et al., 2021). The national climate change adaptation strategy for Sri Lanka notes that atmospheric temperature is gradually rising all over the country (Climate Change Secretariat, 2016a).

2.3.2.2 Rainfall

Researchers have studied the rainfall regime of Sri Lanka extensively because long-term rainfall data have been available since 1860 (Climate Change Secretariat 2016). There are divergent interpretations of the historical changes and future projections, the three main views are summarised below (Climate change Secretariat, 2010; Climate Change Secretariat, 2016a; Eriyagama et al., 2010):

- Rainfall patterns are changed, but conclusive trends are difficult to establish.
- Rainfall has been decreasing (statistically not significant) over the past 30-40 years.
- No significant change in the mean annual rainfall, but the interannual variability is high (interannual or year to year variation of rains has increased)

- The latest IPCC working Group 1 report, climate change 2021 – Physical Science Basis notes that rainfall over south Asia will increase towards 2050 and then gradually decrease (IPCC, 2021).

Detailed analysis of Sri Lanka's monsoon rainfall over the 19th and 20th centuries has revealed a few statistically significant cycles: a 3.5-year cycle in most of central Sri Lanka from January to March and a similar length pattern in south-western Sri Lanka in October. Furthermore, a 2.1-year cycle for north-eastern Sri Lanka was observed from December to April (Malmgren et al., 2007). The spatial patterns of rainfall have been recognised in the literature and relate to four annual rainfall events that include the two monsoons and two inter-monsoons (Marambe et al., 2015; Suppiah & Yoshino, 1984).

There seems to be high confidence and consensus about the high interannual variability of rainfall (Climate Change Secretariat, 2016a; Marambe et al., 2015). Data also suggest that variability of seasonal rainfall has increased over the last decade (2001-2010) compared to the previous decade (1991 -2000) in most places across all climatic zones of the island (Jayawardena et al., 2022; Marambe et al., 2015).

A recent study on spatial and temporal variation of pentad rainfall (five-day aggregates) trends over the last 30 years in Sri Lanka concludes that there are high spatially and seasonally differentiated negative and positive trends. It further concludes that the central highlands and northern Sri Lanka show clearly defined negative trends for annual and seasonal rainfall (Wickramagamage, 2016). The study indicates that northern Sri Lanka shows a reduction in rainfall throughout the year, and this is significant during the second inter-monsoon period. It further suggests that the northeast monsoon has not undergone a downward trend in all areas, whereas the southwest monsoon shows a negative trend for all meteorological stations that the study investigated (Wickramagamage, 2016).

The projected changes in the rainfall regime are as diverse as observed changes. Furthermore, variances in the modelling and downscaling approaches under SRES scenarios have led to "confusing and sometimes contradictory" projections (Eriyagama et al., 2010). The projection outcomes (majority) for rainfall in Sri Lanka indicate higher mean annual rainfall, while few projections indicate lower mean annual rainfall (Eriyagama et al., 2010). These projections suggest that the dry zone of Sri Lanka will become increasingly drier, while the wet and intermediate zones will become increasingly wetter (Climate Change Secretariat 2010; Marambe et al. 2015; Climate Change Secretariat 2016). Projections also suggest that the onset and withdrawal of monsoons will change and vary (Marambe et al., 2015).

The significant issues that led to divergent model outcomes include resolution of GCMs/RCMs that fail to capture the topographic variation in Sri Lanka, the potential difference in baseline data, issues with statistical downscaling, the skill of the modeller and interpretation of emission scenarios for a small location such as Sri Lanka (Eriyagama et al., 2010; Selvarajah et al., 2021). Furthermore, revisiting and quality controlling existing studies, resolving issues about future projections, and setting up an RCM and SSP experiments considering Sri Lanka as the analysis domain could improve the current understanding and clarify divergent modelling outcomes (Eriyagama et al., 2010)

2.3.3 Impacts of climate anomalies on the general climate pattern

Literature shows that El Nino, La Nina, and Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Madden Julian Oscillation (MJO) and Quasi-Biennial Oscillation (QBO) alter the general climate pattern of Sri Lanka (Jayawardene et al., 2015; Malmgren et al., 2003, 2007). Surface and deep oceanic current patterns around Sri Lanka have a modulating effect on Sri Lanka's climate, but these have not been studied in detail (De Vos et al., 2014).

Rainfall in January-March, May, July-August and October-December shows a direct relationship to ENSO (Yahiya et al., 2009). El Nino in January-March and July-August leads to drier conditions, while La Nina leads to wetter conditions for the same periods, except for January-March. Rainfall declines from January to March for both El Nino and La Nina. The October-December period shows higher rainfall during El Nino than La Nina years, which is a departure from the general pattern where El Nino conditions lead to drier conditions (Malmgren et al., 2007; Yahiya et al., 2009).

A correlation between IOD and October-February rainfall (Maha[8] cultivation season) indicates that Maha season rainfall is enhanced by a positive IOD (Zubair et al., 2003). Several researchers discuss the relationship between IOD, QBO and Sri Lanka's rainfall, and they emphasise the need for further studies (Jayawardene et al., 2015; Malmgren et al., 2007; Zubair et al., 2003). The impact of MJO on Sri Lanka's climate regime is poorly understood, and limited data indicate that the positive phase of MJO leads to increased or extreme rainfall events in Sri Lanka. The extreme rainfall events that led to widespread flooding in December 2014 were attributed to a positive MJO event (Jayawardena et al., 2017).

[8] Maha refers to the cultivation season that starts September-October to February. This encompass both second inter monsoon and northeast monsoon. Rains during this period are often called as Maha rains.

2.3.4 Climate Change impacts on agriculture and water storage

Agriculture has shaped the economy of Sri Lanka since historical times; 85% of the population was engaged in agriculture or related activities by mid-1900, and the export of tea, rubber and coconut contributes almost 90% of Sri Lanka's foreign income (Climate Change Secretariat 2010). Sri Lanka has transformed into a more service-oriented economy over the last decades, and the contribution of the agricultural sector has declined to 10%-12% (Ahmed & Suphachalasai, 2014; Climate Change Secretariat, 2016a; Esham & Garforth, 2013). However, 70% of the population continue to live in rural areas, and farming is a significant livelihood activity (Climate Change Secretariat, 2016a; Esham et al., 2017). Furthermore, about 60% of the total cropland area of Sri Lanka is rainfed (Biradar et al., 2009).

The vulnerability of the agriculture sector to climate change is repeatedly emphasised by key national documents such as national climate change adaptation strategy, national adaptation plan, national action plan for Haritha Lanka Programme, Sri Lanka's comprehensive disaster management programme, draft agricultural policy and many other policy instruments (Climate Change Secretariat, 2016a). The projected changes in the onset and withdrawal of monsoon, an increase in the variability of seasonal rains, and an increase in consecutive dry days are the major factors that affect small farming communities (Marambe et al., 2015). The changes in the amount of rainfall and its distribution are predominant factors that affect rice cultivation in the dry zone. Almost 70% of the national rice crop is cultivated between September to February (during the second inter-monsoon and northeast monsoon) in the dry and intermediate zones of Sri Lanka (Eriyagama et al., 2010). The dry zone is critical for food production as most of the agricultural land is situated there (Esham et al., 2017). Projections clearly show the extreme vulnerability of dry zone areas to drought and extreme rainfall events (Amarnath et al., 2017). Small-scale farming systems that are already stressed due to non-climatic factors would be significantly vulnerable to changes in climate (Climate Change Secretariat 2010; Eriyagama et al. 2010).

Paddy cultivation plays a significant role in Sri Lanka's food security (Ahmed & Suphachalasai, 2014; Marambe et al., 2015). It has been negatively affected by the deficits and excesses in the rainfall amounts leading to severe crop failures (Ahmed & Suphachalasai, 2014; Suppiah, 1985). Maha (October to March) and Yala (April to August) are the two predominant cropping seasons that correspond to the seasonal nature of the rainfall regime in Sri Lanka (Yahiya et al., 2009). A study on paddy yield in two cropping seasons and annual rainfall from 1961-1980 shows there is a positive correlation between the paddy production and Maha season rainfall in dry zone districts, while many wet zone districts show a positive association between Yala rainfall and paddy production (Suppiah, 1985).

The vulnerability of Sri Lanka's staple crop (rice) to climate change is recognised in key policy documents (National Climate Change Adaptation Strategy 2011- 2016, National Adaptation Plan 2016-2025) and by many researchers (Zubair et al. 2003; Climate Change Secretariat 2010; Eriyagama et al. 2010; Marambe et al. 2015). For example, climate change-driven vulnerabilities of the agriculture sector were analysed during the preparation of the National Climate Change Adaptation Strategy 2011- 2016. The projections compiled from existing literature indicate key crops are vulnerable to temperature changes, drought, floods and sea-level rise (Climate Change Secretariat 2010). Some projected impacts on rice paddy include early or late-onset and withdrawal of monsoons leading to changes in cultivation seasons, and extreme rainfall events or droughts leading to crop losses, the proliferation of diseases/pests, increased water requirements (by between 13%-23% by 2050), and conflicts among water allocation for irrigation and other uses (Climate change Secretariat, 2010; Eriyagama et al., 2010; Marambe et al., 2015).

Rainfall variability is a significant constraint for agricultural production and economic growth, and climate change will exacerbate these limitations. Variability in rainfall will also lead to low recharging of groundwater and changed surface water storage and river flow (Jayawardena et al., 2022; McCartney & Smakhtin, 2010). Water will be a critical factor that indicates the societal stresses of climate change, and this will manifest through a significant seasonal variation of water availability, prolonged droughts and severe floods (McCartney & Smakhtin, 2010). Almost 70% of the land area of Sri Lanka is situated in the dry zone, where agriculture plays a significant role in sustaining livelihoods and local economies. The seasonality of the rainfall in the dry zone necessitates the storage of water (Dharmasena, 2010b; Esham & Garforth, 2013).

One hundred and three river basins in Sri Lanka drain radially from the central highlands to the coastal plains. Nearly 50% of the rivers in the dry zone have zero to very little flow during the dry months of the year (Eriyagama et al., 2010). Vulnerability mapping indicates that small tanks/irrigation systems in the dry zone of Sri Lanka are vulnerable to drought, and associated agricultural livelihoods would be affected as well (Climate Change Secretariat, 2010). Groundwater is extracted extensively for drinking and other domestic use throughout Sri Lanka; however, the impacts of climate change on groundwater supplies are not yet clear (Eriyagama et al., 2010).

Despite their importance, the ability of small tank systems in the dry zone to support food production is likely to be compromised due to a lack of investments in rehabilitation, maintenance and management (International Water Management Institute, 2010). This lack of investments in STCS and projected climate change impacts will have flow-on effects on the livelihoods of the rural population of Sri Lanka.

2.3.5 Summary

Sri Lanka's climate has changed significantly over the last century. The historical trends in temperature and rainfall show significant change. However, there are divergent views among the research community on the extent and magnitude of change. These views are more divergent for rainfall. The projected impacts of climate change are also diverse due to the application of various methodological approaches, data sets and emissions scenarios. A search for peer reviewed literature for CMIP6 data based climate projections for Sri Lanka did not provide any results. The climate projections and information in national documents are currently based on SRES scenarios with limited information on RCPs. This situation is a significant barrier to the development of long-term strategies to reduce future vulnerabilities in the agriculture and water sectors because the uncertainty associated with climate data makes planning difficult.

Rice production will be affected due to changes in intensity and duration of seasonal rains, prolonged droughts in the dry zone, and salt-water intrusion (from sea-level rise) in the coastal belt of Sri Lanka. Water storage and distribution for potable use and irrigation would likely create conflict among a range of water users. Associated rural water infrastructure, such as small tanks and channels, are already impaired through inadequate investment and maintenance and will be further affected due to prolonged droughts and extreme rainfall events. These will negatively affect the capacity of rural communities, potentially driving them to livelihood and food insecurity. Given the level of uncertainty around future climate and the significance of water to the agriculture sector, one of the foremost priorities for future research is to develop reliable climate scenarios for the country to aid the assessment of vulnerabilities of critical sectors of the economy, such as agriculture. Understanding the impacts of current and projected changes in weather/climate patterns on managing small irrigation systems, agriculture, forest, and fisheries is a priority. Local resource users are key stakeholders in managing natural resources. How these local resource users are involved in management processes, how the processes are impacted by current/projected climate change, and how strategies may be developed to minimise future climate risks are critical questions for further research.

CHAPTER THREE

Literature Review

This chapter explores the theoretical underpinnings of the main themes of my research. The chapter summarises the status of knowledge on broader NRM governance with an emphasis on water governance approaches that enhance food and livelihood securities, climate adaptation and adaptive co-management. The chapter is organised into three sections. Section 3.1 explores the broader NRM governance literature to summarise theoretical positions that guide my research, 3.2 explore the climate adaptation literature that summarises climate adaption in a water governance context, and 3.3 explore ACM literature and its potential as a governance approach to address complex social-ecological systems.

3.1 Natural Resources Management

Natural resources management (NRM) has received significant attention in the literature since the United Nations Millenium Ecosystem Assessment (MEA) highlighted the critical status of natural resources and the urgent action required to manage these resources sustainably (Lemos & Agrawal, 2006). NRM encompasses management actions around forestry, fisheries, agriculture and water (Dale et al., 2020; Lockwood et al., 2010). A vast array of governance strategies are adopted by local community groups, NGOs, state actors and international actors (Lemos & Agrawal, 2006).

NRM requires management actions at watershed/ catchment and landscape levels to preserve critical ecosystem services and functions (Lockwood et al., 2010). The recognition of complexity associated with NRM has led to the development of new governance arrangements. Furthermore, traditional NRM policy settings are considered unsuitable for solving cross-sectoral and multi-level problems associated with NRM (Allan et al., 2020; Lemos & Agrawal, 2006).

NRM governance received significant attention in the literature in America, Western Europe and Australia as governance arrangements shared between government, regional bodies and community (Dale et al., 2020; Lemos & Agrawal, 2006; Lockwood et al., 2010). The case studies and research evidence from multiple cases indicate several broader conditions that support sustainable natural resources management, facilliate the adapative capacity of the actors involved in the management process, and enable holistic solutions to complex resource governance problems. Lockwood et al., 2010, identify eight principles for the good governance of NRM: legitimacy, transparency, accountability, inclusiveness, fairness, integration, capability and adaptability. Researchers used these principles to assess the governance of resource systems in subsequent studies (Allan et al., 2020; Baird et al., 2021; Birnbaum et al., 2015; Dale et al., 2020; Huitema et al., 2016; Serrao-Neumann et al., 2019).

The following section explores the main NRM governance approaches emphasising water and water management, as my research focuses on a traditional water management system. The objective of this section is to explore main approaches to water governance and conditions that support adaptive governance.

Governance systems

The Global Water Partnership describes water governance as political, social, economic, and administrative systems in place to develop and manage water resources and deliver water services at different levels of society (Rogers & Hall, 2003). Water governance attempts to capture complex processes associated with water services for societal needs (Pahl-Wostl, 2017). The literature describes three approaches, centralized, decentralized and polycentric, for governing natural resources, including small irrigation systems. However, it is important to note that the notion of "governance systems", irrespective of the approach, constitutes multiple forms within each of these broad categories.

Centralized Governance

The literature indicates that in the 1970s and 1980s, there was a widely held presumption that the best strategy to govern natural resources was to transfer ownership and responsibility to a centralized government agency. It was presumed that large government agencies could manage the resource demands of the users and limit usage to avoid the depletion and degradation of the resource base (Andersson & Ostrom, 2008). This centralization of irrigation and resource management has continued to the present day, and in most developing countries, the government has become the sole owner of water resources. Furthermore, international aid agencies or multilateral development agencies often influenced the rules for irrigation governance (Ostrom & Gardner, 1993; Wilson & Inkster, 2018). The emphasis on introducing external solutions (institutional, management and infrastructural) to local communities resulted in the loss of traditional rights, marginalization of local communities, and loss of traditional knowledge related to farming (Ostrom & Gardner, 1993; Sithirith, 2017). However, this presumption that external inputs from state actors are needed to successfully manage local common-pool resources, such as water, stems from the colonial experience in many parts of the world, where colonial government agencies opened previously unirrigated areas for cultivating cash crops for export purposes (Ostrom & Gardner, 1993). Furthermore, centralization was a mechanism to consolidate the power of central (government) institutions and diminish the power of autonomous farming communities and their institutions. These issues were widespread in large irrigated agricultural systems where government agencies controlled every aspect of cultivation (Ghorbani et al., 2021; Moore, n.d.; Mosse, 1999; Scott, 1998).

Decentralized Governance

In the 1990s, decentralization was seen as an approach to addressing issues arising from centralized forms of natural resources management. However, the literature indicates that outcomes of decentralized policies on natural resources management have been mixed (Allan et al., 2020; Andersson & Ostrom, 2008). Although this literature does not indicate a consensus about the factors that led to mixed outcomes, several institutional aspects have emerged as concerns. The relationships among actors who have a stake in the governance of the resource have emerged as a key factor (Andersson & Ostrom, 2008; Bodin & Crona, 2009; Crona et al., 2011). The decision-making responsibilities to manage small-scale common-pool resources are localized in a decentralized system where resource users are self-organized. Self-organisation is facilitated through resource users' considerable local knowledge about the resource base, trustworthiness of the assembled group of individuals, reliance on the collective knowledge of the group, its ability to adapt collectively to changing contexts and the low costs of organization (Andersson & Ostrom, 2008; Meinzen-Dick, 2007; Ostrom, 2005).

The sustainability of decentralised governance systems has also received attention. Several factors affect the sustainability of a local self-organized resource user group. They include domination of a few individuals in the group, unwillingness of certain resources users to organize as they are reluctant to devote considerable time and energy, and failures of self-organization when outcomes of the organization do not meet the expectations of the resource users (e.g., farming community agrees to prioritize one crop over others and it fails to yield a good harvest) (Bixler, 2014; Ostrom, 2005). Other factors that affect the sustainability of a locally organized resource group include conflicts among resource users, lack of access to new knowledge, stagnation (when local innovation and experimentation stops) and inability to address issues arising from large-scale common pool resources with multiple user groups in several geographical localities (Gari et al., 2017; Ostrom, 2005; Ricart et al., 2018).

Water management at the basin or sub-basin level poses complex challenges as it provides multiple goods and services. These could interact with each other and, through interdependency, lead to a range of outcomes. Therefore, management interventions must map, understand and respond to this complexity through various institutional and governance mechanisms (Akamani, 2016; Andersson & Ostrom, 2008). Hence, creating institutions that promote free-market privatization, top-down, centralized control or bottom-up decentralization as the sole solutions is problematic. It is important to note that any governance system could operate successfully within a given set of conditions or context (Lockwood et al., 2010; Serrao-Neumann et al., 2019).

Polycentric Governance

Polycentric governance systems are seen as systems that have capabilities to adapt in changing contexts, where citizens can organize into multiple governing authorities at different scales, and each unit has the independence to make and enforce rules within a specified geographical area (Gotgelf et al., 2020; Huitema et al., 2009; Ostrom, 2005). In a polycentric system, some units could be generalised to government agencies while others could be specialized local institutions. In such systems, political authority is dispersed in separately constituted bodies with overlapping jurisdictions that do not stand in hierarchical order (Dale et al., 2020; Skelcher, 2005). How local communities are self-organizing to face their problems was one of the earliest interests in publications on polycentric governance. It was presumed that their skills and local knowledge placed them in an ideal position to solve the issues about their resource base (Akamani, 2016; Huitema et al., 2009). Polycentric systems have a high degree of overlap and redundancy. These redundancies are advantageous as a failure of one unit could be offset by others.

Furthermore, these systems are presumed to be more resilient and have capacities for responding to change and uncertainty (Huitema et al., 2009; Rouillard & Spray, 2017). Local resource users (local actors) contribute considerable knowledge about the local resource base in a polycentric system. This local knowledge, combined with external knowledge brought by actors at various levels in a polycentric governance system, could improve the resource base and enhance the knowledge of the local resource base and vice versa (Gari et al., 2017; Ostrom, 1990, 2005). Polycentric governance systems are considered best to address complex natural resources management issues. They provide flexible, responsive and adaptive mechanisms that capture the ecological, social and cultural dynamics associated with natural resources such as forestry, fisheries, and water. Furthermore, they provide opportunities for wide-ranging institutional responses at various scales appropriate for uncertainty and change within the system (Cash & Belloy, 2020; Cundill & Fabricius, 2009; Folke et al., 2005).

Institutional diversity is a key value in a polycentric system that brings knowledge, skills and capabilities to address complex resource governance issues (Ostrom, 2005). Polycentric institutional structures enable local governance arrangements that can be developed to match varied ecological and social contexts at different levels. They allow local level monitoring and provide early warnings to inform decision making processes. Also, they allow sharing and learning across multiple levels, hence enabling the possibility of developing interventions to address local issues and higher levels of organisation (Dale et al., 2020; Dietz et al., 2003; Lebel et al., 2006). Furthermore, institutional interactions across organizational levels can increase the diversity of responses that can address issues at various scales, vertically and horizontally. These responses can also deal effectively with uncertainty and change (Butler, et al., 2016; Fabricius et al., 2007; Hasselman, 2017). Small local user groups generally manage small components of a resource system (e.g., field canals of irrigation systems, some types of inland fishery). In contrast, government agencies manage large-scale entities such as reservoirs, coastal fisheries, or forestry. Hence, local user groups of collective actors are better suited to small spatial scale management while government agencies can coordinate across many user groups (Dale et al., 2020; Huitema et al., 2009; Meinzen-Dick, 2007).

There are certain disadvantages to a polycentric system as well. For instance, in such systems, there are multiple actors with different aspirations trying to work together, leading to a range of conflicting expectations or outcomes. Furthermore, the complex nature of interactions among these actors will make conflict resolution difficult and costly. Resolution of these conflicts could divert attention from governing the resource base and ultimately degrade it (Ostrom, 2005). Self-organization may be dominated by local elites that could use rules to their advantage. Equity concerns among participating actors and possible risks of extending state control over local resources are other issues associated with polycentric governance systems (Bixler, 2014; Ostrom, 2005). Accountability is also a significant concern in a polycentric system as responsibility is dispersed across various institutional entities horizontally and vertically. Therefore, new institutional entities may need to be formed or existing entities improved to address these issues (Arnold et al., 2017; Huitema et al., 2009; Skelcher, 2005).

3.1.2 Water Governance

Water is a common property resource, but related rights and entitlements are generally vested with the state or its agencies (Gari et al., 2017; Ostrom & Gardner, 1993; Scott, 1998)(Ostrom, 1990; Scott, 1998). State actors' legal and institutional arrangements often disregard the traditional community institutions that function on a set of commonly agreed norms and rules (Scott 1998). These changes led to the dilution of local institutions and the related resource base, as local users were marginalised from the decision-making processes (Shah, 2007; Van Koppen et al., 2007; Wijekoon et al., 2016). These marginalisations led to the exploitation of the resource base by individuals depending on their social and financial capital. Furthermore, certain groups of individuals could exploit the resource base more than others, often leading to conflicts and abandonment of collective responsibility to maintain it (Ostrom & Gardner, 1993). Therefore, incorporating social norms into the institutions that manage local water storage is a critical factor in its success (de la Poterie et al., 2018; Ghorbani et al., 2021; Ostrom & Gardner, 1993).

Water management in small farming systems is critical for rural communities' food and livelihood security. Research indicates that there are several common characteristics of these systems that include local-level governance and associated institutional structures, community-derived laws, rules and customs, participation and high social capital (Bruns, 2007; Gari et al., 2017; Ostrom, 1990, 1992, 1993, 2005; Ostrom & Gardner, 1993; Ricart et al., 2018; UNCTAD, 2011; Uphoff, 1986; Van Koppen et al., 2007; Yang, 2018). These are characteristics of adaptive water governance. They are further explored below within the context of the management of small irrigation systems.

Institutions for water governance

Institutions are a critical element in a governance system. The institutional structures for governing local water resources have received considerable attention in the literature (Gari et al., 2017; Hassenforder & Barone, 2019; Ostrom, 1992, 1993, 2005; Ostrom et al., 1999). The term 'institution' constitutes multiple connotations and has been broadly defined as 'the prescriptions that humans use to organize all forms of repetitive and structured interactions including those within families, neighbourhoods, markets, firms, sports leagues, churches, private associations, and governments at all scales. Individuals interacting within these rule structured situations face choices regarding the actions and strategies they take, leading to consequences for themselves and others' (Ostrom 2005 p.3). However, in an irrigation and local water storage context, institutions have been described as a set of rules used by a group of individuals to organize repetitive activities that produce a set of outcomes affecting those individuals and potentially others' (Ostrom 1992 p.19). Specifically, an irrigation institution is a set of rules for supplying and using water for irrigation in a particular location and provides scope to include both formal and informal decision making processes for managing that water (Ostrom, 1992).

Next, local and traditional institutional structures employed in many parts of the world are reviewed to identify common characteristics. Furthermore, the literature recommends several design principles as key elements for a sustainable institution for water and irrigation management (Ricart et al., 2018; Rouillard & Spray, 2017; Bruns, 2007; Ostrom, 1992, 1993, 2005) and these are discussed as well.

Informal institutions are often designed to address specific physical, cultural and economic conditions of a particular location. The institutional design of such entities is often based on experiences and knowledge of local communities gathered through many generations. These rules generally had provisions to forbid, permit and require particular activities to manage the water resource. Conversely, formal institutions are governed by law, act or set of guidelines enacted by a national, sub-national or local government agency (Altieri & Koohafkan, 2008; Lockwood et al., 2010; Ostrom, 1992, 1993; Ostrom & Gardner, 1993; Panabokke et al., 2002).

The literature on irrigation institutions has attempted to identify a set of characteristics associated with the success of such institutions and their sustainability over time. These were developed into eight design principles by Ostrom (Ostrom, 1990, 1992, 1993). These are shown in Table 2.

Table 2 - Design principles for a long-lasting irrigation institution (summarized from Ostrom 1993)

Principle	Description
Clearly defined boundaries	Boundaries of the area that include individuals or households with rights to use water are clearly defined
Proportional equivalence between benefits and costs	Rules and conditions that specify the amount of water that a person is allocated and his/her responsibilities (labour, material or money requirements)
Collective choice arrangements	Most individuals affected by operational rules are included in the group that can modify these rules.
Monitoring	Actively looks after the physical conditions of the systems and behaviour of users to ensure these are within agreed rules and norms.
Graduated sanctions	Users who do not observe the agreed rules receive sanctions about the seriousness of the offence.
Conflict resolution	Users and officials have ready access to low-cost local-level conflict resolution mechanisms. These could be defined by rules agreed by users.

Minimal recognition of rights to organize	The rights of users to develop their institutions should not be challenged by government agencies.
Nested enterprises	The governance of the resource is organized in multiple layers at a given location.

The design principles are general, and the importance of individual principles varies with the context of their application (Ostrom, 1993). These principles are largely supported by subsequent research specifically designed to evaluate their applicability (Bruns, 2007; Cox et al., 2010; Gari et al., 2017). However, it is difficult to assess the success of these design principles as there could be many other factors that affect the success or failure of an institution (Gari et al., 2017). Some studies have suggested a reformulation of certain design principles and have suggested a diagnostic approach to managing common property resources such as water (Cox et al., 2010). This is further illustrated by Ostrom's own and others' work on diagnostic approaches for managing resources (Anderies et al., 2004; Meinzen-Dick, 2007; Ostrom, 2007, 2009). Subsequently, research has focused on institutional characteristics of complex social-ecological systems where multiple actors might be involved in managing particular resources in a given location (Anderies et al., 2004; Huitema et al., 2009; Ostrom, 2009; Ostrom et al., 2007). The recent literature also highlights the importance of developing diagnostic frameworks to analyse and understand the issues about complex social-ecological systems such as water, forestry and fisheries. Furthermore, research also indicates that such approaches provide significant insights on how various actors interact in managing a resource, how rules are evolved, negotiated and agreed upon, how institutional structures evolve and how external actors could strengthen or disrupt a system (Anderies et al., 2004; Bosomworth et al., 2017; Folke et al., 2005; Leith et al., 2014; Ostrom, 2009).

Locally derived norms, rules or laws

Norms are identified in the literature as an important element for managing local water resources (Ostrom & Gardner, 1993; Van Koppen et al., 2007). Norms are described as widespread established behaviour or specification of a desirable behaviour within a particular community (Kandori, 1992; Truelove et al., 2015). Norms often accompany sanctions and enforcement (Burke et al., 2006; Fujitani et al., 2017; Kandori, 1992). Norms provide strong incentives for people to come together, as adherence to norms provides mutual benefits, and they also help collective action and facilitate the process of institutional development (Fujitani et al., 2017; Kandori, 1992). Norms may change and evolve as the resource base or community changes over time and can be absorbed into formal legal frameworks (de la Poterie et al., 2018; Ostrom, 1990).

The ability of communities or users to develop and enforce norms and rules that govern the usage of local water resources has been recognized as an important factor in using the resource (Kuehne, 2014; Ostrom, 1990; Van Koppen et al., 2007). Locally derived rules are considered an important element in developing a durable irrigation institution as these can capture the ecological, social and economic dynamics of the location. Furthermore, they also provide opportunities to adapt and change the rules when necessary to match the changing conditions (de la Poterie et al., 2018; Ostrom, 1993; Šūmane et al., 2018). Community-based rules or laws provide opportunities for resource users to bring their knowledge and experiences gathered through generations to address issues associated with the resource. These also enable communities to experiment with rules and change them according to local needs (Perreault, 2014; Van Koppen et al., 2007). Community-based laws and rules can absorb and adjust to external interventions of state agencies and complement national and sub-national laws and policies (Mukherji et al., 2009; Rogers & Hall, 2003). While such rules and laws can be very effective in a local context, they may not be effective outside the local setting because they are generally entrenched in a specific context (Jayawardana & Wijithadhamma, 2015; Van Koppen et al., 2007). Therefore, generalising the costs and benefits of a particular set of rules or laws across various geographies or social settings is challenging. These rules could lead to the marginalization of some individuals or community groups (e.g. caste-based access to resources) and the domination of local elites (Ostrom, 1990; Shah, 2007; Van Koppen et al., 2007; Butler et al., 2016).

Community derived laws (customary laws) and rules can play a significant role in managing a local resource but need to be supported by laws and policies of national or sub-national governments (Rogers & Hall, 2003; Scott, 1998; Sithirith, 2017; Webler et al., 2001). However, such top-down legal frameworks frequently fail to recognize community laws or rulemaking processes (Bruns, 2007). The centralization of resources management in many parts of the world has led to the abandonment of local rules and laws (Andersson & Ostrom, 2008). The literature on complex socio-ecological systems and polycentric governance suggests that community laws and rules could play a significant role in managing rural water resources and complement efforts to govern them across multiple localities (e.g., organization of sub-catchment level water users at a basic level) (Anderies et al., 2004; Fujitani et al., 2017; Neef, 2009). Polycentric governance also provides opportunities for local communities to re-engage with local laws, rules and customs to complement efforts to address issues about managing a particular resource (Anderies et al., 2004; Andersson & Ostrom, 2008; Neef, 2009; Van Koppen et al., 2007).

Participation

Participation is a concept that has been widely canvassed in the literature, and here it is discussed in the context of the management of small-scale irrigation schemes. The literature on participation extends from the participation of a particular group, such as farmers (Aheeyar & Smith, 1999; Cejudo et al., 2020; Huitema et al., 2016; Uphoff, 1986), to multiple groups or a variety of stakeholders (Barron et al., 2008; Cunningham et al., 2016). A review of irrigation water management and farmer participation (Uphoff 1986 p.5) identified three characteristics:

- Participation is not a single entity but a category that incorporates many specific kinds of activities, which water users can engage in;
- Participation will be more predictable, productive and sustainable if it is channelled through organizations appropriate to the tasks of irrigation management; and,
- The physical nature of irrigation systems establishes different levels of operation, and the kinds of participation that are appropriate will vary according to where management activities occur in a system.

The published evidence also argues that participation in irrigation management is multi-faceted and includes water, infrastructure and social organization (Eakin et al., 2016; Tengö et al., 2021; Uphoff, 1986). The multi-faceted nature of participation is represented in the design principles (see Table 2) for irrigation institutions (Ostrom, 1990, 1993). The next section discusses various aspects of participation.

Participation is identified as an important factor in successful institutions that govern common pool resources such as water (Gari et al., 2017). Participation in terms of collaboration between various actors for governing common-pool resources is vital as it improves the decision-making processes by opening access to better information. Furthermore, participation can improve the public understanding of the management issues, improve transparency in decision making, and provide inputs and monitoring processes (Barron et al., 2008; Gari et al., 2017; Huitema et al., 2009). However, institutional structure and the related governance mechanisms, and the space for local community involvement in decision-making processes are vital elements that determine the success of participation in managing local water storage (Ostrom, 1993).

The literature highlights the advantages of participation as it promotes trust, deliberations and shared understanding that is needed to mobilize communities for self-organization (Lebel et al., 2006). Participation of users of common-pool resources has certain advantages as they have detailed knowledge of the dynamics of the resource, can undertake collective action and have a responsibility to reduce the probabilities of over or destructive use. Also, it is easy for participants to engage in management during their day to day activities, monitoring and management costs are relatively low, and feedback mechanisms are rapid and able to adjust and change practices collectively (Cain et al., 2003; Cvitanovic et al., 2019; Toole et al., 2009)

Several factors affect participation and hence the success of participatory resource governance programmes, including legitimacy, conflicts, inequity, local incentives and context (Bruns, 2007). Legitimacy refers to the recognition of the rights of the participants to engage in managing the resource. This is extremely challenging in many parts of the world as most natural resources are centrally managed through a government bureaucracy (Shah, 2007). The experience from large-scale irrigation systems indicates government agencies and officers may be reluctant to involve communities in decision-making processes (Mosse, 1998; Shah, 2007; Wijekoon et al., 2016). Conflicts are an issue when individuals from the same resource group have different opinions, and these can escalate if proper conflict resolution mechanisms are not built into institutions that promote participation (Ostrom, 1990). Inequity within a group can occur when certain decisions benefit some individuals but not others. The conflict between head-enders (farmers of the head or upper part) and tail-enders (farmers of the bottom or lower part) of an irrigation system is an example of such a situation (Ostrom & Gardner 1993). The domination of local elites is another factor that could affect participation and collective responsibility (Barron et al., 2008; Ostrom, 1990; Ostrom & Gardner, 1993). Participation of local resource users in managing a particular resource depends on the context of the resource (Berkes, 2009; Nguyen et al., 2016; Šūmane et al., 2018). For example, the participation of resource users in the management of a fishery in a small inland lagoon may be much less complex than managing a watershed (Bruns 2007). Therefore, the participation of resource users to manage complex resource systems has to be planned and supported over the long term to achieve success (Bruns, 2007; Ghorbani et al., 2021; Roncoli et al., 2002).

Social Capital

The literature indicates that shared norms and participation are among the key elements that contribute to developing social capital in a community (Ostrom, 1990). The term 'social capital' became increasingly popular in the latter part of the 20th century, and this led to its theoretical development (Portes, 1998). The literature suggests that several aspects of what constitutes social capital were developed at various stages in Europe and North America, and these have contributed to the current understanding of the concept (Bourdieu, 1998; Coleman, 1988; Portes, 1998; Putnam, 1995; Siisiäinen, 2000; Woolcock, 1998). These multiple definitions and descriptions of social capital are highlighted by Adler & Kwon (2000 p.91). Siisiäinen (2000) emphasises two perspectives:

1. Social capital is described in terms of norms, obligations, trust and social networks (Putnam's view); and,
2. Social capital as a resource that facilitates social struggle in society (Bourdieu's view)

The social organization has been a key component of both perspectives and highlights shared values and obligations, trust and participation in a network comprised of actors with similar values (Siisiäinen, 2000). Furthermore, both Portes (1998) and Woolcock (1998) identify several characteristics of social capital, and these illustrate the elements espoused by Putnam (Putnam, 1995; Siisiäinen, 2000):

- Relationships and exchanges between individuals may lead to co-operation;
- Common rules, sanctions, and norms may be developed and handed down to a group or larger society; and,
- Connectedness and networks can describe access to institutions and external services.

The conflicts and power issues that arise among various actors in a social organization could significantly affect the relationships, values and trust (Siisiäinen, 2000). The literature entails significant debate on the merits of different perspectives (Adler & Kwon, 2000; Coleman, 1988; Siisiäinen, 2000). For this research, social capital is considered as a societal characteristic that enables various actors to participate, develop rules and norms and engage in networks for managing small irrigation systems.

In the context of small irrigation systems, social capital provides a useful conceptual and policy device to contribute towards social and economic development and address complex social-ecological problems through an interdisciplinary approach (Feist et al., 2020; Woolcock, 1998), supports better water and sanitation delivery (Kähkönen, 1999), and is a key component in institutional development for natural resources management (Barron et al., 2008; Ostrom, 1990; Van Koppen et al., 2007). The initial social capital of a community in terms of existing community organizations, customs, rules, common interest, and willingness to participate are key determinants of a successful water management intervention. Furthermore, it provides an entry point to develop the necessary capacities for successful water management interventions (Barron et al., 2008;

Beratan, 2014; Kähkönen, 1999). This is further validated by other research in Nepal and East Africa, where similar conclusions have been made (Ostrom & Gardner, 1993). In Sri Lanka, research carried out in major and minor irrigation systems has concluded that initial social capital, recognition, promotion and investment in social capital are critical for engaging farmers of local communities in water management (Dayaratne, 1991; de la Poterie et al., 2018; Köpke et al., 2019; Moore, n.d.; Panabokke et al., 2002).

Social capital also possesses public and private elements that facilitate association and networking (Adger, 2003). The institutional structures of a state actor might provide an opportunity for people to come together and develop a relationship. However, state interventions could also lead to the degradation of those relationships (Adger, 2003). Social capital plays an important role in accessing and utilizing natural resources such as fisheries, forests and water sources for individuals and societies, where local resource users come together to manage the resource for mutual benefit (Auer et al., 2020; Butler et al., 2016; Campbell et al., 2002; Feist et al., 2020). Evidence also indicates that social capital alone does not ensure the successful performance of a water or sanitation system (Kähkönen, 1999). There are many external factors such as legal, institutional and policy frameworks that directly impact the rights of a community to manage its resources. These interventions from state actors may, in some instances, lead to the destruction of social capital and create conflict that might, in turn, lead to the degradation of the resource (Kähkönen, 1999; Van Koppen et al., 2007).

Based on the above literature review, some key themes for an adaptive water governance system can be identified that include polycentric governance, strong social capital, participation and collaboration, appropriate and supportive local laws and rules/norms, and an experimental approach to resource management. These essential elements are embedded in the scholarship on adaptive co-management (Huitema et al., 2009; Plummer et al., 2017; Plummer et al., 2012).

3.2 Climate adaptation in water governance

The IPCC WG2 report on impacts, adaptation and vulnerability notes that 3 to 4 billion people are exposed to water scarcity at 2°C and 4°C global warming levels (GWL). Furthermore water-related risks may increase the vulnerability of people in more vulnerable and exposed regions (Caretta et al., 2022). Water Security in Climate Change and Climate Resilient Development is a critical pathway for achieving sustainable development goals. Water security is critical as it safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development. It also ensures protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability (Caretta et al., 2022). Therefore, building resilience in water systems by adaptation and transformation is a priority as the compounding effects of climate change expressed as greater societal stressors (Baird et al., 2021).

Adaptation incorporates changes into social-ecological systems that facilitate system-level responses to ongoing and future climate risks (Rickards & Howden, 2012). The dearth of research on addressing barriers to climate adaptation (Lee et al., 2022) compels researchers and policymakers to consider a range of actors across multiple scales (Baird et al., 2021). Climate adaptation provides multiple avenues for action. The focus on the limits of social and ecological systems to tolerate climate risks seeks to adjust those limits (thresholds or tipping points) through targeted action (Rickards & Howden, 2012). This approach seeks to support low-regret actions that provide social, ecological and economic benefits to targeted communities (Holler et al., 2020; Park et al., 2012). Transformational adaptation, that is adaptation action that results in fundamental reorganisation of system structures, properties and control, occurs across multiple scales and levels over long time scales. Transformational adaptations seek to change the social, cultural, economic and ecological use, norms and values to minimise the vulnerability to climate change (Gotgelf et al., 2020; Holler et al., 2020; Rickards & Howden, 2012). Transformational adaptation is the appropriate response to climate change as it seeks to develop system resilience across multiple scales (Béné et al., 2018). However, significant barriers exist, such as costs, short-term government policy processes, accessing and sharing local climate information, and locally relevant decision-making (Cunningham et al., 2021; Ghorbani et al., 2021; Gotgelf et al., 2020; Park et al., 2012).

In the water governance context, climate adaptation needs to recognise the complex interplay of physical, social, ecological and environmental considerations (Baird et al., 2021; Gotgelf et al., 2020; Quealy & Yates, 2021). In water management settings, decisions for managing these resources are a critical consideration. A review of climate change perceptions of agriculture/ water managers found that the challenges of communicating climate and weather information to farmers are a significant barrier (Lee et al., 2022; Mase & Prokopy, 2014). Further evidence also suggests that a mismatch between the place-based local knowledge of farmers and centrally developed climate information leads to mistrust (Ghorbani et al., 2021; Mase & Prokopy, 2014; Šūmane et al., 2018). Trust is a significant consideration for developing linkages between various actors in managing water (Baird et al., 2021). Therefore codeveloping locally relevant climate information and communicating climate information in a locally relevant manner is critical to enable climate adaptation (Cash & Belloy, 2020; Cunningham et al., 2016).

Climate adaptation requires the participation of all actors that manage, benefit or are impacted by a specific resource (e.g. water). Therefore, identifying and engaging these actors are critical to adaptation. The literature indicates that designing and implementing adaptation actions without the participation of all actors could lead to conflicts, and fails to achieve desired outcomes (Bodin & Crona, 2009; Schnegg, 2018). Therefore, untangling and identifying key actors and their roles and responsibilities are essential for identifying existing risks and developing adaptation actions (Ensor et al., 2019; Lauber et al., 2008; Šūmane et al., 2018; Tran et al., 2019). A growing body of evidence suggests that incorporating local and informal institutional knowledge in climate adaptation processes can mitigate the issues associated with formal institutions (Ghorbani et al., 2021; Gotgelf et al., 2020; Quealy & Yates, 2021; Šūmane et al., 2018). In a systematic literature review on barriers to climate adaptation (Lee et al., 2022), the authors highlight the following as critical: recognition of the importance of various actors at different levels and the mechanism that prevents them from collaborating, acknowledgement that current research about barriers does not provide a deeper understanding of their causes, consequences and how to address them, and the need for further research on climate adaptation barriers (Lee et al., 2022).

This literature review in previous sections highlights some key themes for an adaptive water governance system. In summary, they incorporate polycentric governance, substantial social capital, participation and collaboration, appropriate and supportive local laws and rules/norms, and an experimental approach to resource management. These essential elements are embedded in the scholarship on adaptive co-management (Huitema et al., 2009; Plummer et al., 2017; Plummer et al., 2012).

3.3Adaptive Co-Management

The adaptive co-management (ACM) scholarship evolved in the natural resource management literature and is a specific type of adaptive governance that incorporates flexible community-based resource management systems tailored to specific places and situations and supported by organisations working at different levels or scales (Olsson, Folke, & Berkes, 2004; Plummer et al., 2012). Although there are some uncertainties about the term's origin, it is believed that adaptive co-management originated in a CIFOR – Centre for International Forestry Research project in 1997

(Plummer et al., 2012). ACM is increasingly recognised as an approach that could reconcile complex issues created in natural resources management interventions. ACM is an approach that combines:

- Adaptive management: focusing on learning by doing through learning and adaptation over medium to long time scales; with,
- Co-management: focusing on linkages across institutions and resource users to build relationships and promote participation and engagement.

The ACM approach facilitates efforts to address complex social-ecological problems (Armitage et al., 2009; Baird et al., 2021; Folke et al., 2002; Olsson, Folke, & Berkes, 2004; Plummer et al., 2012). ACM scholarship has debated the characteristics, advantages and disadvantages of ACM and its application to real-world problems, in addition to developing the evidence base for nearly three decades. The literature on ACM has gone through several reviews, and a gradual consensus is emerging. This consensus is summarised as follows:

- ACM combines social-ecological dynamics and learning about how to respond to environmental feedback. ACM has the potential to enhance the capacity of resource users and institutions to deal with uncertainty and change (Olsson, Folke, & Berkes, 2004).
- In ACM, the capacity to deal with complex issues is distributed across various connected actors at different levels. These actors operate within different centres. Therefore, interconnections and coordination become very important. Furthermore, they open up opportunities for pooling expertise and collaborative learning (Olsson, Folke, & Berkes, 2004).
- ACM aims to solve resource management issues through collaboration and foster ecologically sustainable livelihoods (Galappaththi et al., 2022; Plummer & Armitage, 2007).
- ACM is not a governance panacea and will not be appropriate in all cases. Researchers are trying to identify specific conditions that enable ACM to succeed (Armitage et al., 2009).
- ACM must be considered a tool in a suite of governance options. Conventional institutional mechanisms, rigid legal and institutional structures, and social and marketing incentives could complement ACM (Armitage et al., 2009).
- The emphasis on trust-building, institutional development, and collaborative and social learning are important elements in ACM that facilitate inclusive and sustainable governance (Armitage et al., 2009; Colding & Barthel, 2019)

Despite these positive attributes, some shortcomings also have been identified. For example, a systematic review of the existing literature (Hasselman, 2017; Plummer et al., 2012) has revealed that the definitional clarity of ACM is insufficient, leading to imprecision, inconsistency and confusion in the concept. Also, robust evidence needs to be developed to understand the concept better. Hence rigorous theory development is essential (Plummer et al. 2012). While ACM works across levels and scales, it usually focuses on an identifiable landscape. Plummer (2013) suggests that further attention is needed to identify how changes prompted by ACM might cascade upwards. He further suggests that ACM might help to address climate change adaptation issues by providing a viable pathway to foster governance, build capacity and enable various actors to address changes brought about by climate change.

Understanding contextual differences and applicability have been identified as significant issues as most ACM literature published in North America and Europe concentrates on case studies from those regions. There is a major concern about the lack of research and case studies from other parts of the world, especially from Africa and Asia (Plummer et al., 2012). The notable exceptions are CIFOR's (Centre for International Forestry Research) research in Asia (Plummer et al. 2012) and a 4-year governance-related experiment on mainstreaming adaptation pathways in local level planning in Nusa Tenggara Barat Province of Indonesia (Butler et al., 2016). The ACM literature has grown significantly since 2017 with several case studies from developing country contexts. These case studies and research evidence include applying ACM in the Vietnamese Mekong delta to examine the interface between flood management and adaptation (Tran et al., 2019), ACM and sustainable tourism management in protected areas in Bangladesh (Islam et al., 2018), ACM and ecological transformation of peri-urban east Kolkata wetlands (Roy-Basu et al., 2020), AMC and knowledge co-production in an Amazonian indigenous community (Matuk et al., 2020).

Differences in socio-political context make it challenging to transfer ACM learnings to replicate successful practices elsewhere (Plummer et al., 2012). Most of the case studies from North America and Europe take place in the context of high social capital, existing institutional structures, incentives for collective action, and supportive policy and legal instruments (Olsson, Folke & Berkes 2004; Plummer et al. 2012). In Indonesia, the weak institutional structures, unpredictable policy frameworks, and lack of trust among key stakeholders (government agencies and communities) are significant barriers to realising ACM. These studies concluded that long-term facilitatory processes are needed to resolve conflicts and build trust among key stakeholders (Butler et al., 2016).

The goal of ACM is another issue that is not settled in the literature. There is significant variation in goal setting for ACM, ranging from knowledge generation and integration to improved sustainability and resilience (Berkes, 2017; Colding & Barthel, 2019). This variation is a significant issue that makes a systematic evaluation of its effectiveness problematical and has led to difficulties in evaluating outcomes of ACM research and establishing generalisable patterns (Hasselman, 2017; Plummer et al., 2012)

There are multiple research pathways to ACM study, which have resulted in multiple research methodologies and approaches, which lead to difficulties in generalising the evidence and outcomes. A diagnostic approach with a framework has been suggested as a strategy to unify various methodological approaches and build up a database of case studies to strengthen the evidence base (Plummer et al., 2017).

3.4 Summary

The literature review explored three themes underpinning my research and provided a broader context. The main outcomes of the review are summarised below.

Water management in agriculture is a major challenge for food production to ensure food and livelihood security for a growing population. Water governance (i.e., small irrigation systems) will need to respond to risks posed by socio-economic, cultural and political changes. Projected changes in seasonal weather/climate will exacerbate or multiply these risks. Therefore, adaptable and flexible mechanisms are envisaged for water governance. The evidence base has grown over the last few decades for the efficacy of polycentric governance and appropriate institutional mechanisms for managing common-pool resources such as water, fisheries and forests. Strong experimental evidence indicates that polycentric governance, collaborative rulemaking (that captures local context), community-derived laws, rules and customs, flexible, self- and facilitated organisation of local actors (participation), and high social capital could provide significant benefits to the management of local common-pool resources.

Furthermore, such institutional structures and governance mechanisms are seen as essential to address challenges posed by climate change. The literature indicates that many elements in traditional management systems can be promoted and strengthened to enhance communities' resilience and adaptive capacity and assets. Adaptive Co-management (ACM) is receiving significant attention as an approach that provides co-benefits for managing common-pool resources and adaptation to climate change. The literature and evidence for ACM are still growing, and the current focus in the ACM scholarship is to develop a robust theory and enhance the evidence base. However, ACM literature clearly shows that it provides significant scope for managing local-level natural resources (including water) sustainably. For ACM approaches to fulfil this potential, they need to be developed over medium- to long-term timescales with significant attention to local contexts.

CHAPTER FOUR

Methodology

In this chapter, I will explain the methodology used in my research. The chapter starts with a brief overview of the literature review and the rationale for the research. Then I will state the research questions and describe the process I followed to answer the research questions. Next, I will describe the study site to orient the reader about the setting for my research. Lastly, I will describe the methods, data analysis, ethical considerations and limitations of the methods.

4.1 Study Area

4.1.1 Introduction

Sri Lanka was selected as the country of focus for my research. I selected Sri Lanka due to my previous experience in the country, my ability to access resources to support field research, ongoing research and development projects related to the topic, the possibility of improvement in the current status of knowledge through this research, and the opportunity to contribute to ongoing research and policy development for STCS in Sri Lanka.

Palugaswewa STCS was selected as the site for an in-depth study of STCS governance (see Figure 10). The rationale for choosing Palugaswewa was based on an initial screening process that included availability of baseline socioeconomic data, costs associated with travel and logistics, access to local community groups and local institutions, and sites with a traditional system of governance undergoing significant social, cultural and economic change (UNDP Sri Lanka, 2014). Furthermore, Palugaswewa STCS is recognised as a Globally Important Agricultural Heritage System by the Food and Agricultural Organization (FAO) of the United Nations in 2017[9]. UNDP and the Government of Sri Lanka identified the tank cascade system at Palugaswewa for a project funded by Green Climate Fund. This project envisages introducing cascade level water management through better access to climate information and seeks to reduce climate risks associated with farming (UNDP Sri Lanka, 2016).

The study area (Palugaswewa STCS) is in the Palugaswewa Divisional Secretariat Division[10] in the Anuradhapura district of Northcentral Sri Lanka. Palugaswewa STCS is situated within the Malwathu Oya river basin and falls within the UNESCO cultural triangle (Ministry of Agriculture & FAO, 2016).

[9] http://www.fao.org/giahs/giahsaroundtheworld/designated-sites/asia-and-the-pacific/the-cascaded-tank-village-system-ctvs-in-the-dry-zone-of-sri-lanka/en/

[10] Divisional Secretariat Division (DSD) is a decentralized administrative unit that provides government services and functions. Local level development plans are developed at DSD level and these plans are collated at district and national levels to develop district and national plans.

The tank cascade is situated within a narrow valley extending from south to north to the east of the Ritigala range. The surface runoff from the surrounding ridges is a primary water source for the cascade system (examination of satellite images via Google Earth indicates runoff from ridges to the northeast, east and southeast).

The cascade covered an area of 1450 hectares and was located in the DL1b agro-ecological zone. This zone is characterised by undulating terrain with low ridges and shallow valleys and a bimodal rain pattern with an annual rainfall (75% expectancy) of 900 mm (Ministry of Agriculture & FAO, 2016; Panabokke, 1999). Two alternating monsoons (Northeast and Southwest) determine the area’s general climate with clear wet and dry seasons. Northeast monsoon is the predominant rainy season (October to January), and March-April and August-September are dry (Ministry of Agriculture & FAO, 2016).

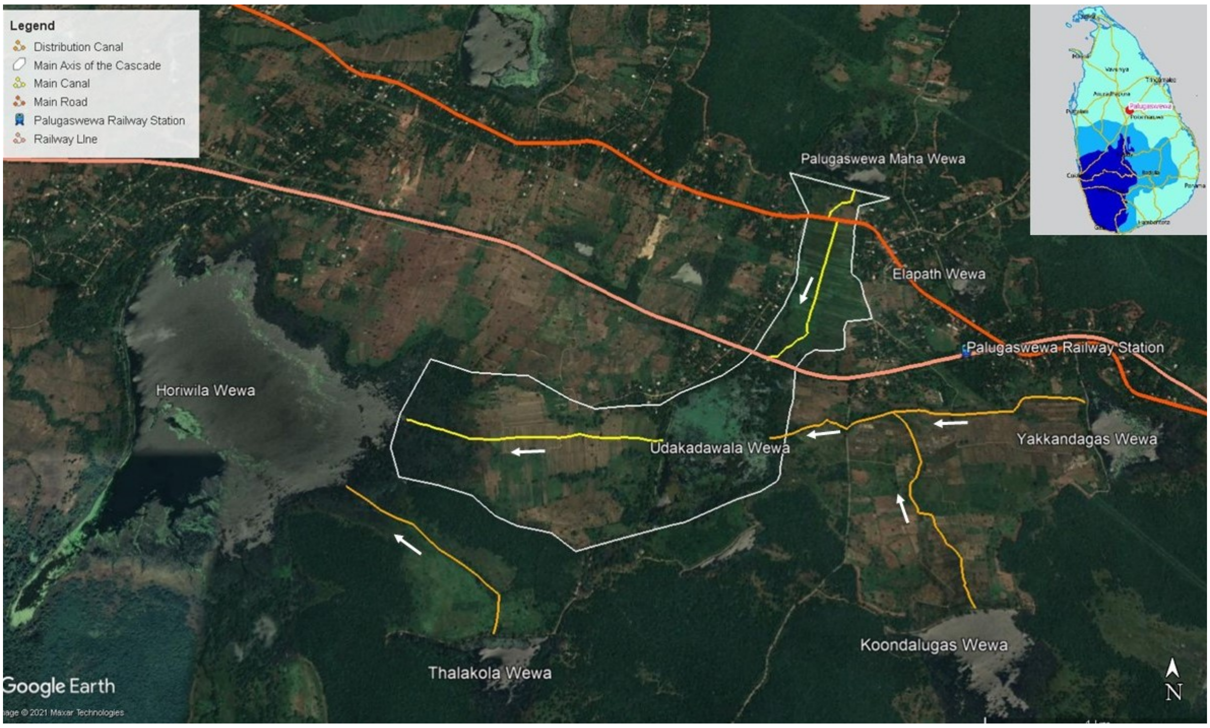

Figure 10 - *Palugaswewa Tank Cascade System (White polygon shows the main axis of the cascade, yellow lines show main “canal” moving spillover on the main valley of the cascade, orange lines show “canals” moving spillover from tanks in the side valleys into the main valley, white arrows indicate the direction of water flow.*

There are about 400 families in the area, with an approximate population of 1,400 people. There are three main villages, Palugaswewa, Udakadawala and Horiwila. These villages are situated in the top, middle and lower parts of the cascade system. The livelihoods of the local communities are mainly related to agriculture. Rice farming is the dominant crop. However, maize cultivation is increasingly popular among farmers, according to the information available from the divisional secretariat office.

Seasonal upland cultivation of crops such as legumes, onions and pulses provides significant income opportunities for local farmers (Ministry of Agriculture & FAO, 2016).

Palugaswewa tank cascade system provides a suitable historical, cultural, and social setting for the research, where communities are organised, linked to government agencies in a small geographical area, and offer potential long-term research opportunities.

4.1.2. Agriculture

Udakadawala and Palugaswewa villages are the oldest in the cascade. The government supported expansion of the Horiwila tank resulted in the establishment of other surrounding villages. (Ministry of Agriculture & FAO, 2016). The local farmers have practised rice farming for nearly a century, complemented by 'chena'. Chena cultivation is a semi-mobile, slash-and-burn upland cultivation type, where a plot of land is cultivated for a few seasons and then allowed to lie fallow. The traditional chena cultivation includes several land plots situated close to each other that are rotated for cultivation (Dharmasena, 1992; Morrison, n.d.). Local communities cultivate chena in the jungle adjacent to the village.

Rice cultivated immediately below the tank bund is divided into several areas depending on the availability of sluices. The cultivation activities are carried out concurrently in each area to minimise the costs, ensure optimal water use, and minimise the damage to adjacent plots of paddy lands.

Agriculture is dependent on the seasonality of rainfall. "Maha" (season corresponds to the northeast monsoon) is the primary cultivation season for Palugaswewa. Local farmers depend on the northeast monsoon to store water for irrigated rice cultivation. Water is a limiting factor that governs the type and extent of rice cultivation. Therefore, planning and scheduling cultivation activities in the village become very important to optimise water use.

4.1.3. Cultivation Decision Process

Water is a limited and scarce resource in the dry zone of Sri Lanka (Panabokke et al., 2002). Therefore, the process of acquisition and allocation determines access to water (Chambers, 1980). The STCS in Palugaswewa is a system that adopts a community allocation process with a "communal source of water allocated among a community of users" (Chambers 1980, p.33).

The seasonal water allocation process in Palugaswewa is the cultivation ('Kanna' in Sinhalese) meeting. The cultivation meeting is the central decision-making platform for planning an upcoming cultivation season (Aheeyar, 2000; Panabokke et al., 2002). Over the last century, the cultivation meeting process evolved from a farmer-driven process to a collaborative farmer and government agency-driven process (Wijekoon et al., 2016).

The local decision processes in Palugaswewa, Udakadawala and Horiwila conform to this legal framework. The literature on the cultivation meeting process shows significant contextual issues or dynamics in the engagement of farmers, agricultural extension officers, and local and divisional level administrators (Begum, 1987; Wijekoon et al., 2016).

4.1.4. Culture and traditions

The Palugaswewa STCS follows strong social and cultural values/norms associated with rice farming. Irrigated rice farming is considered a way of life rather than a mere livelihood in traditional villages (Godsmith & Hildyard, 1984), and Palugaswewa shows these characteristics. Cultural and social ceremonies are essential components in traditional rice farming. This practice involves songs, music, dance, and rituals for local deities associated with each stage of the cultivation cycle. Specific families assumed the responsibilities for these traditional performances and rituals within the village over generations. Furthermore, farming activities are also closely linked to astrology, spiritual beliefs of local deities and chants (Dharmasena, 2010b; Goldsmith & Hildyard, 1984; Leach, 1961). These belief systems are poorly documented in the formal academic literature with few exceptions, such as Leach (1961); and Goldsmith & Hildyard (1984).

Family groups dominate rice farming in Palugaswewa ancient tank system. These closely related family groups cultivate paddy lands adjacent to each other, enabling them to pool labour and other resources. This close relationship leads to close collaboration and effective communication of cultivation information. The literature and the information gathered from local farmers shows that the village headman, '*vel vidane*' and the village temple's chief priest were the key individuals with specific responsibilities for farming. Currently, a farmer organisation and its officials hold these responsibilities (Aheeyar, 2000; Begum, 1987)

Informal discussion with local community workers indicated that close-knit family relationships were vital in rice farming and water management. Furthermore, elderly farmers in the village show that the breakdown of these relationships and associated values as reasons for farming-related conflicts over the last couple of decades. Local farmers cite immigration of new farming families, adoption of rice farming as a part-time/seasonal livelihood, intergenerational differences in values and perceptions, and the transformation of rice farming into a commercial, market-oriented farming system as issues of concern.

4.1.5. Access to the study site

To gain access to the study site, I contacted the UNDP Sri Lanka and its partner organisation (Janathakshan[11]) to access information and connect with local farmer organizations. I obtained written permission from the local administrative office (divisional secretariat division palugaswewa) and local police station as per the security guidance offered to me by the UNDP Sri Lanka Office. The project coordinator for Janathakshan introduced me to a local community worker (employed by Janathakshan) who works with the farmer organisations in the Palugaswewa STCS. This local community worker facilitated introductions to members of the farmer organisations. I explained the research and provided them with the participant information sheet, participant consent form, and clarifying questions (see appendix).

4.2. Research Design

A set of conceptual and philosophical assumptions will guide my research. These conceptual and philosophical positions helped to develop a conceptual framework for the research. I draw from Mason (2002); Creswell (2007); and Bryman (2012) to develop the framework.

The following paragraphs discuss the positions and assumptions of ontology, epistemology, worldview and theoretical perspective. The ontological elements in my research are vital as they help to understand different perspectives. These considerations include people, social actors and social and cultural practices. Furthermore, these perspectives interact, contribute to, facilitate and constrain an understanding of the governance of STCS in Sri Lanka. The recognition and understanding of these perspectives will facilitate the identification of alternative ontological perspectives that might broaden the horizons of the research (Mason, 2002).

Epistemology informs how knowledge is generated and demonstrated through understanding social phenomena (Mason, 2002). Furthermore, it addresses the relationship between the researcher and what is being researched (Creswell, 2007). A pluralist epistemology recognises that in any given research context, there are multiple ways of learning or knowing and accommodating this plurality to facilitate more integrative study. Furthermore, it emphasises equity, difference, diversity, practices, choices and due process (Miller et al., 2008). My research will adopt a pluralist epistemology that

[11] www.janathakshan.lk

facilitates a holistic understanding of complex social-ecological issues associated with the governance of STCS.

A worldview is a fundamental principle guiding one's action. Worldview refers to beliefs, values and principles that a researcher brings to the research (Creswell, 2007). Pragmatism is a worldview that focuses on the research outcomes through actions, situations and consequences (Creswell, 2007). Pragmatism enables the researcher to grasp the social, historical, political and ecological context that underpins the research. Furthermore, it enables the researcher to adopt a holistic perspective to study, learn and understand social and ecological phenomena (Creswell, 2007). This holistic perspective is vital in my research as it facilitates seeking answers to research questions. Pragmatism also allows the researcher to adopt mixed methods to collect data; quantitative and qualitative data collection methods then become suitable to address the specific context of the research (Creswell, 2007). Therefore, a pragmatist worldview is adopted during the proposed research as it allows for addressing significant contextual issues associated with the complex socio-ecological system.

The design of this research was based on Plummer's ACM framework (Plummer et al., 2017). This framework (Figure 11) was devised to diagnose evidence for ACM and to identify the pathways or opportunities to integrate ACM strategies in the management of common-pool resources in social-ecological systems. The ACM diagnostic has been adapted to a number of diverse situations, including co-management of small-scale fisheries (d'Armengol et al., 2018), governance of protected areas (Kimengsi et al., 2019), stakeholder collaboration in wildlife governance (Dressel et al., 2020), and assessment of community resilience to coastal hazards (Nurzaman et al., 2020) among others. I used the ACM framework to provide a structure to explore the governance of STCS in Sri Lanka's dry zone, where each stage of the framework corresponded roughly to one of three phases of my research.

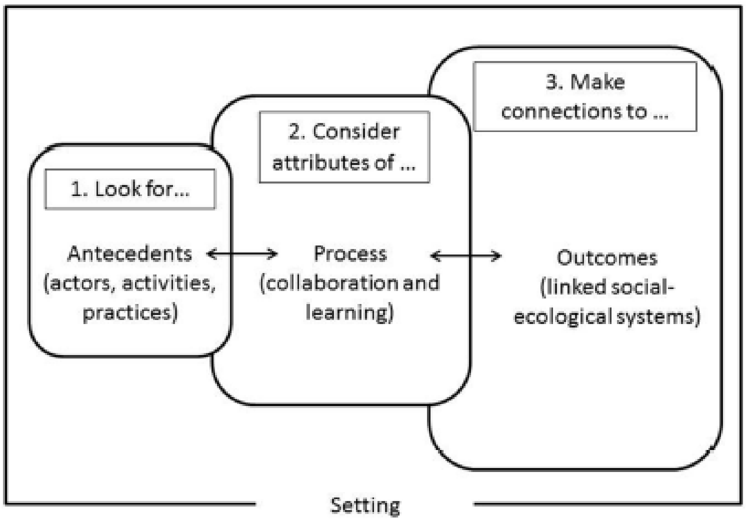

Figure 11 - Framework for diagnosing adaptive co-management (Plummer et al. 2017 p.3)

In association with the ACM framework, my data collection followed a mixed-methods approach. There are multiple definitions of what constitutes mixed methods research. It can be broadly defined as "research in which the investigator collects and analyses the data, integrates the findings and draws inferences using both qualitative and quantitative approaches or methods in a single study or a programme of inquiry"(Tashakkori & Creswell 2007 p.4). A mixed-methods approach allows the researcher to employ quantitative and qualitative research methods to seek answers to research questions within a social science context (Cresswell et al., 2003; Doyle et al., 2009).

The literature on mixed methods research discusses several advantages (Bryman, 2012; Doyle et al., 2009; Johnson et al., 2007) as:

- The availability of a wide range of qualitative and quantitative data and multiple methods of collection and analysis help to neutralise the limitations of more prescriptive methods.
- Methods can complement others within the same research study and provide opportunities to develop a complete answer to a research question.
- Improved data collection processes through a variety of tools/methods.
- Enablement of an investigation of broader research questions and provision of more robust research evidence through convergence and corroboration of findings.

Critique of mixed-method research is concerned mainly with employing different methods concurrently as they could have different epistemological commitments (Bryman, 2012). Qualitative and quantitative research belong in separate paradigms. Furthermore, it has been suggested that integration of qualitative and quantitative methods happens only at a superficial level within a single paradigm (Bryman, 2012), and researchers using a mixed-methods approach do not necessarily combine their findings. Hence, qualitative and quantitative components can be treated as separate entities, often leading to different interpretations of findings (Bryman, 2007; Cresswell et al., 2003; Creswell et al., 2007).

Approaches to mixed methods research vary depending on whether qualitative or quantitative methods precede or follow one another or have equal importance (Cresswell et al., 2003). The theoretical development of mixed methods research has dramatically advanced over the last two decades. These have established mixed methods research as a methodological approach alongside qualitative and quantitative research (Johnson et al., 2007). The context for my research involves studying multiple actors (including farmers, extension officers, community organisations, and government officials) as interacting stakeholders in the governance of common-pool resources (an STCS and its ecosystem services) at varying scales (primarily local and district levels), which conforms to the characteristics of a social-ecological system (Ostrom, 2009; Ostrom & Cox, 2010). Mixed-methods approaches are commonly used to enable the capture of social-ecological system diversity and seek comprehensive answers to research questions (e.g. Baird et al., 2019; Epstein et al., 2013; Partelow et al., 2018).

4.3 Methods

Using a mixed-methods approach in combination with the ACM diagnostic framework, my research consisted of three phases:

1. Historical policy analysis to understand the evolution of the current governance system,
2. Quantitative analysis of the governance structures of an STCS (at a targeted study site) through a social network analysis (SNA), and
3. Qualitative analysis of the decision processes using semi-structured interviews (SSI) with key actors identified through SNA.

4.3.1. Historical policy analysis

The first phase in my research design was to characterise the governance of small tank cascade systems in Sri Lanka and how they evolved. I undertook document analysis (Bowen, 2009) and developed a narrative literature survey (Baumeister & Leary, 1997). For the document analysis, I compiled, revised and analysed a range of sources that included peer-reviewed journal articles, research, workshop, technical and administrative reports (from government, non-government organisations, research think tanks) and grey literature. I examined the grey literature associated with social, cultural and historical aspects of the small tank cascade systems to analyse the perspectives of different stakeholders, as these aspects are largely absent from the peer-reviewed literature. I screened the grey literature to ensure the authenticity, cited information sources, and information consistent with cross-referenced findings in the peer-reviewed literature.

I used keywords for searching[12], selecting and organising literature via google scholar and UTS library databases. Technical and project-specific reports were downloaded from official websites and confirmed as authentic publications of the relevant institution. Then, I scanned the prioritised search results for relevance and organised them into separate folders. These folders were uploaded to the Mendeley reference manager for deeper reading and analysis.

Document analysis is a low-cost method for collecting empirical data and provides multiple perspectives. Combining the data generated from document analysis with surveys, interviews, and observational data minimises biases (Bowen, 2009). The information generated from document analysis is dependent on the quality of the documents. Therefore ensuring credibility, authenticity and representativeness (whether the content represents the general understanding of the topic) are critical for document analysis (Bryman, 2012).

Narrative literature reviews provide insights and help gain a broad understanding of the area of research (Bryman, 2012). Narrative literature reviews are useful to review the state of knowledge for a particular topic. They also help to collate current knowledge about a particular phenomenon (Baumeister & Leary, 1997). These reviews can support the identification of problems associated with a topic or phenomenon and explore a variety of contributory factors (Baumeister & Leary, 1997; Bryman, 2012).

The combination of document analysis (Bowen, 2009) and narrative-literature review (Baumeister & Leary, 1997) allowed me to survey the state of knowledge to construct a historical account of the governance environment and identify problems, weaknesses, and contradictions in the governance of STCS. I reviewed documents on managing small tank cascade systems in Sri Lanka, analysing them through a contemporary natural resources management perspective.

The document analysis and narrative literature review contributed to constructing answers to all research questions and were especially useful in relation to RQ1. The information provided pointers to the key actors to be surveyed for RQ2 and provided clues for diagnosing evidence for ACM in

[12] I used search tips on google scholar at https://scholar.google.com.au/intl/en/scholar/help.html

action for RQ3 in subsequent phases of the research. The information gathered also characterised the broad "setting" for diagnosing evidence of ACM under the framework (Plummer et al., 2017).

4.3.2 Quantitative analysis of governance structures via social network analysis

The first ACM diagnostic step is to understand the local antecedents of current governance. Elucidating the governance structures and relationships among system actors help to reveal the governance processes and actors. Understanding these connections helps to identify collaboration and learning (second ACM diagnostic stage). Natural resources management systems involve multiple actors and different forms of participation (Bodin et al., 2006). Multiple actors participate in managing the STCS in the dry zone of Sri Lanka. However, some actors (government agencies, local administrators, government agricultural officers) may be more influential in some aspects of decision-making than others, such as when to release water, what to cultivate and compliance notices for maintenance. Other actors, such as farmers, would likely have greater control over different aspects of decisions, such as the extent of the cultivated area and the crop mix (Begum, 1987; Panabokke et al., 2002; Wijekoon et al., 2016). These actors operate as both individuals and members of a group or a network to achieve individual and group ambitions. The relationships among the actors in a group constitute a social network (Bandyopadhyay et al., 2010). Hence a social network refers to the "articulation of a social relationship, ascribed or achieved among individuals, families, households, villages, communities, regions and so on" (Bandyopadhyay et al., 2010, p.1). The units of a social network can be individuals, families, households or institutions, and social network analysis focuses on relationships between individual units of the network (Bandyopadhyay et al., 2010; Crossley et al., 2009).

Social network analysis (SNA) is recognized as an approach that facilitates the characterisation and mapping of complex resource governance systems (Bodin & Crona, 2009; Bodin & Prell, 2011). SNA allows social relationships to be visualised in formal terms as patterns of points and lines in a mathematical interpretation that facilitates analysis with high precision (Crossley et al., 2009). SNA reveals relationships among various actors and facilitates tailoring strategies to different actors (Lauber et al., 2008). The organization of actors (structure) could provide insights into how effectively the network functions and several network measures are used to quantify the structure of a social network (Bodin et al., 2006; Janssen et al., 2006). These measures (see Table 3) describe interactions among network actors, including decisions about natural resource governance (Bodin et al., 2006).

Table 3 - Descriptions of network terms and measures modified from (Borgatti, 2006; Borgatti et al., 2002, 2013; Prell, 2012).

Term/ Measure	Description
Node	Any entity (individual/institution) within the network. In this study, all network actors (people) identified by participants are represented by a node. Within the visualisations, nodes appear as squares or circles.
Tie	Every connection between nodes is represented by a tie visualised as lines connecting nodes.
Key players	Key player diffusion algorithm identifies the nodes that have a connection to the most nodes within the entire network, effectively seeking to access all network nodes.
In-degree	The number of incoming ties (connections) to a node
Out-degree	The number of outgoing ties (connections) from a node
Betweenness Centrality	The number of times a node acts as a bridge to create a shorter path to connect other nodes.
Average Degree	The average number of ties (connections) attributed to each node
Density	The total number of ties (connections) divided by the total number of possible ties (connections) in the network
Diameter	Length of the geodesic steps (shortest pathway) across the largest component of the network. Estimates the number of steps to reach everyone within the largest component within the network, i.e. 'Bacon's Law' and 'six degrees of separation.'
Fragmentation	The proportion of pairs of nodes that are unreachable by any path through the network

For this research, I contacted farmers at the study site through a local community worker. I followed a snowball sampling technique (Bryman, 2012; Coleman, 1958). The local community worker introduced me to the farmers, and farmers then nominated other farmers who were associated with the agricultural decision process in the STCS. To collect data for SNA, I asked participants (farmers) to:

1. Nominate up to 5 sources (individuals, institutions or media) that they use to access cultivation, climate and seasonal weather information.
2. Nominate up to 5 individuals with whom they share cultivation, climate and seasonal weather information.

I compiled the participant responses to the SNA survey into an Excel workbook. I constructed two discrete directed symmetric affiliation matrices from the participant responses. In addition, I recorded corresponding attributes such as farming type, water access, location in the STCS, role [farmer/government official] and gender for each participant. A range of network cohesion measures was used to explore the quality of the information flow between network members with both formal and informal roles, including average degree, density, diameter, and fragmentation. I used betweenness centrality to identify those actors that may occupy bridging roles within the network (Freeman, 1977). Table 3 offers descriptions of the metrics utilised for my research.

I used UCINET 6 for Windows to analyse the data. It supports a variety of network measures and visualisation of social networks (Borgatti et al., 2002). Sociograms, a visual representation of actors (individuals/institutions), their relationships, and ties, were developed in NETDRAW (Ade-Ibijola, 2018; Borgatti et al., 2002; Moreno, 1951). In addition, I also used the "KeyPlayer" support package (for UCINet 6) developed by "Analytics Technologies" to analyse and identify key players (Borgatti, 2006) in the STCS.

The SNA and network cohesion measures provided information about the key actors involved in the agricultural decision process. SNA also provided information on how key actors are organised to access and share cultivation/climate information, the quality of the network and its implications for climate adaptation. These pieces of information answer RQ2. The data and analysis outcomes generated from the SNA provide information on antecedents (actors and their roles/responsibilities, activities and practices) as per the ACM diagnostic framework (Plummer et al., 2017).

4.3.3 Qualitative analysis of decision process through semi-structured interviews (SSI)

Semi-structured interviews (SSI) with key actors provided a rich picture of the way in which governance processes function in practice in the STCS. Because this information was integral to and informed by the quantitative SNA, the research design overcomes some of the critiques of mixed-methods approaches described above. In addition, understanding both structure (SNA) and function (key actor interviews) of governance processes in the STCS completes the second stage of the ACM diagnostic and enables an analysis of outcomes in the form of recommendations for improvements in governance (third ACM diagnostic stage).

Interviews can provide a rich and deep understanding of the experiences of individuals. They are an essential and most commonly used data collection strategy in qualitative and quantitative research (Bryman, 2012; DiCicco-Bloom & Crabtree, 2006; Mason, 2002). Interviews help explore people's knowledge, views, understandings, interpretations, experiences, and interactions and provide opportunities to understand the contextual issues difficult to ascertain from quantitative methods (Mason, 2002).

There are several major forms of interviews, including unstructured, structured and semi-structured interviews (Bryman, 2012; Creswell, 2007). SSI generally comprise predetermined open-ended questions designed to understand a phenomenon or a context. SSI also allows new questions during the dialogue between the interviewer and interviewee (DiCicco-Bloom & Crabtree, 2006). SSI is an interactional exchange of dialogue between two people or a larger group. This exchange could happen face to face, via telephone or the internet (Mason, 2002). SSIs are very useful to elicit information from farmers on indigenous or tacit knowledge and practices (Campbell et al., 2002). SSI refers to a context that the interviewer organises as a series of questions in a sequence. However, the interviewer has some freedom to ask further questions to clarify issues emerging from the dialogue. Therefore SSI provides substantial flexibility to the interviewer (Bryman, 2012).

There are diverse social actors associated with STCS (from farmers to government officials). The literature suggests that these actors have varied motivations, perspectives and aspirations to interact and become involved with each other in STCS management (Aheeyar & Smith, 1999; Moore, n.d.; Somasiri, 2008). Furthermore, SNA and semi-structured interviews together provide a holistic understanding of how networks exist in a local context, how various networks interact with each other, how information flows through a network and allows identification of key nodes in a network that might act as multipliers or disseminators (Cunningham et al., 2016, 2021; Wood et al., 2014).

SNA helped to identify the key actors in the STCS, and I interviewed them with the consent of the participant. The interview was kept open as much as possible, and the following questions guided the interview and helped to elicit information for all research questions. Central themes were:

1. *Cultivation decision process* - who are the key actors involved, their main roles and responsibilities, how are decisions made, and the advantages and disadvantages of the current decision process.

2. *Climate information* - from whom do participants access climate information, with whom do participants share climate information, the enablers and barriers for accessing and using climate information, and how participants respond to climate information.

3. *Suggested improvements to the current decision process* – including provisioning of information, capacity building, building community cohesion, and government support.

I transcribed interview data in Microsoft Word for each participant and de-identified the participant. Then, I transferred audio records to secured cloud storage as per the UTS ethics approval and deleted the files from the memory card of the audio recording device. I developed three categories (decision process, cultivation/climate information and process improvement) and primary and secondary codes for each category (Saldaña, 2013). These categories and code structure are in Table 10. Then, I coded the de-identified data in NVivo 12 (QSR, 2019; Saldaña, 2013) and identified emerging themes. The emerging themes contributed towards answering RQ3. The information generated from the above analysis was used to diagnose the antecedents (roles and responsibilities of key actors) and the attributes of processes (the decision process) as per the ACM diagnostic framework (Plummer et al., 2017).

4.4 Compliance with ethics approval

This study was approved by UTS Human Research Ethics Committee (UTS HREC No. ETH18-2825), and I complied with all of the conditions of the approval. I translated the participant information sheet, consent form, and survey forms to Sinhalese (local language) and certified those by an authorised official (JP). All participants signed a consent form, and this was certified by a local community worker, who understood the English version of the document (see appendix).

At each interview, I presented my university identification and described my research. Then I explained the data collection process and how participants' responses would be recorded and stored, and analysed. I answered the questions of participants before seeking consent by describing the consent process. I took precautions not to disturb the participants in carrying out their daily routine. I scheduled interviews outside the critical events in the cultivation calendar to minimise disturbances to their livelihood activities. Most meetings were conducted at midday (for some participants) or in the evenings. I have worked with farming communities in rural Sri Lanka for many years. Those insights helped me plan and use resources effectively.

Following steps were undertaken to ensure participants identities were protected in the research process:

- All survey data forms are stored in a locked cupboard in UTS.
- All names were de-identified before the data analysis.
- Soft copies (excel workbooks) stored in UTS approved cloud storage, password protected.
- The audio records were erased after transferring interview recordings to UTS cloud storage, and these were password protected.

All communications relating to my research complied with the UTS ethics approval.

CHAPTER FIVE

Management of small irrigation tank cascade systems (STCS) in Sri Lanka: past, present and future

Chapter five is a peer-reviewed journal article published in *Climate and Development*. This paper explores how the current agricultural decision process (governance) associated with STCS evolved and its implications for climate change adaptation. It also analyses current STCS governance from a contemporary NRM perspective to explore opportunities for adaptive governance. The paper answers RQ1 - What is the current decision-making process for managing water and cultivations associated with small tank cascade systems? The chapter also characterises the governance environment or the “setting” as per the Adaptive Co-management diagnosis framework (Plummer et al., 2017). I used document analysis and narrative literature review methods to explore sources, compile information and analyse data to develop the paper.

In the interests of reducing the overall thesis length, the literature cited in the paper has not been reproduced in this chapter but is included in the thesis bibliography

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REVIEW ARTICLE

Management of small irrigation tank cascade systems (STCS) in Sri Lanka: past, present and future

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ABSTRACT

Small water storages are recognized as a key invention that facilitated the colonization of the dry zone of Sri Lanka. These small reservoirs, referred to as 'tanks', were initially constructed to collect the local runoff and this practice gradually evolved into the construction of larger tanks. Originally tanks were primarily managed by local communities to suit their livelihoods, often as linked Small Tank Cascade Systems (STCS). During the British colonial period, community-led management structures were disregarded and largely disbanded as government converted the governance of larger water storages into centrally managed structures. Since independence, the management of STCS has passed through various government agencies. This paper describes the management of STCS through history and identifies major issues in the current governance model and the challenges and opportunities associated with renewed interest in STCS to support adaptation to climate change. We conclude that contemporary challenges in using STCS for climate adaptation result from past inadequacies in the governance of this water resource.

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1. Introduction

Sri Lanka is an equatorial island nation located near the Indian subcontinent characterized by a tropical climate. Extensive geological faulting and erosion have led to a wide range of topographical features including three major elevation zones (peneplains). These are a coastal belt, undulating middle plains and central highlands with a peak elevation of 2524 m. Sri Lanka is broadly divided into wet, dry and intermediate climatic zones (Marambe et al., 2015) (see Figure 1).

The climatic and geographical characteristics of the dry zone are reviewed by Panabokke et al., 2002; Marambe et al., 2015. In summary, the dry zone receives a mean annual rainfall of less than 1750mm with a prominent dry season from May to September. The main rainfall season is from October to January and this period is characterized by high yearly variation: 800–1000 mm is a realistic rainfall expectancy (75% probability) for the dry zone. High evaporation and dry winds are characteristic features from May to October in the dry zone of Sri Lanka with daily evaporation rates of 5–7 mm. Furthermore, the dry zone is characterized by an extensive undulating land surface that has resulted in a large number of small inland valleys. The topography and geological characteristics (underlying highly impervious basement rock, overlying weathered rock and shallow to moderately deep soil) of the dry zone are very conducive to the construction of small reservoirs for water storage.

Existing research demonstrates that irrigated wetland agriculture was firmly established in early settlements around 500 BC and was concentrated in the dry zone of Sri Lanka (Panabokke, 2009). This is regarded as an important transition from primarily rain-fed upland cultivation (described as 'chena' or shifting /slash and burn cultivation) to a combination of wetland and upland cultivation. This change in the farming system also enabled small communities to build permanent settlements within narrow valleys of the dry zone (Panabokke, 2009). The highly seasonal nature of the rains and expanding settlements might have led to the construction of earthen dams across narrow valleys to divert or store water for agriculture, domestic use (drinking, bathing, washing) and for livestock (Dharmasena, 2010b; Panabokke, 2009). Irrigated agriculture was fundamental to Sri Lanka's civilization and its expansion throughout the island. The sequential development of small tanks (around 300 BC) culminated in the major, sophisticated irrigation works constructed in the 5th and 6th centuries AD (Panabokke, 2009).

The ancient hydrological civilization of Sri Lanka has received significant attention throughout the 19th and 20th centuries mainly through British civil servants in the colonial period. H. Parker's and R. L Brohier's works (1907 and 1935) are regarded as the most significant work on ancient irrigation systems of Sri Lanka that emphasized the importance and distinctive features such as hydrology and engineering (Panabokke et al., 2002). Leach's (1961) research on land tenure and kinship of a traditional village illustrates the complex social interactions of a community dependant on a local tank.

The interest in small tanks in the dry zone of Sri Lanka has grown recently (e.g. Abeywardana et al., 2018). Government, multi-lateral agencies and non-government agencies invested in rehabilitation and reconstruction of traditional small tanks

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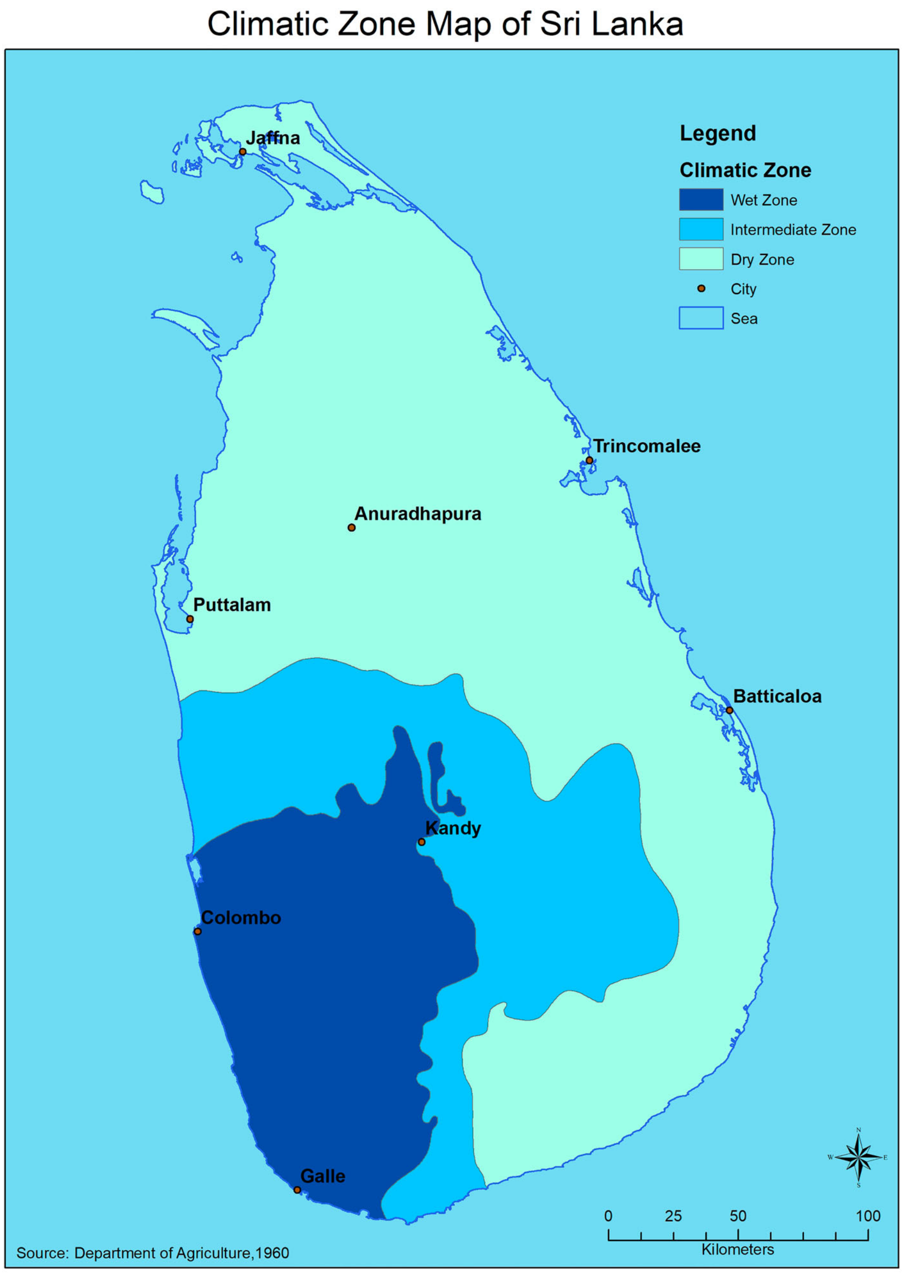

Figure 12. Main climatic zones of Sri Lanka.

systems. Furthermore, UNDP and the Sri Lanka Government started a project with funding from Green Climate Fund to invest over 50 million dollars (US) to rehabilitate small tank systems in the dry zone as a climate risk management strategy (UNDP Sri Lanka, 2016).

This paper aims to review the governance of small tank cascade systems in Sri Lanka with an emphasis on contemporary natural resources management practice. Furthermore, it seeks to identify the main issues, lessons and implications for the future. The review is based on available published, peer-reviewed literature, technical reports and government agency publications in Sri Lanka. Then, grey literature on the history, social and cultural aspects associated with small tank cascade systems was examined to understand different perspectives of stakeholders, as these are largely absent in peer-reviewed literature. All documents were screened to ensure that information is authentic, cites the sources drawn upon, and that evidence presented is consistent with and cross-references findings in peer-reviewed literature. This paper focusses on system governance as hydrological, engineering perspectives are covered elsewhere in literature eg: Itakura & Abernethy, 1993; Panabokke, 1996; Gangadhara & Jayasena, 2005; Mahatantila et al., 2008; Panabokke, 2009. This paper is guided by Baumeister & Leary (1997) on compilation, review and analysis of information for narrative literature reviews.

2. Small tank cascade systems

The undulating terrain of the dry zone that comprises narrow valleys provided an opportunity for early settlers to divert or store water by constructing earthen dams (Panabokke, 2009; Tennakoon, 2000). These early forms of small reservoirs (or

Wewa in Sinhalese) are known as tanks. The term 'tank' evolved from the Portuguese term 'Tanque' that refers to small reservoirs (Dharmasena, 2010a). The literature identifies them as either small tanks or village tanks (tanks with an irrigated command area less than 80 hectares as per Agrarian Services Act No. 58 of 1979) and these terms are used interchangeably (Panabokke et al., 2002), for consistency, the term small tank is used hereafter.

Early forms of tanks constructed across narrow valleys served small communities/villages living adjacent to the tank. Subsequently, more tanks were constructed sequentially along these narrow valleys to support expanding populations (Mendis, 1981; Panabokke, 2009; Tennakoon, 2000). These sequences of tanks in a narrow valley enabled the ancient settlers to divert, reuse and store water, hence optimizing a limited water resource (Mendis, 1981; Tennakoon, 2000). These are now termed as 'Tank Cascade Systems'. Small Tank Cascade Systems (STCS) are defined as 'connected series of tanks organised within a micro-catchment of a dry zone landscape, storing, conveying and utilising water from an ephemeral rivulet'(Madduma Bandara, 1985). Several subsequent studies have introduced minor refinements to the definition by expanding it further and suggest that micro-catchment be replaced by the more appropriate term 'meso-catchment' (Panabokke, 1999).

The structure of an STCS is shown in Figure 2; the main axis of the ephemeral stream runs from top to bottom of the valley and tributaries enter from side valleys. The valleys are generally narrow in the upper areas and broad in lower areas. Therefore, tanks in the upper areas of the valley are small while tanks in the lower areas of the valley are larger. Small tanks in the upper areas of the main and side valleys collect the runoff from the surrounding landscape and transfer it to the downstream larger tank. Therefore, runoff from the surrounding landscape and discharge from upstream small tanks are used, reused and discharged to downstream reservoirs (Panabokke et al., 2002; Tennakoon, 2002). STCS have also been described as 'stock-type' irrigation systems where interconnected storage and regulating reservoirs serve multiple functions of resource management including irrigation, domestic supply, water for livestock and subsurface water for perennial cropping (Itakura & Abernethy, 1993). This indicates the multifunctional nature of the STCS that transformed early settlements of Sri Lanka into a hydraulic civilization by the 3rd to 5th century AD (Dharmasena, 2010a; Panabokke, 2009; Tennakoon, 2000).

Latest published estimates on the total number of small tanks range from 15,000 (Panabokke et al., 2002) to 18,000 (Panabokke, 2009); these estimates also indicate that nearly 50% are abandoned or in a dilapidated state. The decline and abandonment of the STCS since the early nineteenth century has been attributed to many factors that include foreign invasions, extended drought periods, the spread of malaria, abolition of the 'Rajakariya' system or 'King's Work' (an ancient custom of compulsory labour that contributed to the annual communal mode of maintenance of tanks), constructions in hydrologically unsuitable landscapes and government priorities towards building larger irrigation systems in the post-colonial era (Panabokke et al., 2002; Tennakoon, 2000).

Historically, the management of STCS was the primary responsibility of the community and most literature suggests that the state did not control the management of these systems; communities made decisions locally to suit their needs (Aheeyar, 2000; Panabokke, 2009; Tennakoon, 2000). However, land tenure and property rights issues would have dictated the management of these systems since local elites, who owned lands or invested (finance, labour etc) towards the construction of irrigation infrastructure, would have some rights in managing the system (Abeyratne, 1985). The king was the sole owner of the land, therefore the king or his agents would have a role in management decisions taken at the local level (Abeyratne, 1985). Literature also suggests that some tanks were built for specific functions such as provisioning flowers for religious ceremonies to serve monks in monasteries (Tennakoon, 2000).

The literature shows that there was significant interest in STCS following the declaration of independence in Sri Lanka in 1948. A set of policy and legal instruments facilitated the process of rehabilitation and revitalization of STCS over the last few decades. These include the introduction of the Agrarian Services Act No 58 of 1979, several donor-funded projects, the creation of research interests (through the National Science Foundation of Sri Lanka), and involvement of the non-government sector in their rehabilitation (Dayaratne, 1991; Mendis, 1981; Panabokke et al., 2002; Tennakoon, 2000).

These initiatives have created momentum in Sri Lanka to research, develop and rehabilitate STCS. Furthermore, well-functioning STCS are recognized as a key adaptation strategy to ensure food and livelihood security at the local scale (Climate Change Secretariat, 2010). The National Adaptation Plan for Climate Change Impacts in Sri Lanka (NAPS) also identified the development and rehabilitation of STCS as a key adaptation strategy to improve watershed management, enhance the resilience of systems for water resources management and to overcome the scarcities caused by climate change impacts (Climate Change Secretariat, 2016). Furthermore, United Nations' Food and Agricultural Organization (FAO) designated STCS (with a representative system in the northcentral province of Sri Lanka) as a Globally Important Agricultural Heritage System (GIAHS) (Ministry of Agriculture & FAO, 2016).

3. Governance of small tank cascade systems

The governance of STCS can be traced through the institutional mechanisms from the precolonial era to the modern times. Governance and related institutional mechanisms of STCS have changed from community-led systems to central management by government agencies over three time periods (pre-colonial, colonial and post-independent) (Abeyratne, 1985; Aheeyar, 2000; Panabokke et al., 2002). It is also evident that the management rights of water and related infrastructure were gradually transferred to centralized government institutions or their agencies. The literature discusses these under three periods.

3.1. Pre-colonial period

Early forms of institutional mechanisms for managing small tanks consisted of farmers, village headmen and local chieftains, and management decisions were taken at the local level

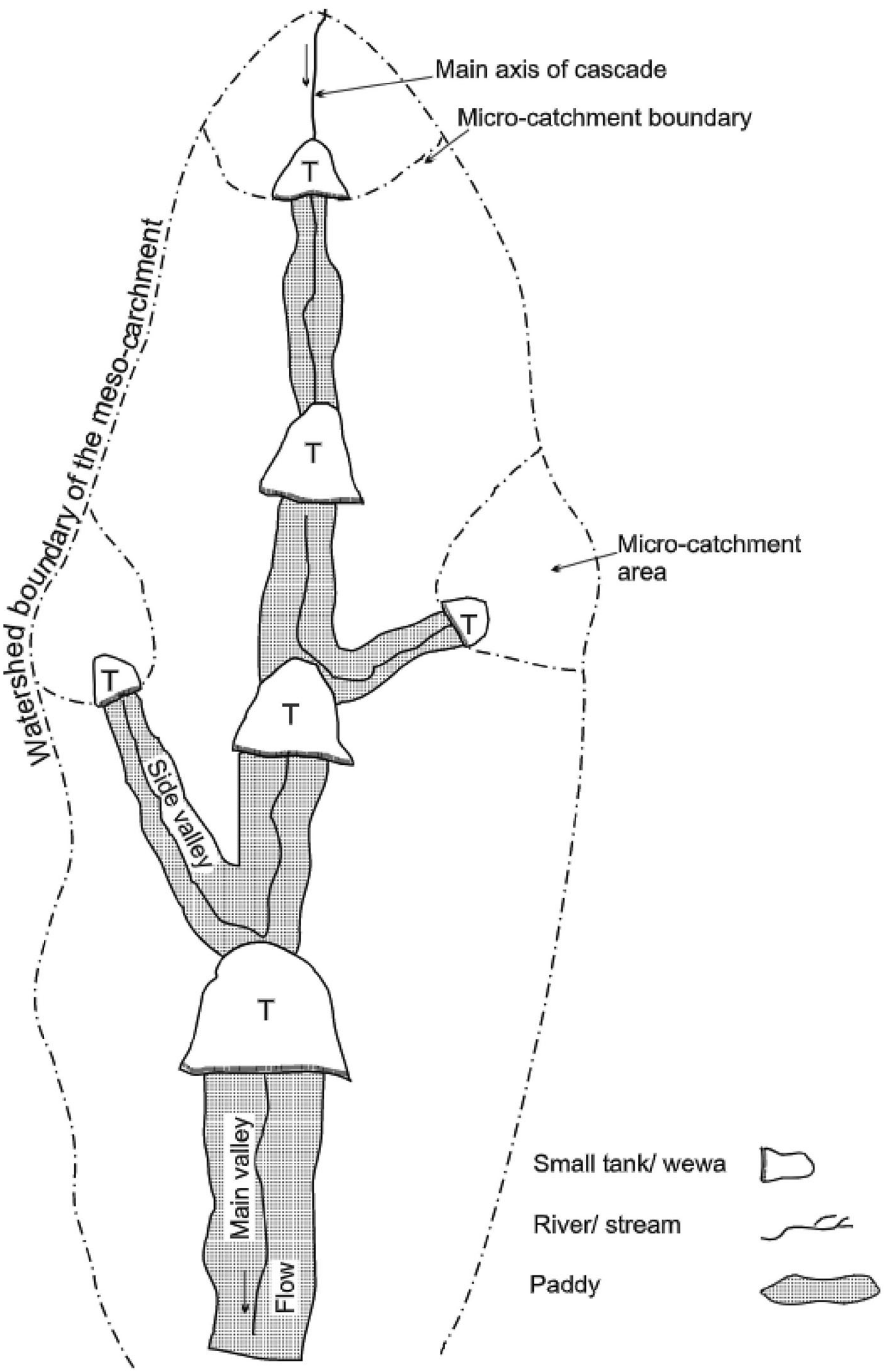

Figure 13. Schematic representation of a typical small tank cascade system (Panabokke et al., 2002, p. 6). Reproduced with permission – Copyright owner IWMI.

to suit the local needs of the community (Aheeyar, 2000; Panabokke et al., 2002). It is believed that management practices evolved through experience and over generations and were gradually organized into knowledge systems that were passed on through oral traditions, rituals and customs (Aheeyar, 2000; Panabokke et al., 2002; Tennakoon, 2000). Furthermore, Panabokke et al. (2002, p. 13), state ' *According to* (Weerawardena, 1986), scripts and pillar inscriptions from 1000 A.D. support the view that farmers adhered to certain laws laid down by the king or regional chieftains to the repair, maintenance, and management of small irrigation systems'. This indicates that the adherence to these laws over generations led to the evolution of traditions and customs that gave rise to a discipline that continued until British occupation (Panabokke et al., 2002).

'Rajakariya' and related customs ensured the successful management of small tank systems for centuries and contained socially, morally and legally decreed requirements with which certain agricultural communities were required to comply. Besides this, there were numerous customary laws, rules and sanctions that were used to manage scarce water resources (Aheeyar, 2000; Panabokke et al., 2002).

The customary laws, rituals, practices and 'Rajakariya' systems led to the individual, village-tank based, institutional structures under the leadership of village headmen, a local chieftain, local elite or a monk (Aheeyar, 2000; Leach, 1961). All decisions on the management of water and cropping were made based on equitable access and rights. These were implemented through village councils or 'Gamsabha' (Aheeyar, 2000; Leach, 1961). These village institutional mechanisms are considered highly effective and existed with very little support from the main administrative centres of the kingdom (Leach, 1961).

The 'Rajakariya' system was prohibited by colonial administrators in 1832 without introducing an alternative system of governance. Hence irrigation systems, thereafter, were not regularly maintained and this led to the degradation of many STCS (Panabokke et al., 2002).

3.2. Colonial period

The abolition of 'Rajakariya' system in 1832 was followed by the introduction of the Crown Land Encroachment Ordinance in 1840. Hence, land and water rights were declared as a crown property. Small-scale farming communities associated with STCS enjoyed common property rights for water, and the Ordinance established the communities as tenants and the Crown as the owner (Abeyratne, 1985). This led to the deprivation of traditional rights and claims of local communities that resulted in abandonment and degradation of STCS (Abeyratne, 1985; Aheeyar, 2000). There was no responsible authority to manage small irrigation systems from 1832 to 1856 (Aheeyar, 2000; Panabokke et al., 2002).

In 1856, the Paddy Lands Irrigation Ordinance was introduced to address issues caused by the abolition of 'Rajakariya'. The ordinance sought to transfer some rights to communities so they could manage local water and land resources for agricultural purposes (Aheeyar, 2000). The ordinance introduced a formal role, irrigation headman ('Wel Widane'). 'Wel Widane' was the representative of the village community and facilitated the state administration of the land and water resources (Abeyratne, 1985; Aheeyar, 2000). 'Wel Widane' was selected from the community and the role was usually filled by an elder farmer. This arrangement succeeded in organizing the community at the local level and involved local communities in the management of water and land resources (Aheeyar, 2000; Panabokke et al., 2002). The Irrigation Department was established in 1900 and this led to the centralization of all irrigation management responsibilities. The Irrigation Department was solely responsible for the management of the irrigation systems that included STCS. The Department's bureaucracy and district administrators (government agents) used communities as sources of labour for cleaning, maintenance and rehabilitation of STCS (Abeyratne, 1985; Aheeyar, 2000; Wijekoon et al., 2016). A new irrigation policy introduced in 1932 further strengthened the Irrigation Department's portfolio with the primary functions of the Department described as construction, improvement and maintenance of irrigation schemes (Aheeyar, 2000).

3.3. Post-independence period

The institutional landscape in Sri Lanka's post-independence period has been complex and chaotic as the management responsibility of small irrigation systems transferred back and forth among many government institutions that included ministries and departments of irrigation, agriculture, and agrarian services (Aheeyar, 2000; Panabokke et al., 2002). This period is characterized by the rapid expansion of large – and medium-scale irrigation development activities in the dry zone of Sri Lanka. These were further boosted by government policy to extensively colonize the dry zone for increasing local food production (Dayaratne, 1991; Siriweera, 2000). Literature also suggests that development of large-scale irrigation infrastructure was prioritized over small irrigation systems (including STCS), as their contribution to national level production of rice and other food crops was regarded as low (Dayaratne, 1991; Mendis, 1981; Tennakoon, 2000). However, several campaigns and projects led by NGO's resulted in the rehabilitation of some small tank systems and various institutional structures were also established. The Agrarian Services Act 58 of 1979 introduced a uniform institutional structure across small irrigation systems and this replaced the various structures that existed across the range of projects and locations (Aheeyar, 2000; Dayaratne, 1991).

Frequent changes in government and related policy priorities since the 1940s have resulted in the transfer of the responsibility for managing small irrigation systems among many government institutions. This has affected the development of a long-term policy framework for effectively managing the small irrigation systems in Sri Lanka (Aheeyar, 2000; Dayaratne, 1991). Agrarian laws that govern the management of small irrigation systems and associated farming systems have been subjected to four major changes since 1947 (Aheeyar, 2000). The laws underwent another major overhaul when The Agrarian Development Act No 46 of 2011 was introduced. These institutional and other changes in the scope of institutional responsibilities for STCS are shown in Table 1.

4. Changes in governance mechanisms and their impacts

The historical changes in governance (Table 1) and associated institutional structures gradually alienated local communities directly responsible for managing land and water resources (Abeyratne, 1985). Community confidence and morale were eroded due to changes in rights and entitlements through amendments in the legal and institutional framework (Panabokke et al., 2002). Top-down management approaches were adopted by the government without consideration of local perspectives on existing water use, and the establishment of institutional structures aligned with administrative boundaries led to a conflict of interests (Aheeyar, 2000).

The impacts of these changes can be viewed from various perspectives. Here, we concentrate on management uncertainties, loss of polycentrism and loss of multi-functionality.

Table 4. Timeline of changes in institutional and governance structures related to the management of small irrigation systems (Abeyratne, 1985; Aheeyar, 2000; Panabokke et al., 2002; Wijekoon, Gunawardena & Aheeyar 2016).

Timeline	Event	Responsible institution
1948	Maintenance of small irrigation systems was transferred from the Department of Irrigation as it concentrated on large irrigation development projects	Ministry of Agriculture
1951 & 1956	Irrigation Ordinance is revised to minimize farmer involvement and create rigid rules/procedures	Department of Irrigation
1958	Paddy Land Ordinance of 1958 created the Department of Agrarian Services (DAS) to manage all small irrigation systems and encourage farmer participation through the establishment of cultivation committees and abolished 'Wel Widane' system. This also provided legal recognition for '**cultivation meetings**'. The focus was on managing paddy lands rather than related irrigation infrastructure. Community involvement was minimum.	Department of Agrarian Services (DAS)
1968	Irrigation Ordinance amended to authorize the Commissioner of Agrarian Services to supervise and control district-level administrators that manage small irrigation system.	Department of Agrarian Services (DAS)
1972	Agricultural productivity laws introduced and responsibility for STCS was transferred back to the Irrigation Department. Agricultural production committees were established, and the Minister had the right to select members of the committee.	Department of Irrigation
1979	Agrarian Services Act No 58 introduced. Responsibilities were transferred to the DAS. Agrarian Service committees were introduced. These committees comprised elected farmers and state officials. State officials outnumber farmers on many occasions.	Department of Agrarian Services
1991	Agrarian Services Act No 58 was amended and farmer organizations (FO's) were established and granted legal recognition to receive maintenance contracts from DAS. Institutional strengthening and social mobilization programmes were implemented to strengthen FOs. FOs were established on village administration boundaries (these boundaries might encompass several tanks).	Department of Agrarian Services
2000	Agrarian Development Act No 46 is introduced and the former Agrarian Services Act 58 of 1979 is repealed. Reintroduced FOs and defined their role and functions. Introduced provisions for addressing paddy land tenure issues.	Department of Agrarian Development
2011	Agrarian Development (Amendment) Act No 46 introduced as an amendment to Agrarian Development Act 46 of 2000. Established agrarian development councils and introduced various provisions to manage and oversee FOs. Provisions on the management of irrigation work and irrigation water introduced. (https://www.lawnet.gov.lk/)	Department of Agrarian Development

4.1. Management uncertainties

The abandonment of 'Rajakariya', a communal management system during the British colonial period, saw the appointment of administrators to manage the water resources. Then, farmers lost the common property rights for their local water resource with the enactment of the Crown Land Ordinance of 1840. These had a profound impact on the productivity, maintenance and sustenance of STCS and led to their gradual deterioration (Panabokke, 2009; Panabokke et al., 2002). The ability of local resource users to take collective decisions and actions to manage their resource base has been acknowledged as a key-value in natural resources management and a characteristic of institutions for irrigation governance (Ostrom 1993; Meinzen-Dick & Pradhan, 2001). Management of small tanks has been the responsibility of the Department of Agrarian Services since 1979. The Agrarian Services Act No 58 established Farmer Organisations (FOs), and relevant amendments to the Act in 1991 supported the strengthening of these entities to work collaboratively with the state officials. However, the functioning of FOs was affected by cultural and social dynamics such as relationships, cultural beliefs, political affiliations and social status of farmers and state officials (Merry, 1988).

The establishment of the 'cultivation meeting' as a critical event in the farming calendar for small-scale, agricultural systems could be seen as a positive initiative towards farmer engagement. Although communities traditionally practised a decision process similar to the cultivation meeting, it was legally recognized by the Paddy Lands Ordinance of 1958. Department of Agrarian Services facilitated the cultivation meeting process with local communities (Begum, 1987). The success of this process depended on many factors such as the type and availability of information for decision making, community consensus building, accountability for decisions, power dynamics within various interest groups, and effectiveness of government institutions in delivering services (Dayaratne, 1991; Merry, 1988; Moore, n.d.). However, governance mechanisms have been inconsistent over the years. A brief examination of Agrarian Services Act of 1979 and subsequent acts indicates this policy incoherence (e.g. decentralizing rehabilitation and repair to farmer organizations and subsequent re-centralization into government agencies and strengthening of bureaucratic controls refer Table 1). This has resulted in politicized decision-making processes, through the influence of state officials. The subsequent loss of ownership of the process was a significant factor that affected noncompliance issues in the management of small irrigations systems (Dayaratne, 1991; Merry, 1988).

The 13th Amendment to the Constitution of Sri Lanka in 1987, created provincial councils to decentralize some functions to the provinces. The management of minor irrigation systems (that incorporate STCS) was devolved into the provincial council mandate. It required provincial councils to develop and legislate provincial statutes to provide a legal framework for managing small irrigation systems. However, only the north-central provincial council (out of seven provincial councils) introduced such legislation. Examination of the functions of provincial irrigation departments indicates that they have a mandate for managing small irrigation systems as well (that include STCS). Moreover, the central Government's Department of Agrarian Development has the same mandate. This creates a potential for duplication and confusion at the local level. Provincial irrigation departments are seriously challenged by a lack of technical and financial resources and the coordination amongst these institutions is often poor. As a consequence, despite the attempt at decentralization, central government agencies still manage small irrigation systems (Wijekoon, Gunawardena & Aheeyar 2016).

4.2. Loss of polycentrism

During the pre-colonial era, paddy cultivation under a small tank depended on complex property rights and tenure systems that incorporated permanent, temporary and lease tenures. Water management and cultivation decisions were taken at the local level by farmers. There is limited evidence from historical research suggesting that the king or his agents did not have a direct role in managing local water resources and cultivation decisions (Leach, 1961). However, such decisions may have been influenced by a broader operational framework, as the king required deliveries of grain or water taxes. This review also indicates that local elites, temples or large landholders who provided land, finances or labour to construct a tank, had management rights in terms of taking portions of the harvest from farmers who cultivated there (Abeyratne, 1985; Begum, 1987; Panabokke et al., 2002; Wijekoon et al., 2016).

Decisions on management appear to have been largely independent at the local level with the participation of farmers under little or no interference from external actors. This situation might have contributed to the development of tank-based or area-specific sets of rules or customs for managing water (Panabokke et al., 2002) and provided opportunities for farmers to decide the extent of cultivation depending on the local availability of water. This freedom and flexibility of decision making would have enabled the farmers some degree of self-governance of their resource and is indicative of a system of governance where authority is distributed among various levels and the decision structure is not entirely organized in a hierarchical order. This is a characteristic of a polycentric governance system. Polycentric governance systems are considered best placed to allow self-organization by local communities in response to local challenges, such as climate adaptation because the skills and local knowledge of community members place them in an ideal position to solve the issues on their resource base (Huitema et al., 2009; Skelcher, 2005). Local resource users (local actors) contribute a considerable amount of knowledge about the local resource base in a polycentric system. The interaction of tacit community knowledge with external knowledge of outside actors at various levels in a polycentric governance system can lead to improvements in the resource base and enhance local knowledge resources and vice versa (Ostrom, 2005).

4.3. Loss of multifunctionality

The primary function of STCS has been debated over the years. Early British colonial administrators and the post-independence irrigation bureaucracy considered them as hydrological entities primarily designed for irrigation. STCS were seen as small entities that cannot support large communities and this led to the prioritization of large scale irrigation development. However, a consensus began to grow since 1980s that STCS are multi-functional landscapes with features that provide hydrological, ecological and social services to rural farming communities (Dharmasena, 2010a, 2010b; Mendis, 1981; Panabokke et al., 2002; Tennakoon, 2000).

STCS have been an essential component of rural farming communities for centuries. STCS and the associated socio-cultural landscape link agriculture, religion and habitation aspects of a rural community (Shannon & Manawadu, 2007). The social and cultural dynamics of a community associated with a small tank system were highlighted by Leach (1961). Leach's research emphasized the role of small tank systems in the lives and livelihoods of people of a rural Sri Lankan village. Subsequent research identified common patterns in small tank systems and the surrounding landscape that provides essential services and functions to communities. These features or components (more than 15) have been extensively described (Dharmasena, 2010a, 2010b). The ecological and social functions provided by these components vary with location and include water filtration, reduction of silt accumulation into water bodies, demarcation of an area of the tank for livestock, and designation of areas for cultivation of perennial fruiting trees, shrubland (for provision of firewood), upland rainfed farming (chena) and downstream irrigated areas for paddy cultivation.

STCS currently are also described as water conservation mechanisms adopted by early settlers to efficiently and effectively use a limited resource. They were further strengthened over generations by adding new elements and features to enhance benefits and minimize any issues that emerged (Mendis, 1981; Tennakoon, 2000). There is increasing evidence that STCS were constructed primarily to manage water in a dry environment and were systematically planned to maximize the use of water (Gangadhara & Jayasena, 2005; Jayasena et al., 2011; Kenyon & Pollett, 2004; Shannon & Manawadu, 2007). Therefore evidence indicates that STCS are not primarily constructed for irrigation purposes but as an entity to manage water in an area with a seasonal rainfall pattern (with a clear wet and dry season).

Ecological features and the importance of the STCS have been discussed by several authors (Geekiyanage & Pushpakumara, 2013; Marambe et al., 2012). These studies also identify various species assemblages associated with small tanks and relate them to specific components of the system as described by Dharmasena (2010a, 2010b). Species inventories comparing STCS and adjacent natural forests indicate that STCS and associated vegetation are comparable to natural dry zone forests in Sri Lanka (Goonatilake et al., 2015). STCS can also be considered as wetlands, under the RAMSAR definition, and several studies have attempted to estimate the value of these systems. The goods and services provided by wetlands were quantified by Emerton and Kekulandala (2003) and these have been adapted to other studies of STCS. Such studies indicate that the benefits associated with tank goods and services underline their high economic and livelihood value to local communities and estimate the economic value of around USD 3911/ha/year. These studies also emphasize the importance of calculating both direct values (such as incomes from agriculture, fishing, plants collected as vegetables, livestock, domestic use) and non-direct values (such as aesthetics, tourism, flood attenuation, groundwater recharge, nutrient and sediment retention) (Vidanage et al., 2005).

5. Discussion

Contemporary natural resources management thinking suggests that multiple legal and normative frameworks are possible in governing natural resources. These could be a national law, state or provincial law/statutes and customary laws (Meinzen-Dick & Pradhan, 2001). The governance of STCS has undergone major changes through pre-colonial to post-independent periods, where management responsibility was transferred from communities to government bureaucracy. Furthermore, subsequent institutional 'churn' and changes to administrative arrangements in the post-independence period (Table 1) perpetuated the decline of STCS. The uncertainty of governance systems and alienation of resource users within the governance system are among the key issues leading to unsustainable resource governance (Ostrom 1990; Ostrom et al., 1999; Dietz et al., 2003). Moreover, evidence from Natural Resources Management (NRM) in other contexts indicates uncertainties in the governance system also lead to poor resource allocation and inefficiencies (Ostrom 1993; Morrison et al., 2004; Bardsley & Sweeney 2010). The introduction of external solutions (institutional, management and infrastructural) to govern natural resources has resulted in the loss of traditional rights, marginalization of local communities, and loss of traditional knowledge related to farming, and similar cases have been documented in other contexts (Ostrom 1990; Ostrom & Gardner 1993; Scott 1998). Several case studies in the grey literature indicate such scenarios may be common in Sri Lanka and merit further investigation. Another aspect of NRM governance in Sri Lanka leading to the decline of STCS is the centralization of NRM governance. Centralized control assumes that government bureaucracy is well placed to govern natural resources by managing the resource demands of the users and thereby limiting usage to avoid the depletion and degradation of the resource base. However, the presumption that external inputs from state actors are needed to successfully manage local common-pool resources, such as local water storages, stems from the colonial experience in many parts of the world, where colonial government agencies opened previously unirrigated areas for cultivating cash crops for export purposes (Ostrom & Gardner 1993). Centralization is also viewed as a mechanism to consolidate the power of central (government) institutions and usually to the detriment of autonomous farming communities and their institutions (Scott 1998).

The establishment of centralized governance mechanisms ignored the multifunctional nature of STCS and their ability to provide multiple ecosystem services and functions. Hence, colonial and post-independent governance mechanisms for STCS primarily favoured engineering and irrigation efficiency with STCS managed as irrigation entities rather than as multifunctional systems. However, NRM governance based on resource /landscape boundaries that incorporates inputs from local resource users has been shown to provide significant benefits in terms of sustainable management of the resource (Robins, 2007). Furthermore, regionalized governance mechanisms, incorporating carefully planned and efficient investments could lead to better outcomes by encouraging the involvement of local actors (Jacobs & Brown, 2014). The NRM governance principles espoused by Lockwood et al. (2010) and Ostrom's design principles for irrigation institutes (Ostrom 1993) that value involvement of local resource users in the resource management process, recognizes their rights, and encourages the participation of multiple actors in multilevel governance provide a broad framework for developing a new governance structure for STCS in Sri Lanka. However, current management structures and institutions are designed on administrative boundaries (Wijekoon et al., 2016) rather than resource/landscape boundaries, which would require a considerable transformation of the current governance structures.

The survival of STCS over millennia up to British colonialism is attributed to the governance structures historically in place at local levels. Farming and water allocation activities are mostly organized at the village level where farmers meet to plan the cultivation season. However, these cultivation decisions are influenced by other actors such as local level and regional level administrators. Government officials are directly involved in the decision making process about local resources. The partial distribution of management responsibility to farmer organizations since 1979 has not been consistent as legislation mandates that government officials need to authorize any cultivation decision arrived at by farmer organizations through their cultivation meeting (Abeyratne, 1985; Wijekoon et al., 2016) deviating from the notion of polycentricity. The loss of polycentrism of STCS governance since British colonialism, inadequate transfer of management rights to farmer organizations, and complexities and overlapping mandates of the institutions have compromised the role and utility of STCS to ameliorate climate risks. This could potentially harm current government investments to rehabilitate STCS to achieve food and livelihood security for local farmers as a climate adaptation outcome.

Polycentric governance systems are considered best to address complex natural resources management issues as they provide flexible, responsive and adaptive mechanisms that capture the ecological, social and cultural dynamics associated with natural resources such as forestry, fisheries, and water. Furthermore, they provide opportunities for wide-ranging institutional responses at various scales that are appropriate for uncertainty and change within the system (Folke et al., 2005). Adaptive Co-management (ACM) that embraces polycentricity is increasingly recognized as an approach that could reconcile complex issues created in natural resources management interventions. ACM has been described as an approach that combines, adaptive management (focusing on learning by doing through learning and adaptation over medium to long time scales) with co-management (focusing on linkages across institutions and resource users to build relationships and promote participation and engagement) (Armitage et al., 2009; Folke et al., 2002; Olsson et al., 2004; Plummer et al., 2012). The ACM literature and case studies to date combine social-ecological dynamics and learning about how to respond to environmental/social feedback, a feature that could improve the role of STCS in dry zone adaptation to climate change. Furthermore, ACM can enhance the capacity of resource users and institutions to deal with uncertainty and change (Olsson et al., 2004) to solve resource management issues through collaboration and to foster ecologically sustainable livelihoods (Plummer & Armitage, 2007). These are vital aspects for envisioning any future governance mechanisms of STCS as the institutional and policy landscape in Sri Lanka is highly unstable and unpredictable. However, the potential to develop such inclusive governance mechanisms would appear remote unless the government makes significant changes to the policies that govern natural resources in Sri Lanka.

6. Conclusions

Viewed through a contemporary understanding of NRM good practice, our review identified four issues that emerge as impediments to improved governance arrangements for STCS under climate change:

(1) Uncertainty surrounding the governance of STCS led to inefficient resource use and planning.
(2) Polycentrism, which was a feature of the traditional management of STCS, was lost in favour of a centralized approach.
(3) The Sri Lankan Government prioritized larger irrigation schemes over STCS, which led to a loss of funding and neglect of small scale irrigation systems.
(4) Loss of recognition of the multi-functional nature of STCS, which de-valued their importance to dry zone communities as more than simply a source of water for irrigation.

The gradual centralization of authority, irrigation centred decision process and engineering efficiency-focused governance mechanisms has significantly weakened small tank cascade systems that evolved as multi-user and multi-functional systems. These governance mechanisms are a significant contributory factor to the dilapidated status of many such systems and lack of community (user) support to manage such systems.

STCS are multifunctional systems that can be revitalized through carefully planned actions that can transform the dry zone landscape to sustain diverse ecosystems, local livelihoods and economic benefits. The (re-)development of STCS is considered a viable strategy to address emerging threats such as climate change, and STCS show potential to buffer against climate variations and help sustain local communities (Bebermeier et al., 2017). The National Climate Adaptation Strategy 2016 recognizes the importance of developing STCS and lists some past projects that have attempted to achieve this outcome. The significance of STCS under climate change is beginning to be recognized and investment in their rehabilitation is underway. The Green Climate Fund-supported joint project (a multi-year project by the Government of Sri Lanka and UNDP Sri Lanka) seeks to explore the resilience of smallholder farmers in Sri Lanka‘s dry zone to climate variability and extreme events through an integrated approach to water management. This project presents an opportunity for relevant stakeholders in Sri Lanka to examine new governance frameworks for STCS. However, its success will depend heavily on the project's ability to re-engage farmers in the management of STCS after decades of uncertainty, politicization and shifting responsibilities. The larger challenge of achieving coherent NRM policy settings in the broader landscape of national politics and economic policy seems to be a significant precondition to support any meaningful action towards dry zone adaptation to climate change.

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CHAPTER SIX

Exploring social networks in a small tank cascade system in Northcentral Sri Lanka: first steps to establishing adaptive governance

(Quantitative analysis of governance structures via social network analysis)

Chapter six is an article submitted to *Environmental Development.* The paper has undergone peer review, and was accepted subject to revision. The revised manuscript (the version included here) is currently under review, and an acceptance decision is expected. The paper answers RQ2 - How is cultivation and climate information accessed and shared for the decision-making process?

This paper follows a social network analysis (SNA) approach to explore decision–making process. It takes a 'deep dive' into the Palugaswewa STCS, a globally important agricultural heritage area, and the subject of Green Climate Fund research into STCS rehabilitation by UNEP and the Sri Lankan Government. The paper visualises social networks at the study site to reveal the key actors in resource management decisions, how they are organised into accessing/sharing cultivation and climate information (social networks), characteristics of these social networks, and their implications for adaptive governance that supports climate change adaptation. The paper also contributes to the first step of the Adaptive Co-management diagnosis framework (Plummer et al., 2017): look for antecedents (actors, activities and practices). I used a survey to collect data and SNA software (UCINET) for analysing and visualising data.

In the interests of reducing the overall thesis length, the literature cited in the manuscript has not been reproduced in this chapter but is included in the thesis bibliography.

Exploring social networks in a small tank cascade system in Northcentral Sri Lanka: first steps to establishing adaptive governance

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Abstract

Systems of irrigation governance that are community-led, flexible, and adaptive are better suited to meet the needs of local communities, resolve conflicts and minimize risks posed by a changing climate. Small Tank Cascade Systems (STCS) in Sri Lanka's dry zone have been critical to ensuring food and livelihood securities of local communities, and governance of STCS to reduce future climate risks will assume increased significance. Adaptive co-management (ACM) practices could reconcile complex natural resources management issues by incorporating flexible community-based resource management systems tailored to specific geographical places and contexts, supported by organizations working at various scales. We sought opportunities to enhance existing systems of resource governance through ACM as a response to the uncertainty surrounding changes in climate. The first steps were to identify actors and processes related to the governance of Palugaswewa STCS through the cultivation meeting, a key decision process for resource management. We used social network analysis (SNA) with a survey of 48 farmers to identify key actors, their roles and responsibilities, practices and decision processes. The findings indicate that current decision processes are compartmentalized within the cascade system with less collaboration among actors in the upper, middle and lower parts of the cascade than anticipated. We conclude that governance structures of STCS could be improved by recognising and incorporating informal actors, farmer subgroups, existing social relationships and community norms. To minimize future climate risks, information provision to farmers needs to recognize existing information flows in local networks, develop strategies to enhance existing relationships, build on existing adaptive/flexible decision processes, foster collaboration across the cascade system and develop governance mechanisms that operate at cascade/catchment level.

Key Words: Small Tank Cascades, Social networks, Water governance, Climate adaptation, Adaptive governance

6.1 Introduction

The demand for water in agriculture will escalate with the increasing population, rising incomes and changing dietary requirements (de Fraiture & Wichelns, 2010). Therefore, governance of water to meet competing demands of industrial, urban and rural water users, provide water for the environment and address water scarcity will be challenging (CA, 2007; de Fraiture & Wichelns, 2010). The complexities associated with political, economic and social institutions are essential considerations to manage and develop water resources. Furthermore, equitable, efficient, and sustainable water management requires the participation of all actors who use and are affected by the resource (Rogers & Hall, 2003). Water governance is undertaken through a variety of processes across the globe. Although water is often regarded as a common property resource, related rights and entitlements are generally vested in the state or its agencies (Ostrom, 1990; Scott, 1998).

Rainfed agriculture (including small irrigation systems) meets about 60% of the food and nutritional needs of the world's population, and it is a major livelihood of marginal or subsistence farmers (Biradar et al., 2009). Small water storage and irrigation systems have the potential to provide higher returns for local communities than larger projects, and effective management of local water storage is a critical factor for food and livelihood security of rural farming communities (Ostrom, 1992; Ostrom & Gardner, 1993). In a global context, the shift in governance from local resource users to centralized government agencies has led to the exploitation of the resource base by individual actors depending on their social status and wealth (Di Baldassarre et al., 2019; Ostrom & Gardner, 1993). Furthermore, such exploitation may lead to conflicts and abandonment of collective responsibility to maintain the resource base (Ostrom & Gardner, 1993). Successful governance of small irrigation systems has several common characteristics: local-level governance and associated institutional structures, community-derived laws, rules and customs, stakeholder participation, and high social capital (Ostrom, 1992; Ostrom et al., 1999).

Historical geological faulting and erosion in Sri Lanka have resulted in diverse landform features. The landform is categorised according to elevation into a coastal belt, plains, and central highlands with a peak elevation of 2524 m (Marambe et al., 2015). The rainfall distribution across Sri Lanka is influenced by a bimodal rainfall pattern that corresponds to two alternating monsoons (southwest and northeast), the situation of the central highlands perpendicular to the alternating monsoons, and landform diversity (Marambe et al., 2015). The rainfall distribution patterns divide Sri Lanka into three climatic zones (wet, intermediate and dry) based on the spatial/temporal variation in rainfall

(Dharmasena, 2010a; Marambe et al., 2015). The dry zone (the location of this study) extends to the northwest, north, northeast, east and southeast of Sri Lanka in the lowest elevation zone. It has a prominent dry season from May to September (Marambe et al., 2015), the extensive undulating land surface that has resulted in a large number of small inland valleys, topography with underlying highly impervious basement rock, overlying weathered rock, and shallow to moderately deep soil (Panabokke et al., 2002). The seasonality of rainfall, topography and soil conditions are very conducive to the construction of small reservoirs for water storage (Panabokke et al., 2002).

In Sri Lanka, small local water storages have been constructed across narrow valleys of the dry zone since 300 BC (Panabokke, 2009). These storages evolved into large complex tanks by the 3rd Century AD (Panabokke et al., 2002). Connected series of tanks within a meso-catchment became known as Small Tank Cascade Systems (STCS) for storing, conveying and utilising water from an ephemeral rivulet (Madduma Bandara, 1985; Panabokke, 1999). The governance of STCS has altered dramatically throughout history (Kekulandala et al., 2021; Wijekoon et al., 2016). In the pre-colonial period, traditional community institutions functioned on a set of commonly agreed norms and rules for managing STCS, and local communities had a variety of property rights that enabled them to manage water and adjacent land resources. During the colonial period, STCS were declared as Crown property by the British colonial administration, which gradually led to dilutions of local institutions as local users were marginalized from the decision-making processes (Kekulandala et al., 2021; Panabokke et al., 2002; Wijekoon et al., 2016). Post-independence, the governance has been marked by persistent shifting of responsibility for STCS among several government agencies, ongoing changes in regulatory instruments and a lack of investment in STCS in favour of large-scale irrigation schemes. The result has been inefficient resource use and planning, loss of polycentrism and a general devaluing of the importance of STCS as multifunctional ecosystems supporting livelihoods of smallholder farmers in the dry zone of Sri Lanka (Kekulandala et al., 2021).

In recognition of the value of functioning STCS to the dry zone, Sri Lanka is investing more than $50m (USD) through a Green Climate Fund grant to enhance the resilience of dry zone farmers by upgrading and improving small irrigation systems (including STCS) (UNDP Sri Lanka, 2016). This investment includes the development of enhanced cascade/catchment-level governance strategies that can contribute towards the food and livelihood security of smallholder farming communities likely to be compromised under a changing climate (Esham et al., 2017; Esham & Garforth, 2013). Kekulandala et al., (2021) proposed adopting adaptive co-management as a possible approach to governance that could address these issues.

Adaptive co-management (ACM) is increasingly recognized as an approach to governance that could reconcile complex issues created in natural resources management interventions. ACM has been described as an approach that combines adaptive management (focusing on learning by doing through learning and adaptation over medium to long time scales) with co-management (focusing on linkages across institutions and resource users to build relationships and promote participation and engagement) (Berkes et al., 2007; Olsson, Folke, & Berkes, 2004; Plummer et al., 2012). The ACM approach facilitates efforts to address complex social-ecological problems because it incorporates flexible community-based resource management systems tailored to specific places and situations and supported by organizations working at different levels or scales (Armitage et al., 2009; Folke et al., 2002; Olsson et al., 2004; Plummer et al., 2012). ACM can enhance the capacity of water users and institutions to deal with uncertainty and change (Olsson et al., 2004). ACM can be considered as a tool in a suite of governance options that might include conventional institutional mechanisms, rigid institutional structures, and social and marketing incentives (Armitage et al., 2009). Trust-building, institutional development, collaborative and social learning are important elements in ACM that facilitate inclusive and sustainable governance (Armitage et al., 2009). Plummer et al., (2017) provide a framework for diagnosing ACM in four parts: 1. Identifying antecedents (actors, their roles and responsibilities and practices); 2. Consideration of decision processes; 3. Establishment of connections to various outcomes (both desirable and potentially undesirable); and, 4. Conducting parts 1-3 within a considered setting.

The cultivation meeting is the current formal process for managing STCS and associated agriculture, making it an obvious entry point to the study of existing STCS governance. It is a process prescribed by law (Agrarian Services Act No 58 of 1979), where government agencies and community institutions (Farmer Organizations) conduct collective decision making for STCS management. The law requires that a cultivation meeting for planning and managing a cultivation cycle (from initial land preparation to harvesting) be held with the participation of all the cultivators of the system. The meeting is convened by the head of the local administrative office, facilitated by the Department of Agrarian Development, and involves attendance by all relevant government departments and line ministry representatives. With the agreement of all parties, the key decisions taken at the cultivation meeting include the extent of paddy lands to be cultivated, date of the commencement of cultivation season, dates for commencement and completion for first and last water issue, cleaning bunds and channels, cleaning and repairing sluice gates, ploughing, and sowing variety and age classes of paddy. Responsibilities are allocated to farmer organisation members, and agreed maintenance work must be completed before land preparation activities can begin (Begum, 1987; Kekulandala et al., 2021; Panabokke et al., 2002; Wijekoon et al., 2016). The literature also indicates that the success of the process depends on many factors, including the availability of information (seasonal weather and agricultural), the effectiveness of government service delivery, community participation and capacity of key government actors (Abeyratne, 1985; Aheeyar, 2000; Kekulandala et al., 2021; Panabokke et al., 2002; Wijekoon et al., 2016).

In this study, we aim to support efforts towards the establishment of ACM for STCS by diagnosing the existing governance of a system in Pulugaswewa in Northcentral Sri Lanka. We used social network analysis (SNA) in conjunction with a survey of 48 farmers to identify the key system actors, their roles (e.g., primarily formal) and structures involved in the cultivation decision process. Through this study, we aim to satisfy the initial steps in Plummer et al.'s (2017) framework (identify antecedents and consider decision processes). The results of this diagnosis are discussed to identify opportunities for integrating adaptive systems of governance in STCS more generally.

6.2 Materials and Methods

6.2.1 Study Area

The study area encompasses a small tank cascade system (STCS) in the Palugaswewa Divisional Secretariat Division (a decentralized administrative unit that provides government services and functions) in the Anuradhapura district of Northcentral Sri Lanka. Palugaswewa STCS is situated within the Malwathu Oya river basin and falls within the UNESCO cultural triangle (Ministry of Agriculture & FAO, 2016). In 2017, the Palugaswewa tank cascade system was recognized as a Globally Important Agricultural Heritage System by the Food and Agricultural Organization of the United Nations[13] and was one of the systems targeted for rehabilitation as a pilot site through the Green Climate Fund.

Palugaswewa tank cascade is situated within a narrow valley that extends in a north-south direction to the east of the Ritigala range. Examination of satellite images via Google Earth indicates that runoff from ridges to the northeast, east and southeast is a main source of water for the cascade system (see Figure 14). The cascade covers an area of 1450 hectares and is characterized by

[13]http://www.fao.org/giahs/giahsaroundtheworld/designated-sites/asia-and-the-pacific/en/

undulating terrain with low ridges and shallow valleys, bimodal rain pattern with an annual rainfall (75% expectancy) of 900 mm (Ministry of Agriculture & FAO, 2016; Panabokke, 1999). Two alternating monsoons (Northeast and Southwest) determine the general climate of the area with clear wet and dry seasons. Northeast monsoon is the predominant rainy season (October to January), and March-April and August-September are dry (Ministry of Agriculture & FAO, 2016).

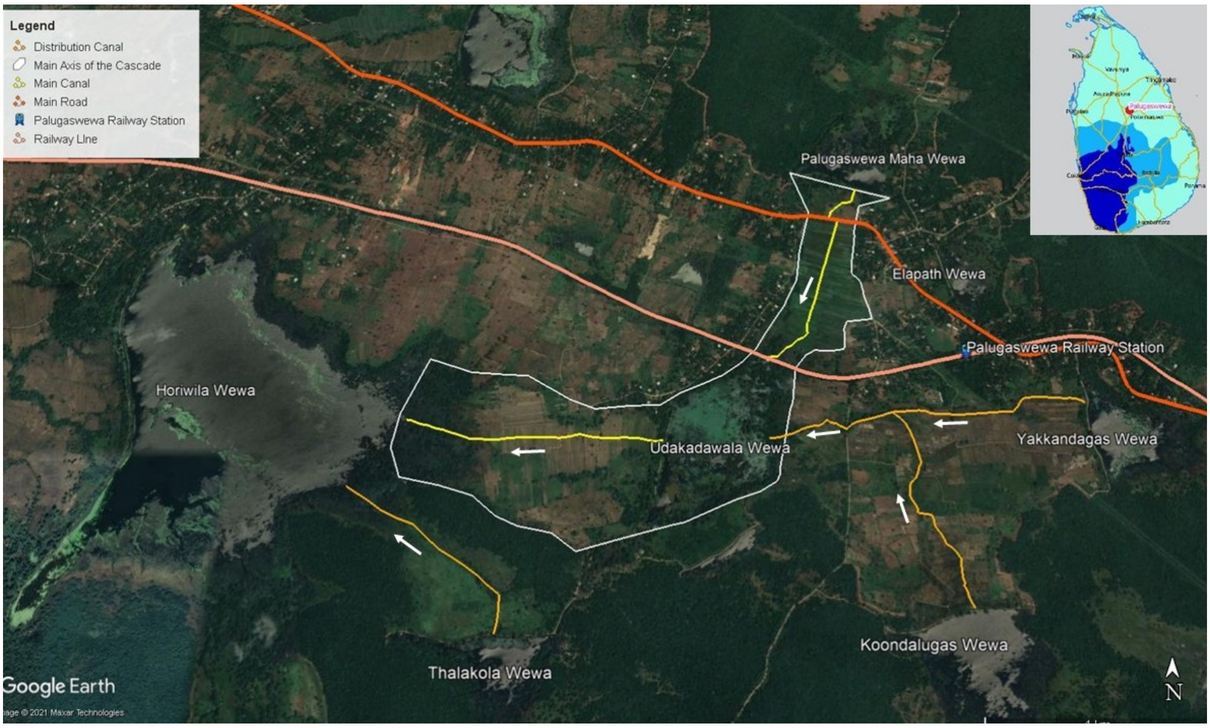

Figure 14 - Palugaswewa Tank Cascade System, white polygon shows the main axis of the cascade, yellow lines show main "canal" moving spillover on the main valley of the cascade, orange lines shows "canals" moving spillover from tanks in the side valleys into the main valley, white arrows indicate the direction of water flow.

(Credit: Nanadana Mahakumarage-nandanageo@gmail.com)

The local population is approximately 1,400 people, made up of about 400 families. It is important to note that they are not all farming families. There are three main villages, Palugaswewa, Udakadawala and Horiwila, in the upper, middle and lower parts of the cascade system, respectively. The village of Horiwila is situated at the lower tank, which is the largest and is classified as a medium/major irrigation system with a cultivation decision process that is different from the middle and upper parts of the cascade. However, coordination is still required between all three parts of the cascade to access certain government agricultural extension services. The livelihoods of the local communities are mainly related to agriculture. Rice is the dominant crop. However, according to information available from the Divisional Secretariat Division Office, maize cultivation is increasingly popular among farmers. Seasonal upland cultivation of crops such as legumes, onions and pulses provides significant income opportunities for local farmers (Ministry of Agriculture & FAO, 2016).

6.2.2 Methods

Social network analysis (SNA) is an approach for mapping complex resource governance systems (Bodin & Crona, 2009; Bodin & Prell, 2011) and particularly for natural resources management that involves multiple actors and different forms of participation (Bodin et al., 2006). We used SNA to map the formal and informal social networks in the study site for accessing and sharing of cultivation and climate information, the cultivation decision process and the key actors associated with managing the local water storage and farming. Forty-eight farmers were interviewed across the upper, middle and lower parts of the cascade system through a questionnaire survey. The full name of each participant, address, farming type (Rice/Upland/Chena/Vegetable), how they access water for cultivation (Tank (Wewa)/ Well/Tube Well/ other), location in the cascade and gender were recorded. Each respondent was then asked whether they *access* cultivation/climate information (Yes/No), how they access it (verbally/letter/notice/TV/radio / other) and to nominate sources from whom they access cultivation/climate information. Participants were then asked whether they *share* cultivation/climate information (Yes/No) and to nominate sources with whom they share this information. Participants were encouraged to provide up to five sources for each query.

Participants were recruited through a snowball sampling technique (Bryman, 2012). A local community worker facilitated introductions to members of the local farmer organisation in the tank cascade system. These farmers nominated other experienced farmers in the cascade system, and these nominations accounted for around 70% of the farmers in the cascade. The survey with officials of farmer organizations and experienced farmers helped to identify female farmers and upland farmers through their nominations. Participants were informed about the research, and written consent was obtained before commencement in accordance with the ethics approval of UTS HREC REF NO. ETH18-2825.

6.2.3 Data Analysis

Generally, networks function through interactions among various actors in the network (Bandyopadhyay et al., 2010). Analysis of how actors are organized (structure) in this STCS could provide insights into how effectively the network functions (Bodin et al., 2006) to access and share cultivation and climate information. Several network measures can be used to quantify the structure of a social network, and these measures describe interactions among network actors, which may include decisions about natural resource governance (Bodin et al., 2006). We used UCINET 6 for Windows to analyse the data as it supports a variety of network measures and visualization of social networks (Borgatti et al., 2002). We identified an access network, i.e. the structural organization of individuals and institutions (actors/nodes) that access cultivation and climate information, and a share network, i.e. the structural organization of individuals and institutions (actors/nodes) that share cultivation and climate information, the roles of key actors (formal and informal) in information flow within these networks, and the structure and function of the network.

Participant responses to the SNA survey were compiled, and two discrete directed symmetric affiliation matrices were constructed (Network 1: Access Information N=151; Network 2: Share Information N=180). A range of corresponding attributes, including farming type, water access, location in the cascade, role [farmer/government agent] and gender, were recorded for each participant. A range of network cohesion measures was used to explore the quality of the information that flowed between the formal and informal network members, which included average degree, density, diameter, and fragmentation. Betweenness centrality was used to identify those actors that may occupy bridging roles within the network (Freeman, 1977). Table 5 offers descriptions of the metrics utilised within this study.

Sociograms, a visual representation of actors (individuals/institutions), their relationships and the ties between them, were developed in NETDRAW (Ade-Ibijola, 2018; Borgatti et al., 2002; Moreno, 1951), and Analytics Technologies Keyplayer software was used for identifying key players (Borgatti, 2006).

Table 5 - Descriptions of network terms and measures modified from (Borgatti, 2006; Borgatti et al., 2002, 2013; Prell, 2012).

Term/ Measure	**Description**
Node	Any entity (individual/institution) within the network. In this study, all network actors (people) identified by participants are represented by a node. Within the visualisations, nodes appear as squares or circles.
Tie	Every connection between nodes is represented by a tie visualised as lines connecting nodes.

Key players	Key player diffusion algorithm identifies the nodes that have a connection to the most nodes within the entire network, effectively seeking to access all network nodes.
In-degree	The number of incoming ties (connections) to a node.
Out-degree	The number of outgoing ties (connections) from a node.
Betweenness Centrality	The number of times a node acts as a bridge to create a shorter path to connect other nodes.
Average Degree	The average number of ties (connections) attributed to each node
Density	The total number of ties (connections) divided by the total number of possible ties (connections) in the network.
Diameter	Length of the geodesic steps (shortest pathway) across the largest component of the network. Estimates the number of steps to reach everyone within the largest component within the network, i.e. 'Bacon's Law' and 'six degrees of separation'
Fragmentation	The proportion of pairs of nodes that are unreachable by any path through the network.

The social networks are characterized here with emphasis on formal governance processes to describe key actors and decision processes. Any associated informal actors and processes revealed are described to illustrate important linkages between formal and informal governance processes.

6.3 Results

6.3.1 Key Actors

Key players (actors) are a measure of network centrality, that is, how central an actor is to the operation of the network and a network may be disrupted or collapsed if key players are removed (Borgatti, 2006). Keyplayer analysis was undertaken for both the access and share networks. Key players of the access network revealed the importance of three farmers: two females and a male (Table 6). The presence of two women farmers as key players was unexpected, as rice farming is predominantly a male activity. In the share network, the three key players identified were two older, more experienced farmers and an official from the farmer organization (also a farmer) (Table 6). The older, experienced farmers were both from the middle tank of the cascade, which is associated with an ancient village with strong family relationships. Within Tables 6 and 7, farmer actors are categorised as being located in the upper, middle or lower tanks as we were interested in identifying information flows and links between tanks.

In both the access and share networks, all key players were informal actors, being farmers rather than formal actors (such as government or farmer organization officials). Both networks were highly fragmented, with the key players being able to reach less than 20% of the nodes (actors) in the network. This indicates that both access and share networks are potentially fragile, with a lack of uniform information flow through the network and the likelihood that communication of cultivation decisions might not reach some farmers in the periphery of the network.

Table 6 - Keyplayer analysis outcomes

<table>
<tr><td colspan="5">Keyplayer Initial Nodes</td></tr>
<tr><td colspan="2">Access Network</td><td colspan="3">Share Network</td></tr>
<tr><td colspan="2">ACC115 - Farmer (upper)</td><td colspan="3">SHA026 - Farmer (lower)</td></tr>
<tr><td colspan="2">ACC045 – Female farmer (upper)</td><td colspan="3">SHA159 - Farmer (middle)</td></tr>
<tr><td colspan="2">ACC120 – Female farmer (upper)</td><td colspan="3">SHA171 - Farmer (middle)</td></tr>
<tr><td colspan="4">Keyplayer in Access and Share networks</td><td>Percentage of nodes reached by these three nodes per network</td></tr>
<tr><td colspan="5">ACCESS</td></tr>
<tr><td>Node</td><td>ACC045</td><td>ACC115</td><td>ACC144</td><td>19.6%</td></tr>
<tr><td>Category</td><td>Female Farmer</td><td>Farmer</td><td>Farmer</td><td></td></tr>
<tr><td>Tank location</td><td>Upper</td><td>Upper</td><td>Middle</td><td></td></tr>
<tr><td>Run number</td><td>1</td><td>1</td><td>1</td><td></td></tr>
<tr><td colspan="5">SHARE</td></tr>
<tr><td>Node</td><td>SHA026</td><td>SHA060</td><td>SHA159</td><td>16.4%</td></tr>
<tr><td>Category</td><td>Farmer</td><td>Farmer</td><td>Farmer</td><td></td></tr>
<tr><td>Tank location</td><td>Lower</td><td>Upper</td><td>Middle</td><td></td></tr>
<tr><td>Run number</td><td>1</td><td>1</td><td>1</td><td></td></tr>
<tr><td>Node</td><td>SHA026</td><td>SHA060</td><td>SHA171</td><td>16.4%</td></tr>
<tr><td>Category</td><td>Farmer</td><td>Farmer</td><td>Farmer</td><td></td></tr>
<tr><td>Tank location</td><td>Lower</td><td>Upper</td><td>Middle</td><td></td></tr>
<tr><td>Run number</td><td>2</td><td>2</td><td>2</td><td></td></tr>
</table>

Centrality measurements identified nodes (actors) that facilitated the flow of information through the network. Nodes with high in-degree values (more incoming ties) (Table 7) represented actors that were relied upon for information. The four nodes with the highest in-degree values in the access network were all government actors (extension officers). Farmers rely upon these officers to access information on fertilizer and seed supply, agrochemical advice and financial support mechanisms. All three tanks had access to information through extension officers. In the share network, those with the highest in-degree values were all farmers from either the upper or middle tanks. The in-degree value was 4-times higher in the access than the share network, indicating a more diffuse information structure within the share network showing that farmers relied on a smaller number of information sources (government officers) in the access network, and then shared this information with a select group of other farmers (see Figure 16). These select groups likely represent kinship ties within families.

Table 7 - In-degree centrality values for access and share networks

Node	**In-degree values**	**Category**	**Tank location**
ACCESS			
ACC037	20	Government	Upper
ACC038	19	Government	Upper
ACC002	15	Government	Middle & Lower
ACC003	14	Government	Middle & Lower
SHARE			
SHA040	4	Farmer	Upper
SHA136	4	Farmer	Middle
SHA143	4	Farmer	Middle
SHA070	3	Farmer	Upper

High betweenness centrality (Table 8) values may identify actors that perform brokering roles within the network as this measures how many times a node is situated along the geodesic path of other nodes (Freeman, 1977). These brokering roles often involve accessing and sharing information formally and informally. In both the access and share networks, farmers only appear with the highest betweenness values. In the access network, these are leaders of the farmer organisations in the upper and middle tanks, while in the share network, leaders of the farmer organisation appear from the middle and lower tanks, alongside a young farmer (middle) and a female farmer (upper).

The young farmer is very active in the farmer organization, routinely involved in organizing meetings and voluntary maintenance activities. The female farmer (upper) is the head of a household and actively participates in several community organizations, including the farmer organization.

Table 8: Betweenness centrality values for access and share networks

Node	Betweenness Value	N-Betweenness	Category	Tank location
		ACCESS		
ACC110	9	0.040	Local Farmer leader	Upper
ACC132	6	0.027	Local farm leader	Middle
ACC100	3	0.013	Experienced farmer	Upper
		SHARE		
SHA141	19	0.060	Farm leader	Middle
SHA139	8	0.025	Young Farmer	Middle
SHA010	5	0.016	Farmer	Lower
SHA044	4	0.013	Female Farmer	Upper
SHA016	4	0.013	Experienced farmer	Lower

6.3.2 Decision Process

The analyses of network metrics demonstrate that information was primarily accessed through agricultural extension officers, familial ties, farmer organization officials and experienced farmers. The network cohesion measures in Table 9 indicate that, on average, in the access network, each node has access to 1.5 other nodes, while in the share network, the average degree was lower at 0.95. This supports the analysis of centrality, suggesting that farmer organization officials, farmers and their family members proactively access information on cultivation and climate but share with a limited group (to family members and neighbours). Density provides an indication of how many connections there are within a community and can be understood to be the probability that there is a tie between any random two nodes in a network (Borgatti et al., 2013). High density indicates there are more connections within a community; networks with high density and cohesion are closely linked and can have high levels of collaboration that may contribute towards strengthening trust among individuals in the network (Bodin et al., 2006). Furthermore, high levels of trust (high-density values) indicate low risks and costs in collaborating with others, and this is important for collective action and collaboration in managing a local resource such as water (Bodin et al., 2006;

Ostrom, 1990). The density of both networks is very low, with the access network having a density of 0.01, while for the share network, it was 0.005. These low values may indicate poor trust among farmers in the network, and the underlying cause needs further investigation.

The measures of in- and out-degree for both networks offer some insight into the direction of the information flow. The access network had an in-degree value of 0.124 and an out-degree value of 0.05. While the share network had a lower in-degree value of 0.017 and a higher out-degree value of 0.235. The relative values of these measures in each network indicate an organization of actors trying to maximise their access to information in the access network (e.g., access information from central sources) and maximise the sharing of information in the share network (e.g., share information with a broad range of actors). The fragmentation values of both networks were very high at 0.989 and 0.994 for the access and share networks, respectively. This corresponds with the low in-degree values (Table 7) and indicates that information may not be reaching some farmers in the periphery of the network. It also indicates that the larger network is comprised of multiple subgroups (See figures 15 & 16). The high component numbers of 151 and 180, which are equal to the number of nodes in these networks, indicate that there are significant weaknesses in information flow through these networks and suggest the presence of potential cliques (isolated sub groups) that are most visible in the share network (Figure 16).

Table 9 - Network cohesion values for Palugaswewa access and share networks

	Cohesion value	**Access**	**Share**
1	Average Degree	1.543	0.95
2	Degree of Centralization	0.05	0.023
3	Out-degree	0.05	0.023
4	In-degree	0.124	0.017
5	Density	0.01	0.005
6	Components	151	180
7	Fragmentation	0.989	0.994
8	Average Distance	1.083	1.199
9	Diameter	2	3

The diameters of the networks are 2 and 3 for the access and share networks, respectively. This indicates that in both networks, there may be nodes acting as hubs or key actors. Although these statistics provide many insights, the visualisation of these networks illustrates a more complex and nuanced story.

6.3.3 Accessing cultivation and climate information

Within the access network, nodes were primarily identified as paddy farmers, with several upland vegetable and maize farmers included. In the visualisation (Figure 15), they appear according to their location in the tank cascade, being upper (pink), middle (khaki yellow) or lower (cyan) tanks. The access network actors from three tanks are depicted in the diagram as nodes (coloured squares). The upper tank has the largest network and appears well connected. Networks in the mid and lower tanks appear less cohesive. This is particularly distinctive in the lower tank. Middle and lower tank networks appear more connected with each other than with the upper tank, which is largely isolated from the rest of the cascade except for connections through three farmers (ACC017, ACC046 and ACC104). There are two groups of farmers that appear as cliques in the visualisation, isolated from the main cascade network (see bottom right of Figure 15) at the lower part of the cascade. Further investigations revealed that the large clique is associated with a vegetable farmer and his neighbours. The small clique is associated with a tenant rice farmer who cultivates a small paddy plot in the fringes of the cascade system. This farmer and his family members do not access water from the main tanks and interact with the farmer organizations.

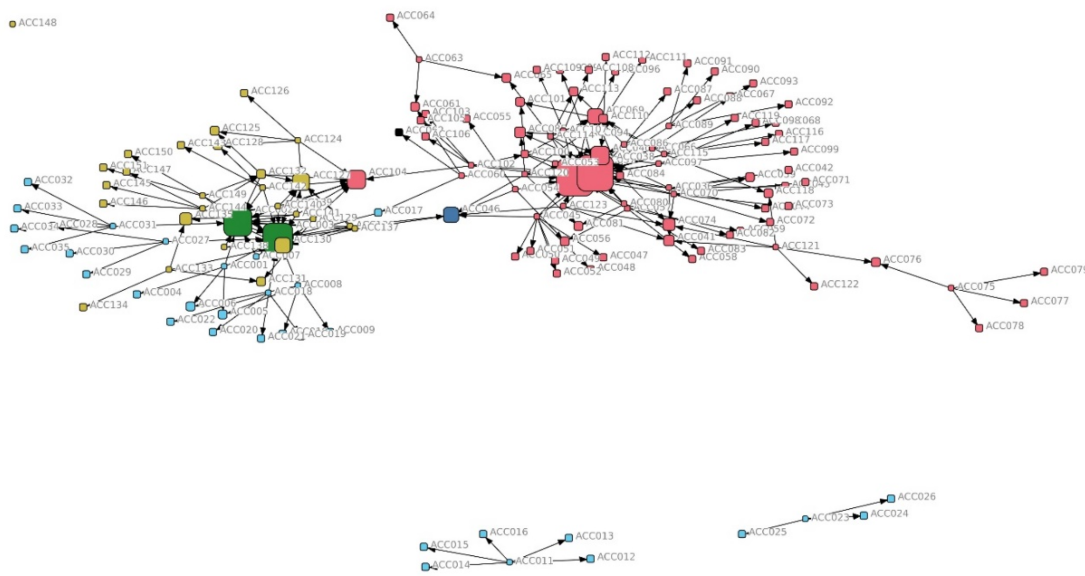

Figure 15 - Palugaswewa tank cascade access network: N=151. Colours represent node categorisation: upper tank (pink), middle tank (khaki yellow) and lower tank (cyan); middle and lower (green); all tanks (blue). Larger symbols denote more network connections.

Government officials that facilitate farming activities for the entire cascade system include four agricultural extension officers (appearing as large pink and green nodes) and a development officer (blue node) responsible for the entire divisional secretariat. Farmers connect with these officials to access information. Agricultural extension officers (large green nodes) link the middle and lower parts of the cascade as they are administratively allocated to these areas. However, it is interesting to note that there is only one link between farmers from the lower part of the cascade to the middle and upper parts (ACC017). In contrast, several linkages occur between farmers from the middle and upper parts of the cascade through another farmer (ACC104).

6.3.4 Sharing cultivation and climate information

Unlike the access network, the Palugaswewa share network consisted entirely of farmers (Figure 16). The network visualisation indicates that information is rarely shared throughout the whole cascade, and within this network, information is not shared with government officials. A major characteristic of the share network is its highly fragmented nature, consisting of a series of small networks of varying sizes that are largely unconnected. This structure may be attributed to the distribution of paddy plots under each tank and family relationships within (and between) tanks in the cascade. There are five individuals from the upper tank and one from the lower tank who does not communicate with anyone regarding their cultivation decisions (by accessing or sharing information through the network) (see top right of Figure 16). There is also a connection from the middle tank to one clique in the lower tank through a single farmer (SHA008).

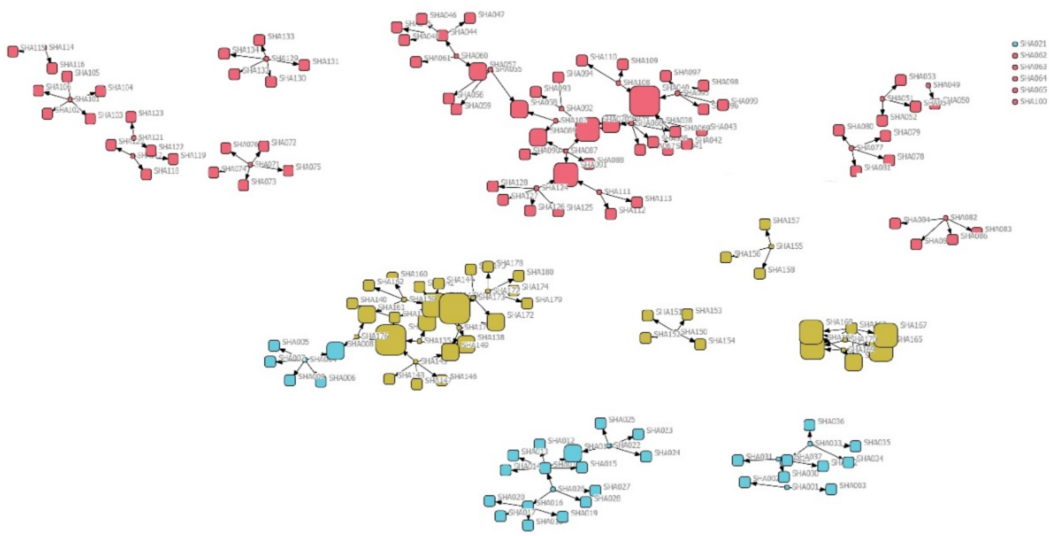

Figure 16 – Palugaswewa tank cascade share network Layout according to cascade: N=180. Colours represent node categorisation: Upper tank (pink), Middle tank (khaki yellow) and Lower tank (cyan).

(For ease of interpretation, this figure has been reconstructed to demonstrate the cascade structure - upper, middle, lower - in the image rather than Euclidean distance among 'like' networks)

6.4 Discussion

We identified the cultivation meeting as the key decision-making process in STCS because it determines the cultivation schedule, water allocation, voluntary contributions of the farming community for cleaning and maintenance, access to government subsidies, and sets local rules/norms for a given tank. SNA tools enabled the identification of key actors involved in the decision-making process, the structure of the decision-making process, and how information was accessed and shared within the community. It also provided information to assist in the promotion of ACM as an enhancement to STCS governance for Sri Lanka's dry zone agriculture under a changing climate.

6.4.1 Key Actors

The ability of actors to work collectively and to retain a degree of independence in decision making at various levels is an important characteristic of ACM (Berkes et al., 2007; Folke et al., 2005; Plummer et al., 2017). In our study, SNA metrics from both the access and share networks (key player analysis, in-degree sums and betweenness centrality measurements) identified 14 individuals central to the functioning of the STCS network in Palugaswewa. Six of these individuals were part of the access network, and ten were in the share network (two appeared in both networks). Given that the cultivation meeting is mandated as part of the formal governance of STCS, government officials would be expected to play a key role in the network. In Palugaswewa, the farmer organizations are supported by four agricultural extension officers. They are two Agricultural Instructors (AI) and two Agricultural Research Production Assistants (KPNS). An AI and a KPNS each are allocated to the upper and middle/lower (shared responsibility for Udakadawala and Horiwila tanks) parts of the cascade. These officials appear as key nodes in the visualisation of the information access network (Figure 15), and the importance of their role in the decision process is indicated by their relatively larger node size. They play a critical role in the cultivation meeting by linking the farmers with the formal government agencies for accessing government regulations about cultivation, information about agrichemicals, and facilitating farmers' access to subsidized fertilizer from the government agencies. Our study suggests that in Pulgaswewa STCS, these officials were effective in this role and supported collective decision processes in the cultivation meeting. However, there are risks in these arrangements as government officials could be, and frequently are, transferred according to organizational procedures, and existing knowledge networks could be disturbed, thus resulting in negative effects on the network function and the productivity of the system (Merrey, 1988). Research in Sri Lanka also suggests that extremely dedicated extension officers who earned the respect of the community are capable of establishing collaborative decision-making mechanisms, but these subsequently collapsed when the key person was transferred or moved out of the region (Dayaratne, 1991; Merrey, 1988).

Women and youth, in general, are under-represented in decision making in Sri Lankan farming communities (Meinzen-Dick & Zwarteveen, 1998). Our study identified two women farmers and a young farmer as important to information flow in Pulgaswewa STCS. The two women were found to perform key roles in the women's farmer association and were actively engaged with the agricultural extension officers. Similarly, the young farmer was actively engaged with the farmer organization from the upper tank of the cascade. These farmers, while not part of the formal governance of the STCS, created unique links between information provided by the agricultural extension officers or farmer organisations and farmers not otherwise connected to the network. The low participation of women has been attributed to formal membership criteria for institutions (i.e. farmer organizations), time commitments for meetings and other activities that can affect their family roles, and that water management and rice cultivation are traditionally seen as male-dominated activities (Meinzen-Dick & Zwarteveen, 1998). Within this study, we found evidence that women may play a key role in STCS knowledge networks despite men dominating the cultivation meeting process. Although this was unexpected, as the participation in the survey was dominated by male paddy farmers, follow up inquiries indicated that there are several women-headed rice farming families and a very strong women's farmer association. The women's farmer organization is supported by agricultural extension officers, and the women organise self-help groups to cultivate vegetables in back gardens and upland areas adjacent to paddy fields. The current governance system revolves around tanks and rice cultivation and does not incorporate other upland cultivation such as maize and vegetables. Farmers indicated that the cultivation of these alternative crops creates economic opportunities for women. Climate change will affect the food production of Sri Lanka due to changes in rainfall and temperature regimes and increased climate variability (Marambe et al., 2015). Smallholder farmers are increasingly vulnerable due to declining agricultural productivity and low livelihood resilience (Esham et al., 2017; Esham & Garforth, 2013). Smallholder cultivation of vegetables is an important aspect of local food security (Joshi et al., 2006; Rahman et al., 2008), and crop diversification could provide additional income streams, contribute to local food security and provide opportunities to build strategies that could lead to reduced risks associated with rice farming. However, further research is necessary to assess the economic contribution to household incomes of crops other than rice and how to integrate these in a future adaptive governance mechanism for the STCS that ensures opportunities for women to participate.

The two individuals that appeared as key actors in both the access and share networks are of particular interest. Interviews with farmers identified these key nodes as “water controllers” (Jala Paalaka in Sinhalese) from the upper and middle parts of the cascade. They are also annually elected representatives of farmer organizations and are allocated specific responsibilities at the organisation’s annual general meeting. These responsibilities include organizing farmers for the cultivation meeting, organizing tank, canal and sluice cleaning, monitoring farmer activities to ensure that they abide by the agreed cultivation schedule, opening and closing sluices at agreed schedules, reporting any compliance violation to the farmer organization, and informing farmers about meetings, fertilizer distributions, seed varieties and harvesting schedules. These roles indicate that they have a very close relationship with farmers throughout the cultivation cycle and are essential for the information flow within the farming community. These two individuals are important because they shared with other farmers the information accessed from government officials, making them key community knowledge actors.

In Sri Lanka, farmers typically use their experience with past climate to predict the monsoonal weather and provide their expectations to their communities for the upcoming cultivation season (Mase & Prokopy, 2014; Senaratne, 2013). Unlike the access network where government officials featured, key players in the share network were mostly older, more experienced farmers who were well respected in the community (as confirmed through follow-up meetings). All aspects of farming within the STCS are sensitive to seasonal weather and will need to adapt to future climate (Senaratne, 2013), and these mature farmers actively engage in the cultivation meeting process by sharing their experience of past seasonal weather events. Interviews with farmers indicated that these farming elders organize an unofficial pre-cultivation meeting before the onset of the northeast monsoon (October to February) and discuss their expectations about the rainfall. This information is communicated to the farmer organization ahead of the formal cultivation meeting and has a significant influence on seasonal STCS management. This informal meeting is significant because farmers do not receive seasonal forecasting information through meteorological or agricultural agencies in time to guide their agronomic decision making. Farmers, therefore, depend solely on the information provided by these community elders acting as knowledge hubs for the village, willing to acquire new information from external sources and provide links to their tacit knowledge for the farming community. Farming elders have been observed in similar roles in agroforestry systems in Ghana (Isaac et al., 2007) and water governance networks in Tanzania (Stein et al., 2011). The success of any new governance mechanism for STCS will need to recognise the role played by these key actors and incorporate their local knowledge into decision processes.

Knowledge brokers (individuals or organisations) play a central role in networks because they mediate the flow of knowledge and information between unconnected actors (Boari and Riboldazzi 2014). Two actors link the upper and middle-lower sections of Palugaswewa STCS performing the role of knowledge brokers. These actors provide opportunities to develop collaborative actions across the cascade that are important for developing cascade-wide governance structures or adaptive governance mechanisms. One actor (blue node in Figure 15) is a government official with responsibility for the whole local administrative area (divisional secretariat division). This government official coordinates development projects throughout the local administrative area and creates linkages among a range of local actors. However, this individual does not perform any direct role in the cultivation decision process. Another actor that connects the two sections of the cascade is a farmer (Figure 15, purple node connecting to yellow clique). Follow up investigations revealed that this farmer has close relatives in the middle part of the cascade (Udakadawala Village), requiring that he frequently interacts with farmers in the middle tank of the cascade and accesses/shares information with them. Ties to family residing outside the home are important influences on knowledge network structures, and our findings are consistent with previous studies in other contexts (e.g. Mönkediek and Bras 2014).

6.4.2 Decision Processes

SNA metrics, such as fragmentation and diameter (see Table 9), can provide insight into structural differences between the access and share networks. For example, the low density in the access network likely indicates decision processes that are top-down and hierarchical (Bodin et al., 2006). The cultivation meetings are organized around village administration boundaries and the main local tank (Palugaswewa Maha Wewa in the upper, Udakadawala in the middle and Horiwila in the lower parts of the cascade). The farmers who cultivate under smaller outlying tanks around the three main tanks in the cascade (visible in Figure 14) are members of the farmer organization established under the main tanks. This allows them to pool resources and organize communities for voluntary rehabilitation of tank infrastructure. Furthermore, farmers cultivating under these smaller outlying tanks follow the same cultivation schedule as the main tank, but they have some flexibility to alter the cultivation schedule to suit their specific needs. The degree to which farmers exercise this flexibility needs further examination as it would be an enabling factor for the development of future adaptive management strategies to manage climate risks collectively. The ability to formulate local norms and rules in decision making is an enabling factor that supports climate adaptation (de la Poterie et al., 2018; Šūmane et al., 2018).

The layout of irrigation infrastructure in Palugaswewa STCS appeared to influence the structure of the knowledge networks. The low-density values in the share network potentially indicated non-cohesiveness, conflicts, disagreements or noncompliance to local norms in managing the local water resource (Bodin & Crona, 2009; de la Poterie et al., 2018). Furthermore, the low centrality and highly fragmented nature of the share network (Figure 16 and Table 9) indicated that organizing local farmers in one large community institution (farmer organization) has not ensured a collaborative response across the whole STCS for governance actions. Several small groups within parts of the system share information among themselves with minimal links to other clusters outside of their tank. This was further explored in interviews with local farmers, which revealed that paddy lands under a given tank are organized into areas demarcated by water distribution canals and field canals. These canals divide the cultivable area into discrete sections, with each section subdivided into several smaller plots. A farmer cultivates several adjacent plots within a given section. Farmers within a section need to collaborate with adjacent farmers to facilitate the movement of water and farm machinery and crop management (i.e. sowing, harvesting). This practice maximizes efficiency by pooling resources and minimizing losses among these smaller groups. The villages of Palugaswewa and Udakadawala (upper and middle part of the cascade) are traditional villages with close family groups cultivating together. These family ties sustain this close collaboration required to manage their irrigation plots within the larger tank. These informal collaborative groups also ensure the appropriation rights are retained within the family group, provide opportunities to share knowledge and innovate, and create hyper-local rules and norms for farming (Ostrom, 1990), which in turn may contribute to improving the resilience of the STCS farming system (Šūmane et al., 2018). The share network also illustrates (Figure 16) the isolation of many small groups operating within the same tank. These fragmented subgroups are organized at different levels indicating nested informal units (Ostrom, 1993) comprised of close family relatives farming adjacent plots. These small co-operative groups may provide opportunities to foster and develop more extensive co-governance mechanisms (Bodin & Crona, 2009; Folke et al., 2005).

The lack of knowledge connections between the upper, middle and lower sections of the STCS indicates that levels of collaboration throughout the whole cascade are low and confirms the effect on decision processes of the formal administrative structure imposed through farmer organizations.

As a result, there are no established mechanisms or agreements to share water across the cascade, to share information about agricultural practices (disease outbreaks, seed varieties, fertilizer) or to improve the efficiency of resource use across the cascade. However, harvesting water for agriculture warrants farmers (informal actors) and government officials (formal actors) to collaborate in resource management across the catchment (Rockstrom, 2000). Furthermore, spatial variability due to high agro-ecological variation (De Silva et al., 2007), high inter-annual variability of rainfall and increasing variability of the northeast monsoonal seasonal rainfall (Eriyagama & Smakhtin, 2009; Marambe et al., 2015; Wickramagamage, 2016) are important factors that need to be considered to optimise decision making within each part of the cascade. In the absence of governance mechanisms that allow for the resolution of place-based trade-offs, these factors could lead to conflicts among farmers in water stress conditions (Ostrom & Gardner, 1993), as projected under climate change for the Sri Lanka dry zone (Esham and Garforth 2013), because of the close hydrological connections between the individual STCS tanks.

6.4.3 Towards an adaptive governance process

The interests and inputs of formal and informal actors are important to build collaboration (Armitage et al., 2008), and this collaboration is an important characteristic that enables ACM (Plummer & Armitage, 2007). The SNA and the interviews with farmers indicated primarily community-led decision processes in the upper (Palugaswewa) and middle (Udakadawala) sections of the cascade. The community interactions, active farmer organization and supportive government officials ensure that local farmers take a lead role in the cultivation decision process. They also allow flexibility in decision processes. However, the lower part of the cascade (Horiwila Tank) is governed under the provisions of the Irrigation Ordinance No 1 of 1946, which requires a government bureaucrat to lead the decision process. Cultivation decisions in this case are based on the water level of the tank, and a technical officer determines a volume of water available for cultivation in a given season. This top down governance arrangement could lead to alienation of the farmers, poor participation of farmers in the decisions process and conflicts (Abeyratne, 1985; Merrey, 1988; Nijman, 1992; Wijekoon et al., 2016).

The network structure and discussions with farmers indicate that compliance issues, disagreements and conflicts do occur within the system. Despite this, there could be multiple reasons for the success and structure of community-led cultivation processes in Palugaswewa that include (but are not limited to) close family ties among the farming community, the high level of community acceptance of traditional value systems (respecting elders, compliance with elders advice on climate, weather and cultivation, voluntary labour for maintenance of the local tank and canal systems, and shared responsibilities for farmland protection), incentives related to access to fertilizer subsidy through government agencies (which is tied to participation in the cultivation meeting and farmer organization membership), and access to crop insurance and compensation (which is also tied to participation and compliance in the cultivation decision process). It is important to note that further research in similar contexts is needed to draw generalizations that might apply to STCS more broadly.

The farming community does not have access to localized and timely meteorological information (seasonal forecasting), making it heavily dependent on the existing knowledge networks through old and experienced farmers to access climate information. It would likely be counterproductive to displace existing networks in seeking to establish new resource governance processes. Rather, existing relationships need to be further investigated to identify opportunities for their incorporation into future knowledge dissemination that communicates climate information to local farmers. Literature suggests that farmers learn about local changes to environmental conditions, and a combination of farmer's traditional knowledge and meteorological information allows local farmers to make informed decisions for planning the cultivation season (Nguyen et al., 2016; U. Nidumolu et al., 2018; Wood et al., 2014). However, research in Sri Lanka indicates that farmers perceive local weather forecasting as unreliable due to increased climate variability (Roncoli et al., 2002), and expectations of future climate based on past experience are often not realized (Senaratne, 2013). In developing enhanced cascade based-governance mechanisms, recognition of both formal and informal ties will be critical for improving the cultivation decision-making process through access to information about cultivation practices and seasonal weather that is both more accurate and timely (Roncoli et al., 2002). There is considerable uncertainty in the current decision-making processes in the cascade due to a lack of reliable location-specific meteorological, soil and hydrological data and unstable institutional and social structures at a wider scale, which warrant rethinking of the current governance mechanisms.

Attempts to develop a cascade-level adaptive governance mechanism could be compromised by different governance regimes practised in the cascade. The decision-making process in the upper and middle tanks enables flexibility, while the top-down decision process in the lower tank constrains farmers' flexibility to adjust their cultivation schedule, increasing their exposure to seasonal risks. These top-down decision processes could be a significant barrier to developing cascade level governance mechanisms as previous research in Sri Lanka indicates that government bureaucracy is hesitant to transfer or share authority to manage water (Aheeyar & Smith, 1999; Uphoff, 1986). The current governance mechanism based on the cultivation meeting process assumes the STCS community is more or less homogeneous. SNA revealed the heterogeneity of the farming community that is comprised of many subgroups with varying levels of autonomy and collaboration in decision making. Therefore identifying existing social relationships, norms and values practised by these groups and recognizing them in the cultivation decision process are important to develop an adaptive governance system (Ostrom, 1993; Stein et al., 2011).

6.5 Conclusions

This study aimed to identify the antecedents and decision processes for cultivation decision-making at the Palugaswewa STCS in north-central Sri Lanka. SNA enabled us to identify the key actors, their roles and activities, the decision process and its related social and institutional structures. These will serve as the basis for further study of STCS governance following subsequent steps in Plummer's ACM diagnostic framework (Plummer et al., 2017). Furthermore, network-based methods are not widely used in complex water management research (Gain et al., 2020), and this study demonstrated that SNA could uncover the structure of social networks, institutions, their relationships and inter-connections, information flows and interactions involved in the governance systems (Bodin & Crona, 2009; Cunningham et al., 2016; Groce et al., 2019).

This study revealed the complexity inherent in the underlying heterogeneity of the farming community, associated social network structures, linkages among formal and informal actors, and the importance of informal pathways for knowledge flows that facilitate the cultivation governance process. It also provided evidence of spatial disconnection and lack of interaction among various farmer subgroups based on the adjacency of plots within the cascade, a finding which appears to have been overlooked in previous studies. Within this complex resource management context, the current decision process is linked to the mandated seasonal cultivation meeting. Encouraged by a range of incentives (e.g. access to fertilisers) and reliance on information from both formal actors (such as government officials and farmer organization officials) and informal actors (such as farmers and neighbours), this arrangement appears to provide limited support to adaptive management in response to seasonal conditions. However, within Palugaswewa STCS, informal actors operate to enhance knowledge flows and collaboration among the farming community, often at a hyper-local scale.

These findings have implications for ongoing attempts to develop adaptive governance mechanisms that could contribute towards minimizing future risks from climate change as envisioned through the GCF funded Sri Lankan Government/UNDP project. However, any such developments in STCS governance must be sensitive to and preserve the best features of existing place-based arrangements. For example, future interventions (as planned by GCF Project) for providing meteorological information to farming communities will need to recognize the roles of informal actors (e.g. farming elders) in information dissemination, as revealed through SNA, rather than disrupt existing networks.

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CHAPTER SEVEN

The agricultural decision process in a small tank cascade system in Sri Lanka: Diagnosing options for adaptive governance

(Qualitative analysis of decision process through semi-structured interviews)

Chapter seven is a manuscript prepared for *Climate and Development.* The manuscript has been reviewed by colleagues at ISF-UTS and finalised by the authors for submission in December 2021. The manuscript answers RQ3 - Can adaptive co-management strategies be adopted for governance of small tanks cascade systems?

This chapter builds upon the findings of chapter five to characterise the STCS governance process by interviewing the key actors identified in SNA. The chapter explores the formal and informal decision processes and their attributes, and enablers and barriers of climate adaptation and adaptive governance at Palugaswewa. The chapter also contributes to the second step of the Adaptive Co-management diagnosis framework (Plummer et al., 2017): consider attributes of processes (collaboration, learning). I employed semi-structured interviews to collect data and used Nvivo to code and analyse data. Then the findings were compared with ACM, adaptive governance and climate adaptation literature.

In the interests of reducing the overall thesis length, the literature cited in the manuscript has not been reproduced in this chapter but is included in the thesis bibliography.

The agricultural decision process in a small tank cascade system in Sri Lanka: Diagnosing options for adaptive governance

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Abstract

Governance of water in small farming systems is critical for local food and livelihood security because it interacts with changes in agricultural practice, socio-cultural context, seasonal weather variability and climate change. Small Tank Cascade Systems (STCS) are a feature of water storage and management in the dry zone landscape of Sri Lanka that enabled food and livelihood security of local communities. The gradual centralisation of STCS governance from pre-colonial times has led to their deterioration, limiting their contribution to climate adaptation. Adaptive Co-Management (ACM) has received significant attention in the literature to reconcile complex issues in resource governance and may assist in the renovation of STCS. We explored aspects of STCS governance in Palugaswewa in North Central Sri Lanka to identify key actors and processes associated with agricultural decision making. We interviewed 15 key actors involved in STCS governance about the current decision-making process, potential process improvements and use of climate information. Our findings indicate that the formal decision process for resource management (the 'cultivation meeting') is mainly community-led, flexible and robust. However, an informal decision process (the 'pre-cultivation meeting') based on local farmers' knowledge and experience precedes and drives the formal cultivation decision process. We conclude that this informal process may compensate for the lack of timely meteorological information, allow space for sharing and co-development of knowledge, and facilitate ACM. Therefore, future interventions to incorporate adaptive governance in STCS need to consider providing timely, user-centred meteorological information, recognising the importance of informal processes that drive decision making, and rethinking legal frameworks at local and national levels to provide flexibility for resource users to diversify agricultural practice.

Key Words: Adaptive governance, Agricultural decisions, Adaptive co-management, climate change adaptation, Sri Lanka

7.1 Introduction

Small-scale farming systems are critical for global food security, but climate change, changing socio-cultural context, and governance uncertainties are significant emerging challenges (Hodbod et al., 2016; Howden et al., 2007). Climate change will significantly impact Sri Lanka's food production as the nation produces nearly 85% of its food requirements locally in small farming systems in the northwest, north-central and northeast dry zones where uncertainty in the amount and timing of rainfall is projected to increase (Eriyagama & Smakhtin, 2009; Esham et al., 2017). An undulating plain and a bi-modal rainfall pattern characterise the dry zone of Sri Lanka (Panabokke et al., 2002). The northeast monsoon (October to February) is the primary source of water for the dry zone, with the remainder of the year relatively dry (Marambe et al., 2015; Panabokke et al., 2002). Historical records and rainfall projections indicate that the monsoon rains are currently variable and projected to be more so into the future. Therefore, agriculture in the dry zone will need to become better adapted to high levels of seasonal weather variability (Eriyagama & Smakhtin, 2009).

Small water storage systems (or small 'tanks') in Sri Lanka are critical inventions that have facilitated settlements in the country's dry zone since prehistoric times (300 BC). Small tank construction evolved historically from individual tanks to tank clusters (Panabokke et al., 2002). These clusters are now referred to as "Small Tank Cascade Systems" (STCS), and they are defined as a "connected series of tanks organised within a meso-catchment of a dry zone landscape, storing, conveying and utilising water from an ephemeral rivulet" (Madduma Bandara, 1985, p5). STCS were the centres of ancient village settlements and were managed by communities with little or no input from outside. A community-led governance system based on rules, customs and traditions developed through generations ensured sustenance of lives and livelihoods. This cooperative management mode was abandoned during the British colonial period and led to the widespread degradation of these systems (Kekulandala et al., 2021; Panabokke et al., 2002). Several national policies identify the development of STCS as a strategy to enhance the rural economy and food and livelihood security (UNDP Sri Lanka, 2016). These policies created a new impetus, through investment from the Sri Lankan Government and UN agencies (UNDP Sri Lanka, 2016), for the rehabilitation and development of tank cascade systems, to improve the climate resilience of farming communities and establish new governance arrangements for their management over the next decade.

Internationally, the institutional structures governing local water resources have received considerable attention in the literature (Gari et al., 2017; Ostrom, 1992, 1993; Ostrom et al., 1999;

Ostrom, 2005). The term 'institution' constitutes multiple connotations; it has been defined as "the prescriptions that humans use to organise all forms of repetitive and structured interactions including those within families, neighbourhoods, markets, firms, sports leagues, churches, private associations, and governments at all scales" (Ostrom 2005 p.3). However, in an irrigation and local water storage context, institutions have been described as "a set of rules used by a group of individuals to organise repetitive activities that produce a set of outcomes affecting those individuals and potentially others" (Ostrom 1992 p.19). Specifically, an irrigation institution is a set of rules for supplying and using water for irrigation in a particular location. It also provides scope to include formal and informal decision making processes for managing water (Ostrom, 1992, 2005).

The current institutional governance and agricultural decision-making processes for STCS are primarily 'top-down' and fail to capture the changing nature of food and livelihood security outcomes, complex resource management scenarios, and the loss of multi-functionality and multi-user capabilities (Kekulandala et al., 2021). These top-down decision processes often disregard local farmers' place-based knowledge in the context of a changing climate (Mase & Prokopy, 2014; U. B. Nidumolu et al., 2015). The gradual centralisation of management responsibility and decision processes that focus on irrigation and engineering efficiency led to the deterioration of STCS (Kekulandala et al., 2021). However, governance variations exist, and institutional structures for agricultural decision-making in some STCS provide some flexibility for farmers to incorporate their local rules, norms and knowledge in the decision process. This flexibility within the current governance mechanism is vital to enhance governance adaptability (Kekulandala et al., 2021; Wijekoon et al., 2016).

The primary agricultural decision-making process in STCS is the 'cultivation meeting', which involves multiple actors and institutions determining a range of seasonal management tasks (Aheeyar, 2000; Panabokke et al., 2002). The governance structure of this process involves actors at the local village, local administration and regional administration levels and represents a loosely organised social-ecological system (Kekulandala et al., 2021). However, the incorporation of seasonal weather and climate information in this governance process, and its influence on decision making to drive adaptive responses, is uncertain.

ACM has received attention in the literature as an approach that reconciles governance-related problems in complex social-ecological systems like STCS (Plummer et al., 2012). ACM combines adaptive management with co-management (Folke et al., 2002). It enables flexible community-based resource management systems tailored to specific places and situations with the support of organisations working at different levels or scales (Armitage et al., 2009; Olsson, Folke, & Berkes, 2004; Plummer et al., 2012). The emphasis on trust-building, institutional development and collaborative and social learning are essential elements in ACM that facilitate inclusive and sustainable governance (Armitage et al., 2009). A framework for ACM establishment proposed by Plummer et al. (2017) consists of four phases: 1. Identification of antecedents (actors, their roles and responsibilities and practices); 2. Consideration of decision processes; 3. Establishment of connections to various outcomes (both desirable and potentially undesirable); and, 4. The implementation of phases 1-3 within a considered setting. In this paper, we are particularly interested in the actors involved in the decision process (phase 1) and how decisions are made (phase 2) to understand how these might influence adaptation to climate change (phase 3). The role of formal actors in the cultivation meeting, such as government officials, has been discussed previously (Aheeyar, 2000; Begum, 1987; Wijekoon et al., 2016). However, the role of informal actors, such as farmers, is not very clear. The existing literature indicates that farmers' beliefs and knowledge are critical elements that determine the outcomes of collective decision processes (in the case of STCS, the cultivation meeting for village-level decisions) and on-farm decisions (Mase & Prokopy, 2014; Nguyen et al., 2016; Senaratne, 2013; Šūmane et al., 2018). In general, individual farmer's beliefs and knowledge about their cultivation practices are exchanged and altered through interactions with networks of other knowledgeable farmers, which are in turn shaped by social and cultural value systems in a specific setting (Roncoli et al., 2002; Senaratne, 2013; Šūmane et al., 2018).

This study explores and analyses knowledge, views, understanding, interpretations and experiences of farmers and agricultural extensions officials about the agricultural decision-making process in the Palugaswewa STCS in Northcentral Sri Lanka to diagnose evidence of and options for ACM (Plummer et al., 2017). We conducted semi-structured interviews with farmers and government officials in the Palugaswewa STCS to examine the agricultural decision process, actors involved in the formal and informal decision processes, how cultivation and climate/weather information is accessed and used, and options for improving the current decision process. Inductive content-coding of interview transcripts revealed a series of themes, and these are discussed in the context of the current understanding of irrigation institutions, adaptive water governance, and evidence for ACM practice. Enablers and barriers for incorporating ACM strategies in existing governance mechanisms are identified.

7.2 Materials and Methods

7.2.1 Study Area

The study site was the Palugaswewa STCS in the Anuradhapura district of North Central Sri Lanka (see Figure 17). The study site encompasses three main tanks and several smaller tanks within Palugaswewa, Udakadawala and Horiwila villages, settlements dependent on this STCS. Palugaswewa STCS was listed as a Globally Important Agricultural Heritage System by FAO due to its irrigation and cultural significance (Ministry of Agriculture & FAO, 2016; UNDP Sri Lanka, 2016). Palugaswewa STCS is situated in the DL1b agroecological zone of Sri Lanka and is characterised by an annual rainfall (75% expectancy) of 900 mm with two distinct rainy seasons and undulating terrain with low ridges and valleys (Ministry of Agriculture & FAO, 2016; Panabokke, 1999). The two rainy seasons correspond to the northeast and southwest monsoons. Northeast monsoon (October to January) is the predominant rainy season, and it is the primary cultivation season for local farmers (Ministry of Agriculture & FAO, 2016). There are 400 families dependent on the cascade, and rain-fed rice farming is a significant social, cultural and livelihood activity. The agriculture-related social, cultural and institutional structures cater to rice farming (Ministry of Agriculture & FAO, 2016).

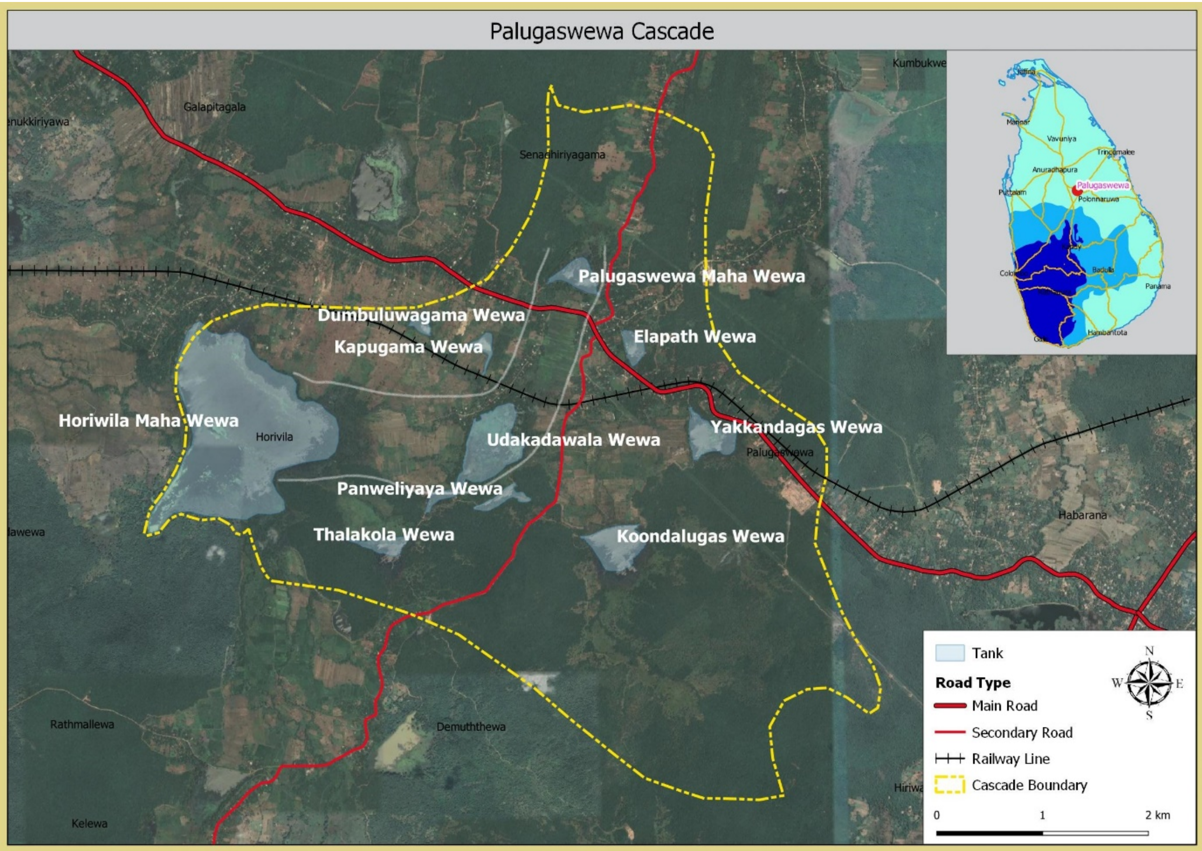

Figure 17 – Palugaswewa tank cascade system

7.2.2 Methods

The study reported here is the second of a two-part research effort comprising:

1. Identification and mapping of key formal/informal actors engaged in the cultivation decision-making process (Kekulandala et al. 2021 in press or see section 6.2).
2. Diagnosing agricultural decision-making process by exploring and analysing knowledge, views, understandings, interpretations, and experiences of key actors to diagnose evidence of and options for ACM (reported here).

For the first component, a snowball sampling technique was employed to identify and map formal/informal actors (Bryman, 2012) involved in resource decision-making for the STCS. A local community worker introduced the research team to farmers, and these farmers then nominated other farmers as potential participants. We surveyed a total of 48 farmers (approximately 15%-20% of farming households) across the cascade. We undertook a Social Network Analysis (SNA) to analyse the survey data, which is reported separately (see Kekulandala et al. in press). Briefly, the SNA component enabled mapping, characterisation, and visualisation of resource governance systems and analyses of natural resource management systems of the STCS, including identification of multiple actors with various levels of participation (Bodin et al., 2006; Bodin & Crona, 2009; Bodin & Prell, 2011)). We used UCINET 6 for Windows to analyse participant responses, and Analytics Technologies Keyplayer software identified key actors in the STCS (Borgatti, 2006) to be interviewed for the current study. These actors included 11 farmers and four government officials. The government officials included two agricultural instructors from the Sri Lanka Department of Agriculture (DOA) and two agricultural production research assistants from the Department of Agrarian Development (DAD).

This study focuses on the second component, which entailed qualitative data collection through 15 semi-structured interviews (SSI) with the key actors identified through the SNA (component 1). SSI generally comprise predetermined open-ended questions designed to understand a phenomenon or a context. These interviews also allow new questions during the dialogue between the interviewer and interviewee (DiCicco-Bloom & Crabtree, 2006). The SSIs were helpful to elicit information from farmers on indigenous or tacit knowledge and traditional practices about a context that the interviewer organises as a series of questions in a sequence (Campbell et al., 2002). The SSI process allows the interviewer some freedom to probe to clarify issues emerging from the dialogue and substantial flexibility for the interviewee to respond (Bryman, 2012).

The following questions guided the interview and helped to elicit information in three thematic areas:

1. *Cultivation decision process* - who are the key actors involved, their main roles and responsibilities, how are decisions made, and what are the advantages and disadvantages of the current decision process.
2. *Climate information* - from whom do participants access climate information, with whom do participants share climate information, the enablers and barriers for accessing and using climate information, and how participants respond to climate information.
3. *Suggested improvements to the current decision process* – including provisioning of information, capacity building, building community cohesion, and government support.

The interviews were audio-recorded with the consent of the interviewee and transcribed. Transcripts were de-identified and coded in NVivo 12 (QSR, 2019; Saldaña, 2013). Emerging sub-themes related to antecedents and decision processes at Palugaswewa STCS are reported as anonymised quotes identified by participant number (i.e. P1-P15). These themes were compared with the initial steps (Identification of antecedents - actors, their roles, responsibilities and practices, and consideration of decision processes) of the ACM diagnostic framework (Plummer et al., 2017) for analysing evidence and options for ACM. Participants were informed about the research, and written consent was obtained before commencement, following ethics approval (UTS HREC No. ETH18-2825).

7.3 Results

The interview data were analysed and organised into three themes; agricultural decision processes, how cultivation and climate/weather information is accessed and used, and options for improving the current decision process (Table 10). In analysing the qualitative data, emphasis has been placed on sub-themes that appeared most frequently in Table 10.

Table 10 – Themes, Codes and Sub codes

Theme	Sub Theme (Primary codes)	Secondary Codes	Number of Interviewees mentioning the sub-theme	Total number of references to sub-theme

Decision process	**Actors**	Farmer Organisation	12	35
		Yaya Representative	11	24
		Farmers	12	20
		Government Officials	12	20
	Roles and Responsibilities	Coordinate	12	21
		Organise	10	18
		Mediate	9	16
		Monitor	11	16
		Communicate	10	15
		Compliance & Participation	8	13
		Advice	5	6
	Decision Making	Collective decisions	9	21
		Discuss	9	11
		Meeting	7	7
		Consultation	4	4
		Communication	3	3
		Deliberation	2	2
	Advantages	Local needs and priorities	10	19
		Culture and traditions	7	11
		Local values	7	11
		Empowerment	4	5
		Community cohesion	3	4
	Disadvantages	Values changed	11	23
		Conflicts	8	12
		Non-compliance	10	12
		Non-participation	8	10
		Knowledge gaps	4	4
		Resource abuse	3	4
		Interference	3	3
Climate information	**Access**	Elders	10	19

		Own knowledge and experience	10	12
		Media	4	4
		Neighbours and Friends	4	4
		Government Officials	2	2
	Use/Response	Anticipate	10	18
		Cultivation practice	9	12
		Planning	8	11
		Minimise damage	4	5
		Change crop mix	2	3
	Share	Farmers	6	8
		Neighbours	7	7
		Relatives	3	3
	Enablers	Knowledgeable elders	10	20
		Traditional knowledge	10	18
		Information sharing	6	8
		Local values	2	4
		Linked communities	1	1
	Barriers	Unreliability of Meteorological Information	6	9
		Changing climate	7	7
		No access to Meteorological information	7	7
		Reliability of traditional knowledge	4	4
		Changes in values	1	1
Process Improvements	Provision of Information		9	26
	Capacity building		9	14
	Build community cohesion		9	9

	Government Support		7	9
	Independence of farmers		4	5
	No change needed		4	4

7.3.1 Key actors

Antecedents such as actors, activities, and practices may indicate an ACM process in a specific setting (Plummer et al., 2017). The key actors involved in the agricultural decision process included Farmer Organization (FO) officials, Yaya Representative (YR), experienced farmers and government officials. These actors and their roles in the agricultural decision process within Palugaswewa STCS are summarised in Table 11.

Table 11 - Key actors In Palugaswewa Tank Cascade and their role in the decision process

Actor	Role
Farmer Organisation (FO)	A local institution that is directly involved in the cultivation decision process. FO is a legally recognised entity under the Agrarian Development Act. FOs are registered under the Department of Agrarian Services. FOs link with government agencies to support local farming with activities (primarily) directed towards rice farming.
Yaya Representative (YR) (i.e. the title of the individuals responsible for management of the paddy tracts in the command areas of the STCS)	This person is responsible for an irrigation command area cultivated under a small tank. Several YRs could be appointed to the same tank if the irrigation command area is large (i.e. in medium or large-scale tanks). Each FO elects a YR for the command area cultivated under each tank. The farmers of the village elect the YR at the annual general meeting of the FO. The primary role (YR) is to coordinate and monitor the cultivation schedule agreed upon at the cultivation meeting.
Farmers	Farmers elect the officials of the FO and YR for the command area. Experienced, long-term farmers play a significant role in the formal decision process at the cultivation meeting and informal processes at the pre-cultivation meeting. Responsible for ensuring that they

	adhere to decisions taken at the cultivation meeting and report any violations to the YR and the FO.
Government Officials	Agricultural Instructor (AI) is an employee of the Department of Agriculture and is responsible for agricultural extension services for rice and other crops. This official is not involved in the cultivation decision process in small irrigation systems (i.e. Palugaswewa and Udakadawala tanks). Agricultural Research Production Assistant (KPNS) is an employee of the Department of Agrarian Development. Responsible for facilitating the cultivation decision process in small irrigation systems, directly liaises with FO to organise the cultivation meeting, and supports FO to access subsidised fertiliser.

A farmer described the key actors as:

Local farmers are the decision-makers. These local farmers include experienced farmers and officials of the farmer organisations. They get together and make decisions collaboratively. Government officials facilitate the process. (P3)

The interviews indicated that FO officials (president, secretary and treasurer) play a crucial role in organising the cultivation meeting, communicating with government officials, preparing seasonal farmer inventories to access subsidised fertiliser, and coordinating maintenance/repairs for the local tank, sluices and canals. The FO performs coordination, facilitation and monitoring roles in the community. A farmer explained the role of the FO as:

Farmer organisation coordinates the activities related to farming. They coordinate with farmers, government officials and others. Farmer organisation provides authority for Yaya Representative to monitor farmers and ensure decisions adhere. (P4)

Government officials also recognised the FO's critical role, particularly in organising the cultivation meeting and the farming community. A government official explains:

The farmer organisation leads the cultivation meeting, and they also appoint a chair to conduct the cultivation meeting. The KPNS officers and the farmer organisation discuss the meeting [agenda] *and plan it accordingly. Farmers select the chair for the cultivation meeting* *in consultation with the KPNS. Generally, either the president or the secretary of the farmer organisation is appointed. (P12)*

It was evident that the YR is an important actor with significant responsibility. Participants indicated that the YR coordinates the cultivation schedule with the farmers and receives authority at the annual general meeting of the FO to 1. Coordinate and monitor the cultivation schedule; 2. Organise local farmers to clean the fields, tank and canals; 3. Release water from the tank on an agreed schedule, 4. Monitor violations of locally agreed rules; 5. Coordinate with government officials to access government-subsidised fertiliser; and, 6. Organise farmer meetings. The participants also indicated that a YR is an experienced farmer and often re-elected for several years. A participant explains the roles of the YR:

[YR]….. *is the person who coordinates the work schedule and monitors the activities. He is elected on an annual basis. Yaya Representative monitors the adherence and compliance of farmers. He checks whether farmers adhere to the agreed schedule, cleans allocated bunds and canal sections.* (P1)

The YR also monitors non-compliance and illegal activities (such as accessing water beyond scheduled times). He communicates with an offending farmer and takes corrective measures. He reports to the FO if he is unable to resolve the issue himself. Another participant explains:

The Yaya Representative monitors the cultivation schedule to ensure farmers adhere to the dates agreed in the cultivation meeting. He is also responsible for reporting any violations to the farmer organisation and taking corrective action with the relevant offender farmer. (P10)

The local farmers are dependent on the YR's actions to ensure equitable access to water, minimise violations of the cultivation schedule and communicate key messages from FO to the local farmers. The interviews with the YR's of the upper and middle parts of the Palugaswewa STCS revealed that although the farming community appoints them annually, they may serve in that position for extended periods. The incumbents in Palugaswewa STCS have served for up to 10 years, which indicates that these two individuals have gained considerable trust and respect from the local farmers.

Experienced long-term farmers are also key actors within the community. They drive the cultivation decision process by advising the cultivation meeting on expected rainfall patterns for the oncoming season, possible dates for land preparation, water release and sowing. These farmers network with each other, share experience and are involved in conflict resolution.

7.3.2 Decision Process

There are several steps in the decision process within Palugaswewa STCS (see Figure 18). The cultivation meeting is the formal decision-making platform for cultivation planning in the Palugaswewa cascade system but is the second of two decision-making platforms. Interviews indicated an informal pre-cultivation meeting that determines the formal decision process.

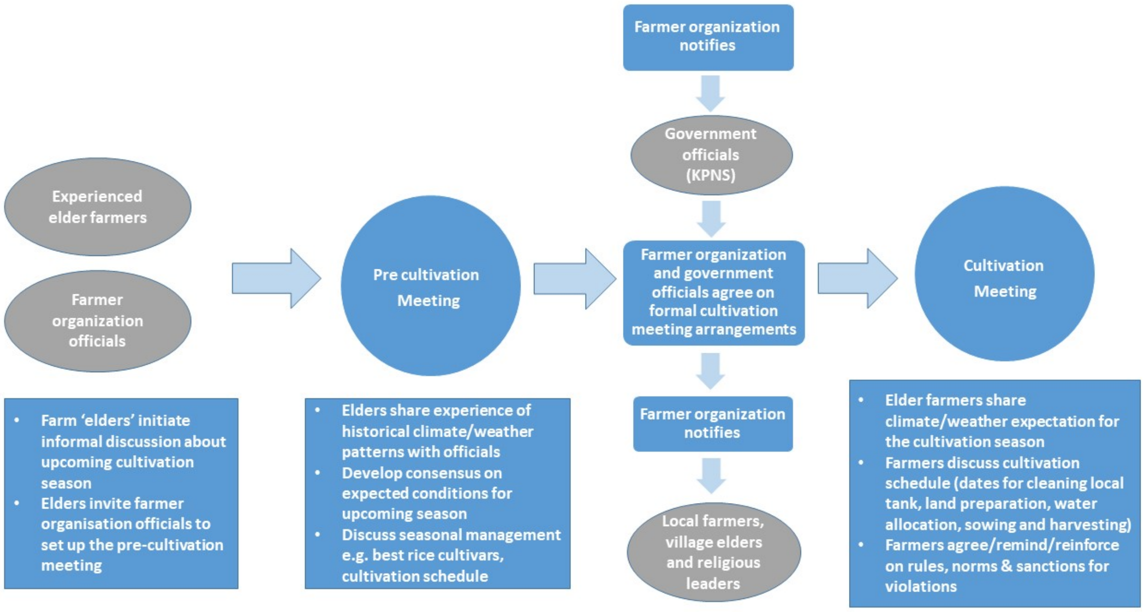

Figure 18 - Agricultural decision-making process in Palugaswewa Tank Cascade System - blue circles represent key decision processes (informal and formal), grey ovals represent key actors, and blue rectangles represent key actions

The informal pre-cultivation meeting, convened by experienced farmers, is the decision process that underpins the formal decision-making at the cultivation meeting (Figure 18). These experienced farmers communicate with each other on a personal level. They also invite FO officials to the pre-cultivation meeting. At this meeting, they discuss the local tank's water availability, their expectations for the oncoming monsoon rains and likely rainfall patterns, and the cultivation schedule. The farmers deliberate based on their collective experience and construct expectations for the upcoming cultivation season. This discussion encompasses the type of crop cultivars (e.g. short season versus long season varieties) and STCS maintenance requirements. They convey the outcome of the deliberations of the pre-cultivation meeting to the FO officials and advise them to organise the formal cultivation meeting in consultation with the government KPNS. A farmer explains:

> *Elderly farmers and some farmer organisation members get together in early October to discuss the season's cultivation plan. This discussion is called the pre-cultivation meeting, and this is not an official meeting. In the pre-cultivation meeting, farmers discuss rain patterns, including the monsoon rains, whether the rain would be enough for the tank to get filled when the cultivation can start, and the suitable seed types. We discuss the entire cultivation season and possible dates for each activity. Then we suggest organising the cultivation meeting* [official meeting] *and agreeing on potential dates. (*P5)

The formal cultivation meeting then allows the key actors to share different perspectives and agree on decisions. The cultivation meeting is legally prescribed under the Department of Agrarian Development and the Department of Irrigation (Kekulandala et al., 2021; Wijekoon et al., 2016).

When participants were prompted to reflect on the governance processes throughout the cascade, they described differences in governance and legal frameworks that applied in different parts of the cascade. The decision process in the cascade's upper and middle tanks (classified as a minor irrigation system based on size) is different from the lower tank (a medium-scale irrigation system) of the cascade. The Farmer Organisation (FO) and farmers take the lead in the decision process in the upper and middle parts of the cascade. In contrast, a government administrator takes leadership for the decision-making in the lower part of the cascade. A participant explained this difference:

> *Generally, we hold the Udakadawala cultivation meeting and then Palugaswewa. There are three main tanks, Palugaswewa, Udakadawala and Horiwila. There are individual cultivation meetings for these tanks. There are several small-scale tanks* [aside from the three main tanks], *and we combined these tanks and held* [separate] *cultivation meetings. The decision process in the medium-scale Horiwila tank is a little different to this. There are many stakeholders in this cultivation meeting. Department of Agriculture, Irrigation Department and the Divisional Secretariat is involved in the process. The Divisional Secretary is the chair. The agriculture department informs the meeting about the expected/forecasted rain and suggests crop mix and seed varieties. Irrigation Department reports the quantity of water available in the tank and how much can be released for paddy cultivation. The farmer organisation uses this information about the acreage that can be cultivated. Then farmers decide about the extent, cleaning and rehabilitation activities and plan the cultivation season. The district secretary needs to approve all decisions before any implementation. (P12)*

The above participant statement highlights the contrast between community-led and administrator-led decision processes. Research in similar STCS indicates that farmer alienation and participation is challenging in medium to large scale irrigation systems with similar top-down governance processes (Aheeyar & Smith, 1999; Merrey, 1988; Wijekoon et al., 2016). Hence, applying two contrasting governance processes within the same cascade (that share the same water resource) could be a barrier to developing collaborations across the cascade to promote cascade level governance mechanisms.

The above participant statement also indicates some flexibilities within the prescribed formal decision process. The thematic analysis (Table 10) suggested that the decision-making process in the upper and middle parts of the cascade involved *collective decisions* (references=21), *discussion* (references=11), and *negotiation* (references=7). The interviews also explored the advantages of the current decision process, and analysis of these data allows ranking of the main advantages of the process as *consideration of local need and priorities* (references=19), *local values* (references =11) and *culture and tradition* (references =11). A farmer highlights this aspect:

> *This system is good for us as we can take decisions to suit our needs. We can decide how much to cultivate and what to cultivate. Rice farming is part of our history, and we know what to do. Outsiders do not know the village, our fields and our practices. This system allows us to make decisions. (P2)*

When participants were prompted to identify any issues with the current decision process, their responses indicated that *changed values* (references =23), *non-compliance to agreed rules and norms* (references =12), and *conflicts* (references =12) were problems to be addressed. Experienced farmers suggested that young and part-time farmers do not necessarily respect the elders' views and abide by the rules set collectively by the farmers. The conflicts are primarily associated with water allocation. A farmer described these emerging concerns:

> *Now, there are many violations of collective decisions taken at the cultivation meeting. Violations are mainly due to the changing nature of paddy farming. In those days* [in the past], *paddy farming was a cultural activity and largely subsistence* [own consumption]. [Now] *it has converted to commercial practice, and people try to rush through the process to get early harvest and income. (P3)*

7.3.3 Climate information in the decision process

The local farming community depends on its accumulated knowledge and experiences about the past climate and seasonal weather to predict future weather and climate patterns. Experienced long-term farmers noted changes in the rainfall patterns and expressed concern about their ability to predict future changes; reliance on collective experience is critical to decision making (see Figure 18). A farmer suggested that:

> *Our knowledge of rain patterns is no longer reliable. The monsoon rains get delayed every year. We get hefty rains when we do not expect rain (P2).*

In general, expectations about climate or seasonal weather play a significant role in determining farming activities. In Palugaswewa STCS, the volume of water in the local tank and farmers' expectations of seasonal rain limit the extent of rice cultivation. The thematic analysis (Table 10) shows that farmers mainly access climate information from *elders* (references=19) and *knowledgeable farmers* (references =12) in the village. Participants also identified these individuals as enabling factors that facilitate the inclusion of climate information in the decision process (Figure 18). Participants identified the perceived *unreliability of meteorological information* (references =9) and uncertainty caused by *changing climate/weather patterns* (references =7) as the main barriers to the use of climate information in the decision process. Farmers reported their reliance on *traditional knowledge to anticipate* (references =18) a particular climate or weather expectation for the cultivation season. Interviewees indicated that they adjust expectations about the seasonal climate/weather patterns and *cultivation planning* (references=11) based on the knowledge shared by elderly farmers. A farmer explains:

> *The experience and knowledge of the farmers are essential to determine the expected climate. The farmer perception determines the rainfall expectation for the season. Experienced farmers share their expertise and anticipation for the season at the cultivation meeting and take decisions accordingly. (P1)*

Farmers explained how they interpret nature to forecast seasonal weather:

> *We observe the fruiting and flowering of some plants, and it tells us about the following season. For example, the good fruiting of Diwul and Mora trees indicate a perfect rainy season. Weaverbirds constructing their nests higher is an indication of a good rainy season. We also look at the night sky*

and the moon phases. When there is a dark small spotty cloud in the night skies, it indicates good rains in weeks. People have given local names for these rains. These names are related to some farming activities. (P3)

Access, reliability, and timeliness were the main issues farmers faced in incorporating meteorological data in the cultivation decision process. A participant explained the access issues for meteorological information as:

Farmer organisation does not receive any climate forecasts, bulletins or advisories from government agencies" (P1).

Participants indicated that they listen to and watch information related to seasonal weather/climate in the media (radio and TV). However, they do not specifically consider this information in the cultivation decision process. A farmer highlighted the issue as:

The messages on TV and radio are not reliable. The forecast tells about the entire province, and we are a small village. They are not helpful when they say it will rain and [we] *do not receive any rains (P10).*

7.3.4 Process Improvements

Meteorological information appears to have little influence on FOs in Palugaswewa STCS. An examination of the meteorological services provided by DOM shows that they do issue a seasonal outlook for the northeast monsoon in late November or early December. However, as a participant explains:

We get a seasonal climate advisory from the government, but we get this advisory in December. Therefore, it is not that useful as farmers have already begun cultivation activities (P12).

In Palugaswewa, the cultivation activities commence in mid-October. Therefore, farmers are unable to use this meteorological information in agricultural decision making. The forecast's geographical scale covers the entire dry zone, making it unsuitable to inform decision-making such as cultivation practice in Palugaswewa.

The provision of early advice on seasonal weather patterns is critical for planning the cultivation season, as a participant explains:

The general pattern for the main cultivation season (Maha) is that we expect monsoon rains after 15th of September, and land preparation starts after the 15th of October. Then the rain gradually increases towards November and December. However, these patterns are changing; for example, this year [2019]*, we received heavy rainfalls in October, affecting land preparation. Then planting was delayed, and we did not get good rains in November and December. Therefore, we need to know the patterns early to help the farmers (P12)*

Therefore, decision-making remains entirely dependent on the skill and experience of elderly farmers to predict oncoming monsoon rains. These farmers are also open to considering meteorological information in the cultivation decision process if they receive it in a reliable and timely form for the cultivation meeting. Farmers emphasised the need for improved information provision for the cultivation meeting:

"Government officials like KPNS or AI should get the information and share it with the farmers during the cultivation meeting. We should be able to make decisions such as can we cultivate paddy, short-term variety or long-term variety, whether we should cultivate upland crops, when the rains arrive and patterns during the season" (P3).

In addition to climate information, discussions with farmers revealed the underlying tensions related to the provision of other government advisory services that constrain adaptation in the current decision process:

There are some issues, such as the spread of diseases and trying to solve those issues. The government provides the seeds, and we no longer produce our [own] *seeds. When some rice varieties do not give farmers the expected harvest, we do not get any explanation. The AI and KPNS cannot do anything; they work on the advice they receive from senior officers. Previously, we prepared our seeds, we knew how to manage problems, and now, we do not know what to do with new varieties. We cannot produce and use our seeds now. Because if anything goes wrong, we cannot get any compensation. We have to use seeds provided by the government (P4).*

7.4 Discussion

7.4.1 Evidence of ACM in Palugaswewa STCS governance

In this study, we sought evidence of ACM and how might ACM operate within the 'setting' of Palugaswewa STCS. We drew on Plummer et al. (2017), who suggest that understanding the setting for ACM informs the analysis of institutional context and biophysical and social-ecological conditions. In Palugaswewa STCS, the interaction of a range of actors that included farmers and government officials, with well-defined roles (e.g. the Yaya Representative) often within formal and informal institutions (such as Farmer Organisations) facilitated self-organisation by the local farming community in the management of the water resource for farming (predominantly paddy rice). The institutions involved in the Palugaswewa STCS played a critical role in the governance of the agricultural decision process, which largely conforms to the characteristics envisaged by Ostrom's design principles for long-enduring and self-organised irrigation institutions (Ostrom, 1990, 1992, 1993) as described in Table 12. These characteristics indicate that the current governance structure in Palugaswewa STCS is relatively flexible, adaptable and robust, with features anticipated to be essential to managing future risks posed by climate change.

Table 12 – Ostrom's design principles and institutional characteristics of Palugaswewa STCS

Ostrom's Design Principle	**Institutional Characteristics of Palugaswewa STCS**
Clearly defined boundaries (Boundaries of the area that include individuals or households with rights to use water are clearly defined)	The irrigation command area of the tank determines the boundary. The FO determines any addition to the command area in consultation with the government officials. Farmers determine the extent of the cultivable area within the irrigation command in each cultivation season. The cultivable area's size depends on the volume of water stored in the tank and rainfall expectations (for the oncoming season) of the farming community.
Proportional equivalence between benefits and costs. (Rules and conditions that specify the amount of water that a person is allocated and his/her responsibilities	Water allocation depends on the amount of water available in the tank and decisions about the extent of cultivation (at the cultivation meeting). Water is released from the tank on agreed days for an agreed period to ensure all parts of the irrigation command area receive an equitable water share.

(labour, material or money requirements)	Farmers need to clear fields, complete fencing and clean adjacent canals before the water is issued. Furthermore, farmers need to provide volunteer labour to clean, maintain and rehabilitate tank infrastructure (bund, sluice, canals) before the water issue. These are discussed and agreed upon at the cultivation meeting. Farmers need to obtain the FO membership by paying an annual membership fee and investing time to attend meetings.
Collective choice arrangements (Most individuals affected by operational rules are included in the group that can modify these rules)	Participants discuss and agree on the rules and norms for farming. Farmers elect FO officials during their annual general meeting. These officials facilitate the cultivation meeting that makes the rules and norms for the cultivation season. This collective decision process enables the farmers to discuss and modify the rules to suit each cultivation season's local conditions, from land preparation to harvesting.
Monitoring (Monitors, who actively audit physical conditions and irrigator behaviour are accountable to the users and/or are the users themselves)	Farmers select and appoint a dedicated monitor (Yaya Representative) at the FO annual general meeting. Farmers collectively set the responsibilities and empower the Yaya with authority to report and issue sanctions against non-compliance with agreed cultivation rules and norms. Additionally, each registered farmer has a collective responsibility to act on any breach of rules and norms.
Graduated sanctions (Users who violate operational rules are likely to receive graduated sanctions, depending on the seriousness and context of the offence, from other users, from officials accountable to these users, or both.	FO issues fines and sanctions to the violators. These are often related to failure to clean canals, fencing and accessing water beyond agreed schedules. Yaya Representatives directly apply sanctions or fines to the violator, proportionate to the violation, and based on the rules decided during the cultivation meeting.
Conflict resolution (Users and their officials have rapid access to low-cost local	Farmers inform the FO or the Yaya Representative about conflicts. FO intervenes to resolve the disputes, and the village elders are involved if there is severe conflict. When the

arenas to resolve a conflict between users or between users and officials)	community fails to resolve disputes, they forward the matters to the government officials (KPNS). KPNS and FO might forward the conflict to a local mediation board or local courts. The Palugaswewa community indicated that all disputes are minor and resolved among themselves.
Minimal recognition of rights to organise (The rights of users to devise their own institutions are not challenged by external governmental authorities)	FO is a legally recognised institution under the Agrarian Services Act No 58 of 1979 and amendments in 1991, 2000 and 2011. This legal and statutory recognition validates the farming community's rights to make rules and norms for each cultivation area based on the local context. However, FO rights and entitlements are limited by the Act's provisions (e.g. cultivating other crops in paddy fields needs special permission from the Department of Agrarian Development).
Nested enterprises (Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organised in multiple layers of nested enterprises.)	The tank cascade system is organised in nested layers. FO situated at the village level comprises several farmer groups that collectively cultivate adjacent plots according to the command area's division by water distribution canals. Government service providers (Department of Agrarian Development and Department of Agriculture) and local government agencies are organised beyond the village and have links to the FO. Agrochemical, machinery and transport service providers are scattered beyond the cascade and are accessed as needed.

Several features of the STCS would enable/facilitate the operation of ACM in Palugaswewa. These include close collaboration among key actors (elder farmers, farmer organisation officials and agricultural extension officers), sharing decision-making powers with state and non-state actors, sharing cultivation and weather information, incorporation of local customs and rules, deliberations and negotiation to agree on a schedule of management actions, and self-organisation for voluntary works (Berkes et al., 2007; Folke et al., 2005; Plummer et al., 2012).

7.4.2 Limitations to ACM practice

Despite appropriate governance structures (Table 12), there are inherent issues with how STCS governance functions that currently limit the flexibility of management and practice. These include agricultural services concerned primarily with rice farming, decision processes focused on engineering efficiency, lack of access to timely seasonal meteorological information, and national and regional policy settings favouring gradual centralisation of irrigation (Kekulandala et al., 2021).

STCS are multifunctional landscapes that can support diverse food and ecological systems, local livelihoods and the local economy (Dharmasena, 2010a; Kekulandala et al., 2021) and show the potential to buffer agriculture from climate variability to sustain local communities (Bebermeier et al., 2017). Rice is the predominant food crop cultivated in Sri Lanka, occupying 29% of the agricultural land, and 30% of rice is cultivated on land under rainfed systems, such as STCS (Chithranayana & Punyawardena, 2014). The cultural significance of rice in Sri Lankan society (Dharmasena, 2010b), preference for rice cultivation, and institutional and legal barriers that limit diversification (Aheeyar, 2000; UNDP Sri Lanka, 2014) have led to a rice-focused cultivation decision process in STCS, which limits farmers' ability to respond to seasonal variations by diversifying crop species. Furthermore, a centralised government agency prescribed the rice cultivars with limited connection to local information on crop performance, which STCS farmers complained also limited their ability to respond to local conditions.

Recognition and incorporation of local needs, rules, values, and norms in local resource governance are essential to enable adaptive governance (de la Poterie et al., 2018; Šūmane et al., 2018). In Palugaswewa, the rice-focused decision process has alienated farmers who cultivate upland crops (such as vegetables, maize), resulted in growing discontent among the farming community, and allowed influential government officials with discretionary powers to overrule farmer decisions. Maize and upland vegetable cultivation are increasingly popular among part-time, women farmers, and production decisions related to these alternative crops are made independently of the STCS agricultural decision process. However, integrating these agricultural activities in the decision-making process, providing extension support for diversifying agriculture, and creating market access for alternative crops require significant government intervention. Incorporating upland cultivation (vegetables, maize) within the agricultural decision process would facilitate women's participation as most vegetable farmers are women (Athukorala, 1996; Meinzen-Dick & Zwarteveen, 1998). However, centralised irrigation bureaucracy and its agents at the local level can act as barriers that prevent communities effective participation in decision processes (Aheeyar & Smith, 1999; Uphoff, 1986). In Palugaswewa, we found evidence of considerable government oversight limiting the activities of FOs in relation to fertiliser access and crop diversification (formally enabled under The Agrarian Development Act 2000, no 46). This situation constrains the FOs capacity to act as an independent institution (Abeyratne, 1985; Perera, 1985) by granting oversight and discretionary powers to the government officials to override farmer decisions (Kekulandala et al., 2021). Such power can undermine the functionality and adaptability of STCS farmers to respond to the dynamic nature of agricultural practices. Furthermore, the lower tank (Horiwila) is classified as a medium scale irrigation tank, a district-level bureaucracy leads the decision process with the support from technical agencies (e.g. national Irrigation Department). The cultivation decisions are established on tank capacity, and the amount of water that can be released for cultivation within particular time frame is determined by a technical agency (Irrigation Department). This predetermination by a technical agency limits farmer’s ability to adjust cultivation decisions to suit local conditions, increasing their exposure to seasonal risk. These top-down, decision-processes could be a significant barrier to develop cascade level governance mechanisms as previous research in Sri Lanka indicates that government bureaucracy is hesitant to transfer or share authority to manage water (Aheeyar & Smith, 1999; Uphoff, 1986).

The changing nature of the political, social and cultural landscape has impacted the agricultural societies of Sri Lanka (Morrison, n.d.). This study found that the traditional power structure in the cultivation decision process in these villages (dominated by full-time rice farmers) is also threatened by part-time and younger farmers. These farmers, whose livelihoods are not entirely dependent on rice farming, often disregard outcomes of collective decision-making, leading to a failure to adhere to cultivation schedules and limited participation in voluntary maintenance activities and night-time watch duties to protect the fields against wild elephant damage. This lack of observance of rules leads to tensions between traditional farmers and part-time farmers. The part-time farmers often find it challenging to commit to all the voluntary work requirements expected by the FO and feel alienated from the decision process as full-time or experienced farmers dominate the cultivation decision process. In other settings, the changing nature of social, political and environmental factors in the governance of common-pool resource systems such as water has been associated with the emergence of tensions among actors over activities that benefit individuals against those that benefit groups (de la Poterie et al., 2018; Ostrom & Gardner, 1993).

It was clear that the lack of timely seasonal weather information and local climate projections had a profound effect on the governance of the STCS. The formal decision process (cultivation meeting), its functioning, and related issues have been discussed widely (Aheeyar, 2000; Begum, 1987; Panabokke et al., 2002; Wijekoon et al., 2016). The cultivation meeting provides farmers with some flexibility to plan the cultivation season considering the water level in their local tank and their expectations about the seasonal/monsoonal rain patterns. However, FO's and local agricultural extension officials in Palugaswewa do not receive meteorological information from the Department of Meteorology (DOM) on time (cultivation season starts in October, and the formal advisory is received in late November or early December). A local informal institutional mechanism (pre-cultivation meeting) compensates for the lack of meteorological data by providing seasonal weather information. Farmers cultivating under small tanks often depend on their collective consensus and shared beliefs on future rainfall to plan the cultivation season (Senaratne, 2013). The robust collaboration among experienced elder farmers has contributed towards an informal but highly influential institutional mechanism (pre-cultivation meeting). The primary function of the pre-cultivation meeting is to establish weather expectations for the upcoming season and plan accordingly. At the pre-cultivation meeting, farmers discuss their collective experience on previous cultivation seasons, develop a collective expectation for the season and communicate the expectation to the FO. Elderly farmers present this information at the formal cultivation meeting. It is important to note that the current legal framework does not recognise the pre-cultivation meeting process. However, this is a critical event that governs water management and agriculture at Palugaswewa STCS. Previous research indicates that co-designing and co-producing climate forecasts with farmers is vital to gain their acceptability, trust and confidence in the information (Mase & Prokopy, 2014; Ziervogel & Downing, 2004). The current institutional arrangements do not allow farmers to communicate their information needs directly to a specialised agency such as DOM and DOA. Therefore, information flow directed from centralised national agencies to local officials is hierarchical, imposes limitations on knowledge co-production and requires resolution to address a severe constraint to ACM in Palugaswewa and similar STCS in Sri Lanka.

Salience, credibility, and legitimacy are attributes of a knowledge system that builds users' trust in a rapidly changing societal context with multiple sources of access to information (Cash & Belloy, 2020). Farmers' ability to predict oncoming seasonal weather patterns is a critical element of their power in the village's traditional power structure. This study demonstrated that farmers use various environmental indicators to predict seasonal weather, including animal behaviour, fruiting and flowering patterns in plants, changes in wind and cloud patterns and moon phases. However, we did not find evidence to determine the validity of these indicators. Previous research shows that the northeast monsoonal rain patterns are highly variable, with late-onset and early withdrawal becoming common (Eriyagama & Smakhtin, 2009). Such variability could seriously compromise a farmer's ability to predict seasonal weather patterns in the future and lead to significant governance issues in Palugaswewa STCS and other similar systems that rely on local knowledge for cultivation decision processes. In Palugaswewa, some farmers reported experiencing difficulties predicting seasonal weather, which could lead to erosion of trust and power enjoyed by elderly farmers and the decision process associated with cultivation meetings. Formal institutional settings, changing agriculture context and minimal structural support are significant barriers to local knowledge development (Šūmane et al., 2018). Societal changes towards market economies may lead to the gradual erosion of customary leadership and knowledge structures, as production at the household level becomes insufficient to meet subsistence needs (Roncoli et al., 2002). Such situations may, in turn, lead to the need to supplement rural household livelihoods through non-farming activities and a further deterioration of farming-based institutions, knowledge and leadership structures (Roncoli et al., 2002; Šūmane et al., 2018).

Adaptive approaches in uncertain settings are required to build knowledge and understanding about the resource base and related ecosystem dynamics, consider ecosystem feedback for designing practices to respond, and support flexible institutional structures (Berkes et al., 1998). The tank cascade systems such as Palugaswewa are multifunctional, offering ecosystem services beyond food production and involving multiple stakeholders (Kekulandala et al., 2021). Therefore, reducing tensions among stakeholders, creating space for local-level resource planning, decentralising water management responsibilities and integrating the values and beliefs of all stakeholders is essential to ensure their engagement in governance processes (Ricart et al., 2018; Singh et al., 2020). This local-level decision-making also provides space for the integration of multiple knowledge sources. Local knowledge combined with the local level formal decision processes can contribute to the enhanced resilience of agricultural practices (Ghorbani et al., 2021; Kuehne, 2014; Šūmane et al., 2018). Polycentric governance systems and flexible decision processes are essential for STCS to effectively respond to a range of environmental shocks and stresses to ensure food and livelihood security and maintenance of ecosystem services (Berkes, 2017; Hodbod et al., 2016; Newig & Fritsch, 2009). However, a vital precondition for enabling adaptive governance in a local setting depends on developing a coherent national NRM policy framework that enables coherent and stable political and economic policy settings, which have to date been missing in Sri Lanka (Kekulandala et al., 2021).

7.5 Conclusions

We aimed to explore evidence for ACM in the agricultural decision process associated with Palugaswewa STCS, following the ACM diagnostic framework of Plummer et al. (2017). The study focused on antecedents and processes to identify key actors, explore their activities and examine the process of decision making in existing governance arrangements for STCS. We found evidence for ACM in the agricultural decision process with the interaction of formal and informal institutional settings. The decision process is primarily community-led in the upper and middle parts of the cascade, whereas government bureaucracy leads the decision process in the lower part of the cascade (designated a medium/large tank). In the case of medium/large tanks, state-led, top-down rigid structures with uniform rules and user groups (FO) limit farmers' involvement in the decision process, provide limited scope to adapt systems to meet farmers' needs and constrain local level decisions, flexibility and adaptability (Meinzen-Dick, 2007; Ostrom & Gardner, 1993).

In contrast, in small tanks (like the upper and middle parts of the cascade), the existing governance process is stable, respects traditional values and engages the farming community in decision-making. However, an informal decision-making process (the pre-cultivation meeting) supplements the formal decision process to predict seasonal weather patterns relying on tacit knowledge of experienced farmers. The Government of Sri Lanka, supported by the Green Climate Fund, is attempting to rehabilitate and reconstruct STCS in the dry zone of Sri Lanka and develop cascade level governance mechanisms. However, these aims could be compromised if the importance of informal decision processes (e.g. the pre-cultivation meeting) are not considered in any future governance mechanism. Recognition of such informal arrangements is critical because they precede and inform formal decision making at the cultivation meeting and would: 1. support and reify farmer's rights to diversify beyond rice cultivation; 2. allow for the incorporation of local norms and values in STCS governance; and, 3. introduce flexibility and autonomy, and facilitate cross-scale collaboration in medium to large scale irrigation tanks.

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CHAPTER EIGHT

Towards an adaptive governance approach

8.1 Introduction

In this chapter, I will summarise my research findings and provide my perspectives on the outcomes of my research. I will briefly explain how I answered each research question by referring to the findings of each chapter. I will also explain my perspective on the main findings of each chapter. Next, I will discuss the contribution of my research towards the governance of small tank cascade systems (STCS) of Sri Lanka, climate change adaptation in dry zone farming systems and expanding the evidence for adaptive co-management in a developing country context. Lastly, I will describe my research accomplishments and discuss the limitations of my research.

8.2 How I answered my research questions

I have structured this section as follows (for each research question); first, I will state each research question. Next, I will describe the process I followed to answer the research question and briefly outline the key findings. Then, I will reflect on the implications of my research findings on the ongoing efforts to rehabilitate and improve the governance of STCS in Sri Lanka, my perspective on whether improved governance of STCS in the dry zone of Sri Lanka can contribute to climate change adaptation and lastly, how my findings are contributing to expand the evidence base for ACM in a developing country context.

RQ1: What is the current decision-making process for managing water and cultivations associated with small tank cascade systems?

This question (RQ1) led me to examine how the current decision process has evolved, the main actors involved, their roles and responsibilities, advantages and disadvantages entailed in the existing arrangements, and implications for climate adaptation under current formal policy settings. I answered this question in three steps; firstly, I carried out a literature review on STCS of Sri Lanka and their management within the broader context of a changing and variable climate (Chapter two). Secondly, I undertook a detailed review of how the current decision-making process evolved and its implications for climate adaptation within the current formal policy settings (Chapter 5). Lastly, I carried out a social network analysis (SNA) to identify key actors involved in decision-making and their responsibilities at my study site (Chapters 6 and 7).

I found that an administrative arrangement (irrigation command area) between two government agencies (The Department of Agrarian Development and The Irrigation Department) determines the current decision-making process for managing cultivation and water for rice farming in Sri Lanka.

Tanks with an irrigation command area of less than 80 ha are considered small tanks managed by the Department of Agrarian Development (DAD). Tanks with an irrigation command area greater than 80 ha are managed by the Irrigation Department (ID). The legal statutes of these two agencies determine the decision-making processes. As STCS can be composed of several tanks of varying sizes, this arrangement means the decision-making processes about the management of water resources and water-dependent agricultural activities may vary between tanks within a single STCS, even though the system shares the water resource. I then examined in detail the prescribed decision processes of both these government agencies. I found that tanks administered by DAD provide greater opportunities for local farmers to engage in and lead the cultivation decision process than tanks administered by Irrigation Department (Kekulandala et al., 2021; Wijekoon et al., 2016). I found that the decision process in the upper and middle parts of the Palugaswewa STCS (see Figure 10) is primarily community-led, DAD officials facilitate this process, and this allows for substantial flexibility in the decision-making process that enables adjustments to suit local conditions (chapters 5, 6 and 7). Legally, DAD officials can overrule the farmer decisions, but my findings in Palugaswewa STCS show that conflicts between DAD officials and farmers are rare. In the lower part of the cascade, the ID official determines the volume of water released for cultivation and the dates for water release. The farmers need to plan their cultivation activities around these predetermined dates. Therefore, the ability of farmers to adjust cultivation schedules to suit local conditions is limited.

I argued that departmental administrative arrangements are designed to deliver statutory responsibilities of the respective departments rather than food and livelihood securities of the targeted community or a locality. The findings of chapters 5, 6 and 7 revealed a significant gap between these administrative arrangements and community expectations regarding food and livelihood security. My review (chapter five) of the governance of STCS showed that the current governance process resulted from the gradual transition from a primarily community-led process in the pre-colonial period to a government agency-led process during the colonial and post-independence periods in Sri Lanka. This transition resulted in a loss of polycentrism, significant institutional churn, a top-down decision process, and a lack of support from technical agencies (i.e. the Department of Meteorology). These changes have been associated with less than optimal natural resource governance, particularly water resources. Furthermore, poor coordination among government agencies has led to significant uncertainty at the local level in STCS management, contributing to their degradation (Abeywardana, et al., 2019; Ratnayake et al., 2021; Vidanage, 2019).

In Palugaswewa STCS (findings presented in chapters six and seven), the principal resource decision-making process (known as the 'cultivation meeting') was organised around the three main tanks in the cascade system (Palugaswewa, Udakadawala and Horiwila) (Figure 10). These tanks are situated in the upper, middle and lower parts of the cascade, respectively. Social network analysis (SNA) and semi-structured interviews (SSI) with key actors showed that the formal decision process in the upper and middle parts of the cascade was informed and guided by a supplementary informal decision process (see Figure 18). My research did not find evidence of an informal decision process in the lower part of the cascade (Horiwila tank) because the ID (rather than the DAD) determines the cultivation schedule. An ID official determines the volume of water available for cultivation and dates for releasing it from the tank.

The informal decision process (the pre-cultivation meeting) in Palugaswewa and Udakadawala tanks provides a seasonal weather expectation to the formal cultivation meeting, as the farming community does not receive seasonal weather forecasts from government agencies. This lack of access to seasonal weather information impedes adaptive management responses. The elderly farmers of the villages convene ahead of the cultivation season to pool their collective knowledge of the past weather/climate patterns to develop a seasonal whether expectation to supplement the formal decision process (the cultivation meeting). I argued that the existing literature on STCS of Sri Lanka has mainly focused on the formal decision process. However, the informal decision process is the key driver that determines the outcomes of the formal decision process. I also argued that relying upon farmers' past experience to forecast future seasonal weather will pose risks to the food and livelihood securities of the farming community (Alexander & Block, 2022; Guido et al., 2020; Roudier et al., 2014; Senaratne, 2013). I highlighted research evidence from other contexts to show that traditional knowledge systems struggle to predict future weather/climate change. Therefore, I concluded that further research in similar contexts is needed to expand the evidence base about local variations in STCS governance in Sri Lanka to help determine the need for changes to enhance adaptive management. I suggested that the success of future governance interventions will need to incorporate strategies that accommodate informal governance processes and provide agricultural and climate information tailored to suit the local context.

I also identified the key actors in the decision-making process at Palugaswewa STCS as the agricultural extension officers, farmer organisations, elderly farmers, and Yaya representatives. Agricultural extension officers and farmer organisations lead and facilitate the cultivation meeting (formal decision process) in the upper and middle tanks of the cascade. However, a district-level administrator (district secretary or a representative) leads the cultivation meeting in the Horiwila tank.

In contrast, elderly farmers lead the pre-cultivation meeting (informal decision process) in the Palugaswewa (upper) and Udakadawala (middle) tanks of the cascade (these tanks are classified as small tanks). However, a district-level administrator (district secretary or a representative) leads the cultivation meeting in the Horiwila tank (classified as a medium-scale tank with an irrigation command area higher than 80 ha). The sociogram constructed through the SNA for the access network (see Figure 15) showed that the information flow between upper, middle and lower parts of the cascade is minimal for the cultivation decision processes. The agricultural extension officers are responsible for providing support for farmers in the middle (Udakadawala) and lower (Horiwila) parts of the cascade. However, interviews with farmers and extension officers did not reveal any formal linkages for information sharing about cultivation or climate. I also found that the cultivation meeting process in the upper and middle parts of the cascade is primarily community-led, a situation favoured by governance researchers in a range of contexts (Huitema et al., 2009; Ostrom, 1990, 1993) that might not be the norm in STCS generally. I argued that changes to governance arrangements in Palugaswewa STCS should account for a range of factors associated with successful community-led management, including farmers and government extension officials establishing respectful working relationships, recognition of elderly farmers' role in establishing seasonal weather expectations, self-organisation/collective-action to minimise costs and maximise efficiency, maintenance of traditional social values (respect for elders) in these villages, and ensuring access to government-subsidised fertiliser through participation in farmer organisation activities.

Next, I will summarise the implications of my findings (RQ1) on adaptation planning for STCS. STCS can provide multiple ecosystem services and buffer against future risks posed by climate change (Bebermeier et al., 2017; Climate Change Secretariat, 2016b; Goonatilake et al., 2015; Vidanage, 2019). The National Adaptation Plan for Climate Change Impacts in Sri Lanka 2016-2025 identifies the rehabilitation of STCS as an adaptation pathway to minimise climate change impacts on rural farming communities (Climate Change Secretariat, 2016a). The current governance process for managing STCS is predominantly a top-down process in which farmers do not have access to seasonal weather/climate information and use their knowledge of past weather patterns to construct a seasonal weather expectation. Seasonal rainfall projections for Sri Lanka are highly uncertain (Eriyagama & Smakhtin, 2009). The unavailability of seasonal, localised meteorological information is a significant barrier for adaptation planning at local scales (Alexander & Block, 2022; Asante et al., 2021; Vermeulen et al., 2013). Therefore, supplying localised seasonal weather/climate information through a co-design process that involves technical agencies and the local community is essential to improve the acceptability of the forecast information (Cash & Belloy, 2020; Guido et al., 2020; Roncoli et al., 2002; Roudier et al., 2014). Furthermore, future planning for climate adaptation in STCS in the dry zone of Sri Lanka needs to consider and engage informal decision processes (such as pre-cultivation meetings) in governance processes. The poor coordination among government agencies at local, sub-national and national levels needs rectifying to facilitate cohesive adaptation planning processes (Panditharatne, 2016). Ultimately, the highly uncertain and poor NRM policy coherence at the national level appears to compromise adaptation planning and constrain governance improvements at the local level (Kekulandala et al., 2021; Lee et al., 2022).

Lastly, I will summarise my contribution to expand the evidence for ACM. Participation and learning are key pillars of ACM (Plummer et al., 2012; Trimble & Plummer, 2019). The informal decision process (pre-cultivation meeting) allows farmers to participate and share their knowledge on the historical trends of seasonal weather patterns and develop expectations about the upcoming cultivation season. The formal cultivation meeting also provides opportunities for farmers and government officials to share the local knowledge on expected seasonal weather patterns, agricultural advisories, information on fertilizer and agrochemical availabilities and develop a shared understanding of the roles and responsibilities for the upcoming cultivation season. The organizational interactions (both formal and informal), networks (both formal and informal), shared responsibilities and power for decisions, co-learning, formal and informal knowledge and institutional settings that provide linkages with external institutions are described as key elements that facilitate ACM in practice (Armitage et al., 2011; Plummer, 2009; Plummer et al., 2012). In Chapters 5, 6 and 7, I discussed how these elements were diagnosed to provide evidence for ACM. Diagnosing antecedents and processes for ACM through SNA and SSI provided clear evidence of ACM in practice. The most recent comprehensive review on ACM (Plummer et al., 2012) highlighted the need for ACM evidence in the global south. Therefore, my research contributes to expanding the ACM evidence base in the global south together with other recent contributions (Islam et al., 2018; Kellogg & Samanta, 2018; Roy-Basu et al., 2020; Tran et al., 2019).

RQ2: How is cultivation and climate information accessed and shared for the decision-making process?

I answered this question through a survey of STCS actors to gather data for social network analysis (SNA). SNA was a valuable tool to characterise and visualise the STCS governance system (chapter 6). SNA enabled me to identify key actors in the decision-making process, how the farming community was organised to access and share cultivation and climate information, and a suite of metrics that described important characteristics of the information networks (chapter 6). I followed the SNA with semi-structured interviews (SSI) with key actors to understand their roles and responsibilities, the elements of the cultivation decision process, and critical enablers and barriers for accessing and sharing cultivation and climate information. Their suggestions to improve the current decision-making process were also canvased (chapter 7).

I found that agricultural extension officers, farmer organisations, elderly farmers, and Yaya representatives were key actors that provided cultivation information for the farming community, while elderly farmers act as the source of seasonal weather/climate information. The network centrality measures (Table 7) and access network sociogram (see Figure 15) illustrated the importance of agricultural extension officers in information flow through the STCS. These officials facilitated the cultivation meeting process, organised education programs, and supported farmers in accessing government subsidised fertiliser and crop insurance. Farmer organisations were important actors because they led and coordinated the cultivation meeting, organised the local community, coordinated voluntary maintenance work, supported farmers to access subsidised fertiliser and mediated conflict resolution. The Yaya representative held significant responsibility for organising the farming community, monitoring the cultivation schedule compliance, mediating conflicts, and providing information to the farming community. Elderly farmers shared their knowledge on cultivation practices and appropriate crop cultivars, guided the cultivation meeting and mediated conflict resolution. I observed that these key actors have unique and shared responsibilities in the decision process (both informal and formal). These findings have several implications for ongoing efforts to develop new governance mechanisms for STCS. Firstly, the self-organisation, collective choice rulemaking, establishment of local rules and norms, and facilitatory role of the government officials need recognition. Secondly, statutory and administrative rules of the government agencies need to recognise and complement local rulemaking, and the decision processes (cultivation meeting) need the flexibility to accommodate local conditions and requirements (to avoid the 'governance panacea', Ostrom et al., 2007; Pahl-Wostl et al., 2012)

In contrast to the smaller upper tanks, in the lower part of the cascade (the larger Horiwila tank), a district secretary or a representative (see Figure 8) took the lead in the cultivation decision process. I did not find evidence of a supplementary informal decision process in the Horiwila tank, which significantly limited the role of local farmers in decision making. In Horiwila, a district administrator scheduled the cultivation meeting, and the Department of Irrigation, in keeping with its statutory responsibilities, set the conditions for the cultivation season (such as volume of water released, dates and times for water release). Based on this, the farmer organisation plans the cultivation activities according to the given schedule, with support from government extension officers to access seeds and fertiliser. These top-down processes fail to recognise local level dynamics, limit farmers' capacities to adjust cultivation schedules to suit local conditions, increase their vulnerability to changes in seasonal weather, and limit climate change adaptation (Baird et al., 2021; Gotgelf et al., 2020; Moser & Ekstrom, 2010).

I found that sharing cultivation and climate information (see Figure 16) was more diffuse than accessing cultivation and climate information. The SNA showed that elderly farmers act as knowledge hubs for sharing information, confirming their role in informal governance processes in the STCS. Interviews with key actors revealed that the diffuse structures in information-sharing resulted from clusters of farmers (family relatives or neighbours) cultivating adjacent paddy plots. These subgroup group structures enabled them to maximise efficiency by sharing labour, machinery, seeds, agrochemicals, fertiliser and market access. I also found that while these subgroups actively access cultivation and climate information from many sources, they share this information only within their subgroup. Presumably, such behaviour provides a competitive advantage over their neighbours for a better harvest or a better market price (Merrey, 1988; Molden et al., 2013; Somasiri, 2008).

Interestingly, network metrics (centrality measures) and sociograms revealed several women as key actors in the STCS. Rice farming is primarily male-dominated (Athukorala, 1996; Begum, 1987), and my findings (chapters 6 and 7) showed these women were household heads of paddy lands inherited following the death of their husbands. These women were active in the local community in other roles; for example, one woman farmer from the upper part of the cascade was a community activist and served in several community organisations as a volunteer. My conversations with these women farmers also highlighted the existence of a women's farmer organisation. The women farmers cultivate vegetables in the kitchen and backyard gardens. Agricultural extension officials supported them to access seeds, training and markets. All four agricultural extension officials in the Palugaswewa STCS were women. However, while these officials and the women farmer organisation worked together very closely, the women's farmer organisation was not represented in the cultivation decision process. The current decision process primarily focuses on rice farming and fails to recognise the importance of non-rice agriculture's potential to diversify farmers' livelihoods. Evidence indicates that diversification of agricultural production systems provides opportunities to mitigate future climate risks and improve the resilience of farming communities (Crane et al., 2011; Esham & Garforth, 2013; Howden et al., 2007)

Based on the above findings, I argued that understanding how a farming community is organised in a particular setting is an essential precondition for developing and introducing alternative governance mechanisms (Fujitani et al., 2017; Hassenforder & Barone, 2019). In a farming community, considering informal knowledge pathways within a local community for cultivation and climate information is vital to ensure minimal disturbance to existing knowledge networks as local rules, norms and values embedded in these networks play an important role in decision processes (Burke et al., 2006; de la Poterie et al., 2018; Šūmane et al., 2018). Furthermore, network metrics (see Table 9) indicated the potential vulnerability to changing existing information access and sharing structures. The dense network structure observed in Palugaswewa STCS was dependent on a small number of key knowledge brokers to enable information access and sharing, which predisposes the decision processes to collapse should these actors be removed or excluded (Boari & Riboldazzi, 2014; Bodin et al., 2006; Hamilton et al., 2020). For example, the respectful relationships developed by the extension officials with other key actors in the farming community enabled primarily community-led decision-making in the upper and middle parts of the cascade. However, it is common for government officials to be transferred frequently between regions, disrupting the decision processes while relationships are re-established, affecting governance performance and system productivity (Dayaratne, 1991). I argued that any future interventions to provide cultivation, weather and climate information to the farming community need to be co-designed with the local farmers (including key actors) to ensure existing, particularly informal, networks remain intact as these networks facilitate climate adaption (Cunningham et al., 2016; Schmidt, 2017). The decision process in the upper and middle part of the cascade provides significant flexibility to adjust the cultivation schedule to suit local needs and conditions, an essential element supporting climate adaptation. I noted that these flexibilities could facilitate the development of adaptive governance mechanisms as envisioned by ongoing projects in Sri Lanka.

Efforts to develop adaptation strategies for local farmers in the dry zone of Sri Lanka need to recognise farmer's perceptions of climate change (Esham & Garforth, 2013), governance decisions made at local levels and the role of shadow networks that generate knowledge locally (Olsson et al., 2006; Schmidt, 2017). Therefore, inclusive governance that incorporates diverse actors in agricultural decision-making (going beyond rice) (Davidson, 2016) maps agricultural value chains (U. Nidumolu et al., 2018) and co-designs adaptation pathways (Butler et al., 2016; Gotgelf et al., 2020; Roncoli et al., 2002) are critical. However, efforts to develop climate adaption through improved governance can be compromised due to current NRM policy incoherence and top-down governance processes at the local level (Kekulandala et al., 2021; Lee et al., 2022; Panditharatne, 2016).

Participation, collaboration, learning and trust are essential elements that facilitate ACM as discussed under RQ1 in this chapter. In Chapters 6 and 7, I discussed several barriers that may interfere with ACM practice. The diagnosis for ACM (Plummer et al., 2017) showed that some key actors (agricultural extension officers) involved in the decision-making process could be transferred to a different location as per the departmental policies. These relocations may disturb the existing network structure, trust and working relationships, collaboration and learning between the communities and the government agencies. The attitudes and motivations of key players, such as agricultural extension officers, play a role in facilitating collaboration and learning, hence ACM practice (Ghorbani et al., 2021; Tran et al., 2019; Trimble & Plummer, 2019). The SNA also highlighted several network characteristics that interfere with ACM. The fragmented nature of the share network indicated hyper-local groups within the larger network. These hyper-local groups may not share information or collaborate with other actors to gain a competitive advantage, thereby, interfering with knowledge exchange in the ACM process. My research shows that SNA can be used as a tool to diagnose antecedents as per ACM diagnostic framework (Plummer et al., 2017). This research provided added to emerging evidence of the potential of SNA to diagnose the system antecedents and issues that can interfere with ACM practice (Cunningham et al., 2021; Groce et al., 2019; Hamilton et al., 2020; Kuslits et al., 2021; Tesfaye et al., 2019).

RQ3: Can adaptive co-management strategies be adopted for governance of small tanks cascade systems?

I answered this research question by diagnosing evidence for adaptive co-management (ACM) in Palugaswewa STCS using the ACM diagnostic framework (see Figure 11) (Plummer et al., 2017). This framework entails the following steps carried out in a given setting: 1. Identify antecedence (actors, activities and practices), 2. Consider attributes of processes (collaboration, learning), and 3. Make connections to outcomes in linked social-ecological systems.

The setting for this analysis is the governance environment for managing STCS, which I described in chapter five. I referred to the institutional context, connecting the biophysical (water/STCS) and social (resource users) domains to describe the setting for the research. I argued that the governance environment for STCS resembles a complex socio-ecological system. In chapter 5, I explained the institutional, social and cultural contexts of the Palugaswewa STCS. In chapter 6, I described the antecedents of Palugaswewa STCS through SNA. SNA helped me identify the key actors involved in governance, characterise the networks involved in the governance process and, using network measures, provide insights into ACM practices such as collaboration, learning and social cohesion. In chapter 7, I used SSI to characterise the decision process in Palugaswewa STCS, providing evidence for elements of ACM at play. My findings also highlighted an informal decision process, where elderly farmers collaborated to co-design seasonal weather expectations for the local farming community to inform agricultural practices. This informal decision process drove the formal governance process, and interactions (deliberations, negotiations, mutual respect, and transactions) between these two processes indicated further elements of ACM in operation (Huitema et al., 2009; Plummer et al., 2012). I highlighted iterative learning processes in the STCS in the form of farmers relying on experience to interpret changes in the fruiting/flowering of trees, moon phases, zodiac signs and animal behaviour to predict seasonal weather (Folke et al., 2005; Plummer et al., 2012). The institutional structures associated with the informal and formal decision processes in Palugaswewa STCS resembled adaptive institutions that can respond to changes in the governance environment (chapter 7). My findings also indicated that local institutions associated with the governance processes in Palugaswewa STCS resembled a loosely organised polycentric system (Ratnayake et al., 2021; Skelcher, 2005). The decision processes in the upper and middle parts of the cascade provided substantial flexibility for the farming community to adjust the agricultural calendar and organise the farmers cultivating under smaller peripheral tanks around the main tanks of the cascade. The social relationships within closely-knit family groups, knowledgeable elderly farmers and supportive agricultural extension officials are vital enablers in adaptive governance within the cascade system.

In general, women and youth are involved in vegetable and maize cultivation in Sri Lanka (Athukorala, 1996; Meinzen-Dick & Zwarteveen, 1998), and seasonal fruit and vegetable cultivation is becoming very popular among the local farming community, albeit still dominated by rice production. Palugaswewa STCS is located close to two historical cities with major tourist attractions (Anuradhapura and Polonnaruwa). The tourism industry has increased the demand for hospitality workers (before the COVID-19 outbreak), and local youth have found employment in the tourism sector. These non-farm income sources serve as opportunities to address resource constraints in rice farming. I argue that these alternative livelihood opportunities will become an increasingly important source of community adaptation options as pressure grows in the water-intensive rice farming sector under a changing climate (Athukorala, 1996; Cejudo et al., 2020). There is a dearth of research on the role of women and youth in local resource governance and climate adaptation (Davidson, 2016). Therefore, future governance interventions need to consider gender aspects and the participation of women/youth in local decision processes.

Several barriers could compromise ACM practice in Palugaswewa STCS and might constrain climate change adaptation. The governance process in the lower part of the cascade (Horiwila) remains a top-down system with very little flexibility for farmers to adjust the cultivation schedule. The linkages among the farmer organisations across the three main tanks of the cascade remained limited, despite being hydrologically connected. Furthermore, decision processes are organised along administrative boundaries around the three main tanks rather than the cascade (catchment) boundary, and future governance interventions need to consider cascade-level governance mechanisms. My findings show that the rice-focused decision process has favoured full-time rice farmers over part-time farmers, excluded vegetable and maize farmers (predominantly women and youth), and has increased the vulnerability of the farming community to external shocks such as price fluctuations, fertiliser inaccessibility and variable seasonal weather. The dominance of rice farming is attributable to farmers being legally prevented from cultivating other crops in paddy fields. Therefore, integrating the diversity of farming groups within the decision process, diversifying into other crops, enabling rice farmers to cultivate less water-intensive crops under drought conditions, and expanding government incentives to non-rice crops could improve the adaptive capacity of the local farmers.

Lastly, I argued that providing timely and localised seasonal weather/climate information is critical to minimise future risks posed by climate change. Therefore, the scope for improved seasonal weather/climate information to facilitate ACM practice in Palugaswewa STCS is high. However, the provision of better meteorological information and more informed agricultural advice needs to consider the extensive knowledge of local actors. Any changes to current advice dissemination should be co-designed with the local community and communicated through existing networks to ensure salience, credibility and legitimacy with STCS farmers (Asante et al., 2021; Cash & Belloy, 2020).

8.3 STCS governance through a contemporary NRM perspective

In chapter 5, I explained the transformation of STCS governance from a primarily community-led to a government bureaucracy-led process through the colonial and post-independence periods of Sri Lanka. Broadly, the governance of natural resources (e.g., water, forests, and fisheries) determines the sustainability of the resource base. Furthermore, our understanding of natural resource management has significantly evolved over the 20th century. This understanding evolved from viewing natural resources through an “ecosystems” perspective to a “complex adaptive systems” perspective and to exploring interactions between human and biophysical environments through a “social-ecological systems” perspective (Baird et al., 2021; Berkes et al., 1998; Blomquist, 2009). The social-ecological systems (SES) perspective recognises that delineation between social and ecological systems is arbitrary and artificial.

Furthermore, social-ecological systems theory recognises complementary feedbacks between social and ecological domains (Berkes et al., 1998; Folke et al., 2005). Ostrom's framework on SES identifies four sub-systems that interact with each other: 1. Resource system (designated by resource boundary), 2. Resource units, 3. Governance system and 4. Users (Ostrom, 2009).

Briefly, there is a nexus between water and agriculture, wherein the demand for water in agriculture will escalate with increasing population, rising incomes and changing dietary requirements (de Fraiture & Wichelns, 2010). Therefore, water governance to meet competing demands of industrial, urban and rural water users, provide water for the environment and address water scarcity is challenging (CA, 2007; de Fraiture & Wichelns, 2010; Pokhrel et al., 2021). The complexities associated with political, economic and social institutions are essential considerations to manage and develop water resources. Furthermore, equitable, efficient, and sustainable water management requires the involvement of all actors who use and are affected by the resource (Rogers & Hall, 2003). Climate change will exacerbate these complexities as agricultural production systems are susceptible to variations in the climate system (Howden et al., 2007; Waldman et al., 2020). The vulnerabilities of socio-ecological systems (agricultural production systems such as STCS) to potential risks of climate change warrant a transformational change in governance to meet food and livelihood securities of communities (Berrouet et al., 2018; Esham et al., 2017; O'Brien & Sygna, 2013; Rickards & Howden, 2012; Vermeulen et al., 2010). Water governance is undertaken through a variety of processes across the globe. Although water is often regarded as a common property resource, related rights and entitlements are generally vested in the state or its agencies (Ostrom, 1990; Scott, 1998).

Rainfed agriculture (including small irrigation systems) meets about 60% of the food and nutritional needs of the world's population, and it is a significant livelihood of marginal or subsistence farmers (Biradar et al., 2009). Small water storage and irrigation systems can provide higher returns for local communities than larger projects, and effective management of local water storage is critical for the food and livelihood security of rural farming communities (Gain et al., 2020; Ostrom, 1992; Ostrom & Gardner, 1993). In a global context, the shift in governance from local resource users to centralised government agencies has led to the exploitation of the resource base by individual actors depending on their social status and wealth (Di Baldassarre et al., 2019; Ostrom & Gardner, 1993). Furthermore, such exploitation may lead to conflicts and abandonment of collective responsibility to maintain the resource base (Ostrom & Gardner, 1993). Small irrigation systems with successful governance have several common characteristics: local-level governance and associated institutional structures, community-derived laws, rules and customs, stakeholder participation, and high social capital (Ostrom, 1992; Ostrom et al., 1999).

Centralised governance approaches (organising social and ecological systems as mere administrative entities) has contributed to the degradation and deterioration of resources and the dependant communities (Scott, 1998). In chapter 5, I highlighted that this "conventional" resource management perspective is dominant in the management of STCS in Sri Lanka. The Sri Lankan Government presumed that a centralised bureaucracy was best suited to manage the demands for water use for agriculture in STCS (Kekulandala et al., 2021). As highlighted in Table 4 of chapter 5, the institutional churn in STCS administrative arrangements is indicative of the government's policy perspective favouring top-down governance. This perspective has essentially treated the resource users (farmers) as passive participants in the governance process (Somasiri, 2008; Uphoff, 1986; Wijekoon et al., 2016), does not account for multi-functionality of the STCS, considers STCS only as irrigation entities (Kekulandala et al., 2021), and designed governance arrangements on administrative boundaries rather than resource boundaries (Wijekoon et al., 2016).

The evidence from limited STCS research (Abeywardana et al., 2019; Abeywardana et al., 2019; Bebermeier et al., 2017; Kenyon et al., 2004), and my findings from Palugaswewa STCS (chapters 6 and 7) indicates that they are complex social-ecological systems (see Figure 4). In chapter 2, I explored Sri Lanka government reports (National Climate Change Adaptation Strategy, Second National Communication to UNFCCC) and evidence from the literature (Eriyagama et al., 2010; Eriyagama & Smakhtin, 2009; Gunda et al., 2016; Marambe et al., 2015) on climate change impacts in Sri Lanka. The dry zone of Sri Lanka produces nearly 70% of the nation's staple food, rice. Small agricultural systems such as STCS contribute 30% of the rice production in Sri Lanka. The northeast monsoon is the primary source of rainfall in the dry zone, and it is projected to become increasingly variable (year to year and inter seasonally) (Climate Change Secretariat, 2016b; Eriyagama et al., 2010; Eriyagama & Smakhtin, 2009; Marambe et al., 2015). This variability will impact the farmers' capacity to anticipate and plan the cultivation season. These climate/weather uncertainties could compromise smallholder farmers' food and livelihood securities (Esham et al., 2017) in STCS.

Building resilience in SES is a crucial requirement for ensuring sustainability (Berkes & Seixas, 2005). Multiple legal and normative frameworks consisting of national law, state or provincial law/statutes and customary laws can be incorporated into the governance of STCS (Meinzen-Dick & Pradhan, 2001) to build flexibility into the current governance process. SES governance designed on resource /watershed boundaries that incorporates inputs from local resource users can provide significant benefits in sustainable management of the resource (Robins, 2007). However, chapters 6 and 7 demonstrated that administrative boundaries determine the current STCS governance rather than hydrological boundaries. Therefore governance interventions for STCS need to refocus on the resource or watershed boundaries because the resource units (individual tanks) in a cascade system are hydrologically connected to upstream and downstream tanks, water users and ecosystems. Governance interventions need to expand the system boundaries to consider the connectivity of individual tanks within the larger cascade system to enable climate adaptation across the cascade as current governance considers each tank as an individual entity rather than elements of a larger system.

The diagnosis of the Palugaswewa STCS illustrated the importance of informal governance processes that drive, inform and, to some extent, legitimise the formal governance process (Chapter 6 and 7). As discussed earlier, recent attention on STCS has mainly been concerned with the formal governance processes. This research uncovered and characterised the informal decision process (see Figure 18), which appears to have gone unreported in academic literature until now. This discovery is a major outcome of my research. Understanding and recognising informal institutions and their roles within STCS are critically important for developing more appropriate governance mechanisms. The design principles for irrigation institutes (Ostrom, 1993) and NRM governance principles (Lockwood et al., 2010) that recognise the rights and value of local actors, encourage the participation of local actors and encourage multi-level governance to improve the STCS governance. This process can be further encouraged by incorporating carefully planned efficient investments to involve the local actors (Jacobs & Brown, 2014) as feedback from local actors is critical to adjust governance to local biophysical and social context (Moss & Newig, 2010). My findings from the Palugaswewa STCS indicate some flexibility within the current governance system that allows local resource users to lead the agricultural decision process. Empirical evidence from other studies shows that harnessing the knowledge of local resource users can significantly improve system resilience for better livelihood and food security outcomes (de la Poterie et al., 2018; Ghorbani et al., 2021; Roncoli et al., 2002; Senaratne, 2013).

Chapter 5 highlighted the many changes that have occurred over time in policy regarding the management of the STCS of Sri Lanka. The current policies, priorities and legal framework are likely to be subject to further change with evolving government priorities. The policy incoherence within national, provincial and local policy processes can significantly affect the natural resource systems and their users (Berkes & Seixas, 2005; Cash et al., 2006; Nayak & Berkes, 2011). Climate change projections for South Asia and Sri Lanka suggest significant changes to seasonal monsoon rains

(Ahmed & Suphachalasai, 2014; Eriyagama et al., 2010). Therefore, climate change adaptation planning for STCS is a priority in Sri Lanka's current national climate change adaptation plan (Climate Change Secretariat, 2016a). The GCF project also intends to create policy changes to enable communities to manage water resources and build adaptive capacities of local communities against risks posed by climate change (UNDP Sri Lanka, 2016). The small farming systems in the dry zone of Sri Lanka are a critical contributor to the national food security (i.e. rice self-sufficiency), local level livelihood security and nutrition outcomes (Esham et al., 2017; Esham & Garforth, 2013). National adaptation planning and the GCF project goals, national and local level interest, and civil society action on climate change can create windows of opportunity for policy design and intervention by identifying institutional barriers to climate change adaptation and enabling policy opportunities for action across national, provincial and local scales (Aamodt & Stensdal, 2017; Michaels et al., 2006; Panditharatne, 2016; Rose et al., 2020). If the policy environment in Sri Lanka becomes more amenable to more bottom-up management of STCS, my research findings can help strengthen these processes. These are vital aspects for envisioning any future governance mechanisms of STCS as the institutional and policy landscape in Sri Lanka is highly unstable and unpredictable. However, the potential to develop such inclusive governance mechanisms would appear remote unless the government makes significant changes to existing natural resources governance policies in Sri Lanka.

8.4 Actors informal and formal

Governance of SES needs to recognise the inherent complexities of interactions (formal and informal) among actors at various levels (local, sub-national and national), uncertainty and change (Folke et al., 2005). Self-organisation of individuals and institutions to coordinate actions, and networks that connect individuals and institutions organised at various levels, enable adaptive governance (Barnes et al., 2017; Folke et al., 2005; Olsson et al., 2006, 2014). Social network analysis (SNA) enables the mapping of complex resource governance systems (such as STCS) to show the organisation of such actors across multiple levels (Bodin & Crona, 2009; Bodin & Prell, 2011) and different forms of interactions among actors (Bodin et al., 2006; Cunningham et al., 2016; Janssen et al., 2006).

In chapters 6 and 7, I described the key actors and their roles and responsibilities in the Palugaswewa STCS governance process. The SNA was able to identify formal and informal actors as key individuals that drive and facilitate the decision process (cultivation meeting) in the Palugaswewa STCS, where government agency representatives (extension officers) act as intermediaries between the bureaucracy and the farmers. Their roles and responsibilities are mainly concerned with implementing government regulations and managing cultivations as per the legal prescriptions (e.g. cultivation meeting). The government officials (from DAD and ID) in Palugaswewa effectively facilitated the cultivation decision process by proactively supporting the collective processes in the cultivation meeting. My observations during the interviews indicated that these officials worked very closely with farmer organisations during the cultivation decision process. Research in Sri Lanka suggests that highly dedicated extension officers who earn the community's respect can establish collaborative decision-making mechanisms, but these subsequently collapse when the key person is transferred or moved out of the region (Dayaratne, 1991; Merrey, 1988). The disruptions to existing networks and removal of key actors can lead to disturbances to the governance systems, affecting the production systems and related livelihoods (Fan et al., 2020; Waldman et al., 2020). Therefore, such changes or transitions need to be carefully planned and alternative arrangements designed in consultation with impacted communities (Cooper & Wheeler, 2015; Schmidt, 2017; Shah, 2000)

The roles and responsibilities of key formal actors in STCS governance have been described previously (Aheeyar, 2000; Begum, 1987; Panabokke et al., 2002; Wijekoon et al., 2016). However, the role of informal actors was not well understood. The emerging evidence shows that the organisation of informal or shadow actors/networks is crucial for enabling adaptive governance in an SES because informal actors self-organise to respond to a crisis, and the knowledge generated through such organisation evolves and is incorporated into emerging institutional structures (Olsson et al., 2006; Schmidt, 2017). The knowledge generated through informal institutions can facilitate climate change adaptation, but communication gaps between formal actors, such as government departments, and informal actors, such as farmers, can lead to conflicting management objectives (Cooper & Wheeler, 2015). Therefore identifying actors (formal and informal) and their relationships and visualising the shadow/informal actor-networks are essential to understand systems of governance and address shortcomings in the governance process (Cross et al., 2005).

The formal governance system in Palugaswewa STCS revolves around the cultivation meeting. However, my findings showed that informal actors and an informal decision process (pre-cultivation meeting) act as the primary driver for the cultivation meeting. In chapter 6, the between-centrality measures in SNA identified several farmers as key actors in disseminating weather/climate information for the farming community. Semi-structured interviews (SSI) with these farmers revealed their roles as the primary drivers in the cultivation decision process. These farmers acted independently outside the formal cultivation meeting process. The primary function of the pre-cultivation meeting was to develop a consensus about seasonal weather expectations for the upcoming cultivation season (Maha) each year. The pre-cultivation meeting appears to have developed as a compensatory mechanism for the lack of timely and localised meteorological information for planning the cultivation season. Self-organised farmers who are community elders rely on their collective past experience about the weather events and climate patterns to predict future weather/climate patterns (Ghorbani et al., 2021; Senaratne, 2013). It is important to note that all aspects of farming in the dry zone depend on seasonal rains. Therefore, the roles performed by these elders are critical to the farming community. Empirical evidence from other similar contexts in Sri Lanka indicates farmers typically use their experience with past climate to predict the monsoonal weather and provide their expectations to their communities for the upcoming cultivation season (Senaratne, 2013). Similar observations in Iran (Ghorbani et al., 2021), Ghana (Isaac et al., 2007), Italy (Nguyen et al., 2016), Burkina Faso (Roncoli et al., 2002), Kenya (Guido et al., 2020), Europe (Šūmane et al., 2018), Lesotho (Ziervogel & Calder, 2003), and India (U. Nidumolu et al., 2018), and in a review of literature on agricultural decision-makers in United States, Australia and Canada (Mase & Prokopy, 2014), supports my findings. However, the reliance of STCS governance on such informal decision processes acting in the absence of timely meteorological information (in Palugaswewa STCS) raises several questions.

Generally, local knowledge evolves, responding to the changes in the local environment, including weather and climate (Guido et al., 2020; Nyong et al., 2007), and mostly depends on cumulative experience and oral narratives (Reyes-García et al., 2016). Farmers in Palugaswewa STCS reported using various indicators (ecological, meteorological or 'cultural') and their past experience to construct a weather/climate expectation for the village. However, the current pace of change in the climate system is making the local knowledge (seasonal weather expectations) less reliable (Naess, 2013; Roncoli et al., 2002). In Sri Lanka, farmers are already reporting that predicting the future seasonal conditions based on past experience is challenging (Senaratne, 2013). My findings from the Palugaswewa STCS show that farmers already struggle to predict seasonal weather due to high variability in the rainfall. Therefore, providing meteorological information to local actors (Andersson et al., 2019), complementing and creating synergies between local knowledge and meteorological information (Tengö et al., 2021; Ziervogel & Calder, 2003), and co-designing and co-generating meteorological advice for dry zone communities (Berkes et al., 2007; Roncoli et al., 2002; Singh et al., 2020) are essential aspects for reframing adaptation to match the changing nature of food production and agricultural livelihoods (Ensor et al., 2019; Eriksen et al., 2015).

Local indigenous or tacit knowledge forms an integral part of local resource governance processes as it can complement meteorological information (Ghorbani et al., 2021; Gotgelf et al., 2020; Šūmane et al., 2018). Nevertheless, there is considerable uncertainty in the current decision-making processes in the Palugaswewa STCS due to a lack of reliable location-specific meteorological, soil and hydrological data. Therefore, providing reliable and timely information is a vital component of improved governance processes in the cascade system that requires multi-layered institutional arrangements (Lebel et al., 2006). The SNA also highlighted the importance of networks within the cascade for communication of cultivation and climate information. These established networks and decision processes can help to co-design knowledge to improve the governance of the cascade. The resilience of the cascade system can be enhanced by the combination and integration of different types of knowledge through co-design and co-learning (Armitage et al., 2011; Berkes, 2009; Folke et al., 2005).

8.5 Governance systems

My findings (chapters 6 and 7) highlight the nuances of the established decision processes. The extent of the irrigation command area is the primary factor determining the main government actors involved in the decision process and their boundaries. My findings (chapter 6 and 7) and literature on STCS in Sri Lanka (Aheeyar, 2000; Begum, 1987; Wijekoon et al., 2016) show that local actors cultivating under small tanks have much more flexibility and engagement in the governance process than those under medium/large tanks. The farmers cultivating under the cascade's smaller upper and middle tanks at Palugaswewa were more engaged in the governance process, driving the cultivation meeting with government officials (from DAD) performing a facilitator role. In the larger, lower tank, the (Horiwila) ID engineer establishes the conditions for cultivation, and a government civil servant (district/division secretary) leads the cultivation decision process. The decision process at Horiwila is designed to maximise the utility of water through predetermined governance actions, which limit farmers' ability to experiment, develop local knowledge, norms, and institutional practices, and likely constrain the farming community's adaptation responses (Altieri & Koohafkan, 2008; Davidson, 2016).

The government extension officials, NGOs, and CBO's provide services for improving agricultural productivity in the Palugaswewa STCS, and they are aimed at the cultivation meeting. The interplay between the informal and formal decision processes for planning the cultivation season in Palugaswewa STCS is significant (see Figure 18). However, despite its importance to STCS governance, the informal pre-cultivation meeting has previously received limited attention from researchers and policymakers in Sri Lanka. In chapters, 5 and 7, I have discussed the functions and critical decisions taken at the cultivation meeting. Furthermore, I explained the decisions taken at the pre-cultivation meeting in chapter 7, described the pre-cultivation meeting process and identified the actors involved as resembling a shadow network (Olsson et al., 2006). Shadow networks act as platforms for new ideas and new learnings as they enjoy greater freedom to experiment than the constraints faced by formal government institutions (Schmidt, 2017), allowing them to enrich the formal governance system (Cooper & Wheeler, 2015). Therefore, recognising and acknowledging the pre-cultivation meeting process within the formal agricultural decision-making process can support climate change adaptation as shadow networks (involving the pre-cultivation meeting actors) bring place-based knowledge and practices to problem-solving (Cooper & Wheeler, 2015; Schmidt, 2017). Therefore, future attempts to develop adaptive governance mechanisms in Palugaswewa STCS must consider and incorporate the pre-cultivation meeting process.

Currently, the decision process is organised on an individual tank basis within the larger cascade system. The government officials and farmers entertain some flexibility to organise farmers cultivating under peripheral tanks around the main tanks in the cascade system into a single cultivation meeting around the main tanks in the upper, middle and lower parts of the cascade. However, decisions are still taken at tank level rather than cascade level, although each tank is hydrologically connected to the upstream and downstream tanks. The greater flexibility in the governance process in the upper and middle parts of the cascade allows farmers to adjust the cultivation schedule to suit the local conditions. It also encourages greater engagement and participation, facilitates self-organisation, collective choice rules, monitoring and agreeing on sanctions for non-compliance for collective choice rules (see Table 12). These flexibilities enable rapid improvisation and modification of agricultural practices to changed conditions (Olsson et al., 2006) and are critical enablers of an adaptive governance system (Davidson, 2016) that can facilitate climate adaptation (Baird et al., 2021).

Local community institutions are well suited to manage natural resources in a small locality confined to a defined boundary. However, the interconnectedness of the resources base (i.e. water in Palugaswewa STCS), communities, and other catchment stakeholders, requires governance approaches extending beyond administrative boundaries (Neef, 2009). The current governance mechanisms do not encourage the linkages among the farmers across the cascade. The literature indicates that collaborations across the resource boundary (the cascade and its hydrological catchment) can improve sustainability and resource efficiency, provide better outcomes in a resource deficient scenario (low rainfall season) and minimise resource conflicts (Bodin, 2017; Conley & Moote, 2003; Neef, 2009; Ostrom & Gardner, 1993). However, the current variations in governance regimes practised within the cascade could compromise attempts to develop a cascade-level adaptive governance mechanism. The decision-making process in the upper and middle tanks enables flexibility, while the top-down decision process in the lower tank constrains farmers' flexibility to adjust their cultivation schedule, increasing their exposure to seasonal risks. These top-down decision processes could be a significant barrier to developing more holistic governance mechanisms for Palugaswewa STCS, as previous research in Sri Lanka indicates that government bureaucracy is hesitant to transfer or share authority to manage water (Aheeyar & Smith, 1999; Uphoff, 1986).

8.6 Local values, norms and rules

The current governance mechanism for STCS presumes that the farming community is relatively homogeneous. The SNA (chapter 6) shows that the farming community is significantly heterogeneous, comprised of close family groups/neighbours organised into small associations with varying levels of autonomy and collaboration. These hyper-local groups or small shadow networks emerge from kinship, friendship or acquaintance relations (Ramirez-Sanchez & Pinkerton, 2009; Schmidt, 2017) and are critical for day to day interactions in support of livelihood activities (Salpeteur et al., 2017). Kinship ensures collaboration and support to manage disturbances/variations to the resource (Ramirez-Sanchez & Pinkerton, 2009) and contributes towards lowering the group's economic vulnerabilities as they often share resources and burdens (Fabricius et al., 2007). However, aside from revealing the presence of these hyper-local subgroups, little is known about how they access resources and information, how they participate in STCS management or their broader representation as resource users in the decision-making process; equitable access, participation and representation may not be the norm (Murray & Little, 2000; Schmidt, 2017). The hyper-local, granular structure of the STCS farming community has not been recognised in previous research in Sri Lanka. The reasons for these multiple subgroups within a single tank extend from close familial ties with neighbouring households cultivating adjacent paddy plots and close collaborations likely to maximise resource use efficiency (e.g. labour and machinery). The SNA and interviews with the farmers indicated that these subgroups might compete with other such groups within the same irrigation command area. Other authors have suggested that holding important tacit knowledge within the group (about best seed variety, access to fertiliser, labour, machinery, water access, market access) rather than sharing with the community may confer a competitive advantage (Schmidt, 2017). However, government agencies need to recognise sub-group dynamics, existing social relationships, norms and values, and their potential to influence the cultivation decision process when providing extension services and in the enhancement of adaptive governance in Palugaswewa STCS (Dacks et al., 2020; Elinor Ostrom, 1993; Stein et al., 2011).

There are additional implications of the sub-group structure at Palugaswewa STCS. For example, normative expectations within the kinship group may restrict the behaviour of individuals and how they act within the larger community (Schnegg, 2018). Kinship ties often disregard violations of collective choice rules and lead to resource degradation (Dacks et al., 2020; Schmidt, 2017; Schnegg, 2018). Interventions that fail to recognise these sub-group-level dynamics within the farming community may lead to conflicts and breakdown of collaborations across different subgroups to comply with the cultivation decisions.

Forms of traditional values, rules and norms are driven by various considerations that include the status of individuals, community groups, and ceremonial and cultural values (Murray & Little, 2000; Wilson & Inkster, 2018). Values or beliefs related to interactions between the resource and users contribute to developing local knowledge systems (Cejudo et al., 2020; Tengö et al., 2021). When agrarian societies transform, the traditional knowledge systems and related rules/values are increasingly challenged (Kumara, 2016; Li et al., 2019). The elderly farmers in the Palugaswewa STCS perform several critical roles within the governance process. They take the leadership for generating weather/climate expectations for the cultivation season through the pre-cultivation meeting, advising the cultivation meeting about the cultivation schedule, mobilising the farming community for voluntary maintenance (tank and canal cleaning), and are involved in conflict resolution. Close-knit familial relationships, cultural values (respect for elders), and the tacit knowledge generated over decades endow them significant power in decision-making. However, it is important to note that this traditional power structure is closely associated with experience gathered through rice cultivation and may be disrupted in light of the changing nature of the political, social and cultural landscape, which has affected the agricultural societies in Sri Lanka (Kumara, 2016; Morrison, n.d.).

My findings showed that the traditional power structure in the cultivation decision process in these villages (dominated by full-time rice farmers) is threatened by part-time and younger farmers. These part-time farmers' livelihoods are not entirely dependent on rice farming. Their livelihoods often include non-farm incomes from other sectors such as tourism. These part-time farmers described their inability to contribute to all voluntary maintenance activities and cultivation schedules established for the STCS as they attempted to manage multiple livelihood activities. These conditions have led to discontent and ultimately non-compliance with STCS rules by the 'part-time' farmer cohort and tension between traditional and part-time farmers. Not surprisingly, the part-time farmers are often alienated from the STCS decision process, as full-time or experienced farmers generally dominate it. The differences in perceptions of water underline the tension in the relationships between full-time or elderly farmers and part-time young farmers. The elderly farmers (common to indigenous cultures in general) perceived water as a social and cultural asset, while young or part-time farmers perceived water as a utility (Wilson & Inkster, 2018). Such differences in perceptions have been identified as factors that lead to conflicts among resource users. In other settings, the changing nature of social, political and environmental factors in the governance of common-pool resource systems, such as water, has been associated with the emergence of tensions among actors over activities that benefit individuals against those that benefit groups (de la Poterie et al., 2018; Ostrom & Gardner, 1993).

Diversity in ecosystems and livelihood strategies are essential to mitigate variations and shocks in climate, economic and socio-cultural contexts (Fabricius et al., 2007). The transformation of rice farming from a subsistence livelihood to a market-oriented enterprise, expanding population and changes in aspirations have led some farmers to diversify into non-rice crops such as maize and vegetables. Young farmers and women farmers are predominantly involved in vegetable farming within the cascade. However, women and youth, in general, are under-represented in rice farming decision making in Sri Lankan farming communities (Athukorala, 1996; Meinzen-Dick & Zwarteveen, 1998). Palugaswewa STCS's formal decision process involved two women as key actors. The interviews with these two women revealed that they inherited the paddy plots after their husbands' deaths. While not part of the formal governance of the STCS, these farmers created unique links between information provided by the agricultural extension officers or farmer organisations and farmers not otherwise connected to the network. Generally, low participation of women in decision making has been attributed to formal membership criteria for institutions (i.e. farmer organisations), time commitments for meetings and other activities that can affect their family roles. In addition, water management and rice cultivation are traditionally seen as male-dominated activities (Athukorala, 1996; Meinzen-Dick & Zwarteveen, 1998). A women social worker from the upper tank in the cascade acted as a knowledge broker to share decisions of the cultivation meeting with other farming households. My findings also identified two active women's farmer organisations, and they organised self-help groups to cultivate vegetables in back gardens and upland areas adjacent to paddy fields. The current governance system revolves around tanks and rice cultivation. It does not incorporate other upland cultivation such as maize and vegetables. Farmers indicated that the cultivation of these alternative crops creates economic opportunities for women. Smallholder farmers are increasingly vulnerable due to declining agricultural productivity and low livelihood resilience (Esham et al., 2017; Esham & Garforth, 2013). However, smallholder cultivation of vegetables remains an essential aspect of local food security (Joshi et al., 2006; Rahman et al., 2008), and crop diversification could provide additional income streams, contribute to local food security and provide opportunities to build strategies leading to reduced risks associated with rice farming. Further research is necessary to assess the economic contribution to household incomes of crops other than rice and how to integrate these in a future adaptive governance mechanism for the STCS that ensures opportunities for women to participate.

Despite these challenges, there are multiple reasons for the success and current structure of community-led cultivation processes in Palugaswewa. These include close family groups cultivating together, the high level of acceptance for the traditional value system (respecting elders, compliance with elders' advice on climate, weather and cultivation), adequate voluntary labour to maintain the local tank and canal systems, and shared responsibilities for farmland protection. The government also provides some incentives that facilitate the community-led decision process. These include access to fertiliser subsidy (tied to participation in the cultivation meeting and farmer organisation membership) and crop insurance and compensation (also tied to participation and compliance in the cultivation decision process).

The complex patterns of socio-ecological interactions transcend disciplinary boundaries (Bodin & Tengö, 2012), requiring a multi-disciplinary approach for designing future governance interventions in Palugaswewa STCS, and further research in similar contexts is needed to draw generalisations that might apply to STCS more broadly.

8.7 Disconnects between local level /cascade, regional/ national scales

The policymaking process in Sri Lanka is predominantly a top-down process implemented through the government's civil service arm (district and divisional secretaries). The 13th Amendment to the Constitution of Sri Lanka allows specific sectors to devolve into the provincial councils (Kekulandala et al., 2021; Wijekoon et al., 2016). Irrigation functions are devolved to provincial councils, provided the council has enacted a legal statute for irrigation. However, only a few provincial councils have enacted these statutes, and these provincial entities are vastly under-resourced (Wijekoon et al., 2016).

In Palugaswewa STCS, there is significant government oversight that limits the activities of the FOs. This oversight extends to approving all FO decisions, access to fertiliser subsidy and crop diversification through DAD or ID representatives. This significant oversight constrains the FOs capacity to act as an independent institution (Abeyratne, 1985; Perera, 1985). The discretionary power of these government officials might undermine the dynamic nature of agricultural practices and farmers capacities to adjust cultivation to changing weather/climate, socio-cultural and market contexts (Kekulandala et al., 2021). The governance arrangements in the lower tank (Horiwila) in the Palugaswewa STCS illustrate government agencies' discretionary power because, as described previously, it is a medium-scale tank with governance led by a district-level bureaucracy and supported by a specialised agency (e.g. national Irrigation Department). The cultivation decisions are established on tank capacity, and the amount of water that can be released for cultivation within a particular time frame is determined by a technical agency (Irrigation Department). This predetermination by a specialised agency limits farmers' ability to adjust cultivation decisions to suit local conditions, increasing their exposure to seasonal risk. These top-down decision processes could be a significant barrier to developing cascade level governance mechanisms as previous research in Sri Lanka indicates that government bureaucracy is hesitant to transfer or share authority to manage water (Aheeyar & Smith, 1999; Uphoff, 1986).

The agricultural decision process in STCS's, extension services and other government support catered to rice cultivation as rice self-sufficiency has been a political priority since the post-independent period. The focus on rice connects local agricultural production to national economic and health issues as rice-based agricultural policies have broader social and economic costs. The government generally spends 3-7% of GDP on fertiliser subsidies, which create incentives for the rice farmer, while the significant production costs also tend to prevent diversification (Wijetunga & Saito, 2017). Diversification at the farm level provides multiple livelihood options for farmers and enables climate adaptation (Esham et al., 2017). Therefore, the fertiliser subsidy has created a perverse incentive for rice cultivation, limited farm-level innovation, and inefficient resource use contributing to environmental costs (Semasinghe, 2014). Furthermore, the rice focused decision process, other policy instruments for decision-making, market access, and crop insurance have led to poor nutrition outcomes in rural Sri Lanka through the over-consumption of rice in Sri Lankan diets (Esham et al., 2017; Weerasekara et al., 2018) with flow-on impacts to human health.

Climate adaptation requires close interaction of local communities, specialised agencies (agriculture extension, meteorological services) and bureaucracies at local, sub-national and national levels (Rahman et al., 2021). Government bureaucracies are generally slow to respond to local needs and operate at a scale that can be problematic (Reid & Huq, 2014). However, community-based adaptation experiences show that local interventions can enhance the resilience of local communities when bureaucracies engage with diverse actors at various levels (Rahman et al., 2021; Reid & Huq, 2014). Therefore, effective climate change adaptation policy and planning require collaboration, participation, learning and co-designing (local actors and bureaucracy) in a multi-level governance structure (Amaru & Chhetri, 2013; Blomquist, 2009; Gotgelf et al., 2020; Nalau et al., 2015). Current national adaptation planning in developing countries has been criticised for its focus on the reduction of greenhouse gas emissions at the behest of international funding organisations rather than local adaptation needs (Holler et al., 2020).

8.8 Limitations

This research was focused on Palugaswewa STCS. It is a unique locality with historical, social and cultural significance, and FAO designates the Palugaswewa STCS as a globally significant agricultural heritage system (GIAHS) (Ministry of Agriculture & FAO, 2016). The UNDP is currently undertaking a comprehensive study to map functional STCS in Sri Lanka (Pers. Com UNDP Sri Lanka). Panbokke et al. (2002) estimate 8148 functional STCS in four districts in north-central Sri Lanka. Therefore, there is a strong likelihood that a high level of diversity in governance systems exists in STCS throughout the dry zone and generalising the findings and conclusions of this thesis for all STCS is problematic. The tool employed here to diagnose ACM depends on the setting, which can change due to place-specific social and cultural contexts. However, several common conditions enable some generalisations. They include similarities in the governance prescription (the cultivation meeting) applied across all STCS based on the irrigation command area of the tank, the decision process designed around individual tanks and village administration boundaries, and the formal institutional structure at the local level. Social network analysis has not been used previously to characterise natural resource/water governance in Sri Lanka. The influence on policy that can be leveraged through a study of a single cascade system will likely be limited, despite the interest of international organisations such as UNDP in STCS generally. However, the study has contributed to expanding the evidence base critical for influencing STCS governance policy in the future.

The Green Climate Fund (GCF) project to rehabilitate STCS is ongoing. My research was carried out at the initial implementation stage of the GCF project, where implementers (UNDP) were consulting local farmers for tank rehabilitation activities. The GCF project implementation has been significantly delayed and subject to travel restrictions from the global pandemic, preventing me from collecting additional information. Despite this, my research captures a rich picture of governance at a single point in time. Follow up data collection would allow comparison and evaluation of the impacts of changes in the post-rehabilitation stage resulting from GFC initiatives.

The research findings provide the local-level perspective of the STCS governance environment. The disconnect between the national and local actors warrants a comprehensive understanding of the national perspectives on STCS and climate change adaptation. These national-level actors enjoy significant power over policy and legislative design, and engaging them is vital for developing cohesive policy that facilitates adaptive governance at the local level. I had planned to share my research with the sub-national and national level actors/policymakers to understand their perspectives on the findings, governance options and enablement of climate adaptation through effective management of STCS. However, these plans were abandoned due to the global pandemic and resulting travel restrictions and remain an ambition to be fulfilled in the future.

The STCS governance environment catered for rice farming. The rice value chain connects many actors at local, regional and national levels (Senanayake & Premaratne, 2016). The disturbances in the agricultural production ripple through the entire value chain, and value chain analysis provides opportunities to understand the implications of disturbances and vulnerabilities (Lim-Camacho et al., 2016). The setting for this research (Palugaswewa STCS) involved multiple external actors (rice mill owners, rice paddy buyers, agrochemical and fertiliser providers and marketplaces) connected to agricultural production in Palugaswewa STCS that lay outside the scope of the study. However, due to seasonal weather and climate variability, production disturbances also impact these value chain actors (Lim-Camacho et al., 2016; U. Nidumolu et al., 2018). The lack of understanding of how rice value chains are affected by governance disturbances associated with STCS (and vice versa) is limited in this research.

CHAPTER NINE

Conclusions

9.1 Introduction

This thesis explored the potential for adaptive co-governance of the Palugaswewa STCS to improve the contribution of STCS to climate adaptation of farming communities in the dry zone of Sri Lanka. The research sought answers to three questions inspired by the stages of the ACM diagnostic framework (Plummer et al. 2007):

RQ1: What is the current decision-making process for managing water and cultivations associated with small tank cascade systems?

RQ2: How is cultivation and climate information accessed and shared for the decision-making process?

RQ3: Can adaptive co-management strategies be adopted for governance of small tanks cascade systems?

Past research on STCS indicates that they provide multiple ecosystem services and can buffer against future risks posed by climate change (Bebermeier et al., 2017; Climate Change Secretariat, 2016b; Goonatilake et al., 2015; Vidanage, 2019). Their importance is reflected in The National Adaptation Plan for Climate Change Impacts in Sri Lanka 2016-2025, which identifies the rehabilitation of STCS as an adaptation pathway to minimise climate change impacts on rural farming communities (Climate Change Secretariat, 2016a).

9.2 Research Context

Climate change impacts will continue to exacerbate existing environmental, economic and social vulnerabilities through to year 2100 (IPCC, 2021, 2022). Monsoon rains over South Asia are projected to increase over the 21st century with higher annual variation (IPCC, 2021). In Sri Lanka, the climate pattern has gradually changed over the last century, and projected changes show significant ongoing alterations in seasonal rainfall, shifts in monsoonal rains and changes in rainfall intensity and duration (Ahmed & Suphachalasai, 2014; Climate Change Secretariat, 2016a; IPCC, 2022). The seasonal monsoonal rains are critically important for food production in Sri Lanka's dry zone as these regions contribute to more than 60% of total food production and 75% of total rice production for Sri Lanka (Climate Change Secretariat, 2016a; Esham et al., 2017; Marambe et al., 2015). The agricultural practices and productivity associated with STCS are strongly linked to prevailing local conditions due to high agro-ecological diversity in the dry zone determined by geomorphology and seasonal rainfall (Köpke et al., 2019; Marambe et al., 2015; Panabokke et al., 2002). Changing and variable climate will impose risks to existing agricultural practice impacting social, cultural and economic aspects. Therefore climate adaptation interventions need to consider not only physical risks of climate change but also social, cultural and economic impacts.

Historically, the governance of STCS was a community-led process, and it enabled the local farmers to adjust the agricultural practice to suit local conditions with very few external inputs (Abeywardana et al., 2019; Kekulandala et al., 2021; Leach, 1961). These community led processes enabled the local community to respond to seasonal variations and adjust the cultivation practice accordingly. However, the gradual centralisation of governance into a government bureaucracy and irrigation efficiency-based decision systems limited the farming communities to adjust the cultivation season as other government services (fertilizer and seed distribution) related to farming are designed for a set calendar time frame(Kekulandala et al., 2021).

The centralised governance and management of STCS as irrigation entities rather than social-ecological systems has led to the deterioration and degradation of social, cultural and environmental norms and values that contributed to the continuation of STCS over millennia. Sri Lanka's social, economic and cultural transition from an agricultural economy to a service oriented economy has impacted the agricultural/farming communities as well (Köpke et al., 2019; Williams & Carrico, 2017).

Adaptive Co-management (ACM) is recognised as an approach that can capture ongoing changes, facilitate polycentric governance, foster partnerships/participation, and allow experimentation and adaptability. The literature further indicates that it can meet the governance challenges of complex natural resources management issues (Plummer et al., 2017; Plummer et al., 2012). My study investigated evidence for ACM in Palugaswewa STCS and potential of ACM as a governance intervention for STCS.

9.3 Significance of findings

The Sri Lankan policymakers have considered STCS as irrigation entities with governance mechanisms designed to achieve irrigation efficiency (Dharmasena, 2010b; Ratnayake et al., 2021). My analysis on the evolution of STCS governance and related policy (chapter 5), revealed that centralised and top-down governance arrangements that are designed to achieve irrigation efficiency and production targets often disregard the local knowledge and farming preferences of local communities. The broader policy preferences of the successive governments are catered towards achieving rice self-sufficiency rather than food and livelihood securities of farming communities. The irrigation efficiency and rice production-focused policy and governance interventions have failed to recognise the changes in the farming practice due to changing weather/climate patterns, social-cultural preferences (full time vs part time farming), rice value chains and high input costs. My analysis also reviewed the recent literature on STCS and these indicate a developing consensus that STCS are not merely irrigation entities but multifunctional landscapes. STCS provide multiple ecosystem services in addition to provisioning water for agriculture (Abeywardana, et al., 2019; Dharmasena, 2010b; Ratnayake et al., 2021). For example, STCS can be considered wetlands as per the RAMSAR convention. The ecosystems services provided by wetlands and STCS have been demonstrated to provide significant environmental, social and economic benefits to local communities (Emerton & Kekulandala, 2003; Goonatilake et al., 2015; Vidanage et al., 2005), and have the potential to buffer climate change impacts (Kenyon et al., 2004).

Furthermore, continuous institutional churn led to inefficient resource use and planning.. The multi-functionality of these systems was also degraded due to management that viewed STCS merely as irrigation entities. I concluded that these factors are significant barriers for developing adaptive governance and climate adaptation for STCS in Sri Lanka (Kekulandala et al., 2021; Quealy & Yates, 2021).

In Palugaswewa STCS, I uncovered an informal decision process (pre-cultivation meeting) that guided the formal decision process (cultivation meeting). I concluded that the pre-cultivation meeting was a compensatory mechanism for the lack of localised seasonal weather and climate information. The information and decisions generated from the pre-cultivation meeting drove the formal decision process (cultivation meeting). However, the pre-cultivation meeting was not recognised in formal legislation, which mandates other aspects such as attendance at meetings and access to government support. I found that the current government and other agency support for agricultural production were targeted towards the cultivation meeting but not the pre-cultivation meeting. It appeared that the rice-focused decision process had prevented the diversification of crops and limited the flexibility to respond to changes in the local context in the Palugaswewa STCS. The discovery of the informal decision process and how it guides the formal decision process is a significant outcome of my research. Peer-reviewed literature, to date, has failed to report informal decision processes in STCS. The anecdotal evidence from the discussions with farmers and NGO's working with STCS suggests that informal decision processes may be the norm. However, further research is necessary to understand the knowledge production process in these informal decision process and its implications for the governance of STCS. The current and future research and interventions to rehabilitate and develop STCS (i.e., GCF-funded project) needs to consider these informal decision processes in planning future governance interventions.

Another significant contribution of my research is demonstrating how climate information is accessed and shared within a farming community and its associated risks. Previous research indicated that past weather/climate experiences are not reliable indicators of future weather/climate (Guido et al., 2020; Roudier et al., 2014; Senaratne, 2013). My research revealed that local farmers do not have access to meteorological data and seasonal forecasts. Farmers depend on their collective experience of historical weather patterns to predict future weather. A quick analysis of meteorological information provided by the department of meteorology are not easy to understand, have little value at the local scale, and timeliness does not match with the cultivation seasons. Therefore, I concluded that future research and interventions to minimise climate risks would need to recognise the roles of informal actors, provide meteorological information in a form that is understandable to local farmers, co-design seasonal weather expectations based on experimentation (combination of seasonal meteorological data and place-based knowledge of farmers), recognise local values, norms and rules, diversify agriculture beyond rice, and reimagine intervention in agricultural production from a larger, value chain perspective.

I also demonstrated that social network analysis (SNA) can be used to diagnose a governance system to identify key actors, their interactions, structure and organization. Using the World Heritage listed Palugaswewa STCS as a case study, I used social network analysis (SNA) to characterise STCS governance and identify the key actors, processes and structures. I demonstrated that SNA matrices and visualization tools can provide insights into a governance system. The outcomes of my analysis have implications for future interventions. I concluded that the underlying heterogeneity of the farming community, interaction of formal and informal actors, and informal information flow pathways were critical to communication of cultivation and seasonal weather information. A significant finding of the SNA was the discovery of hyper-local farmer subgroups within the larger information-sharing network of the STCS comprised of farmers who cultivate adjacent plots or have kinship ties. These subgroups seem to have been overlooked in previous studies of STCS, and the interactions within and among these subgroups have consequences for governance outcomes because they likely compete for resources. SNA metrics (centrality measures) provided a structural perspective to the governance of STCS and revealed several inherent vulnerabilities. These vulnerabilities included a lack of farmer interactions across the cascade, compartmentalisation of governance around main tanks, and dependence on several key actors to access and share cultivation/climate information. I concluded that these vulnerabilities could be a significant barrier to developing adaptive governance and climate adaptation responses and need further research to expand the evidence base in Sri Lanka beyond Palugaswewa STCS.

The evidence from the literature (Kekulandala et al., 2021; Köpke et al., 2019; Quealy & Yates, 2021; Ratnayake et al., 2021) and observations at Palugaswewa STCS showed that STCS resemble complex social-ecological systems. Therefore, I argued that future research and governance interventions need to consider the complex nature of STCS in the design and implementation of future research and governance interventions.

I demonstrated that ACM diagnosis framework (Plummer et al., 2017) provided insights into ACM in Palugaswewa STCS. A combination of SNA and semi-structured interviews can be used as a tool to provide information to populate the first two steps of the ACM diagnosis framework to diagnose antecedents and processes. I was able to demonstrate evidence for ACM in Palugaswewa STCS and expand the evidence base for ACM in a developing country context. The networking, local knowledge generation, collaboration, local rulemaking and supportive institutional structure revealed through this research in Palugaswewa STCS can facilitate both ACM and climate adaptation. However, I concluded that compartmentalised governance, top-down decision processes, and lack of access to localised meteorological information are likely to compromise ACM implementation.

9.4 Opportunities for future research

Adaptive co-management (ACM) research predominantly captures the developed country context, and evidence from developing countries (global south) is slowly emerging (Butler et al., 2016; Tran et al., 2019). Furthermore, the need to expand the evidence in developing countries is well recognised (Plummer et al., 2012). The agriculture, fishery and forestry sectors in Sri Lanka can provide additional studies to expand the ACM evidence base. Cross-sectoral research covering multiple resource use contexts can support researchers to identify common variables that enable ACM (Olsson et al., 2007; Plummer et al., 2012). ACM also facilitates climate change adaptation by building adaptive capacity and generating adaptive responses (Plummer, 2013). Sri Lanka's National Climate Change Adaptation Plan 2016-2025 recognises the importance of developing strategies to minimise projected impacts for water, agriculture, fisheries and forestry sectors as poor people's livelihoods are connected to these sectors (Climate Change Secretariat, 2016a). The NRM policy context in Sri Lanka requires a resetting to accommodate contemporary NRM perspectives that include but are not limited to multi-stakeholder participation, local level rulemaking, governance designed on resource boundaries rather than administrative boundaries, and collaboration and collective accountability (Kekulandala et al., 2021; Lockwood et al., 2010). ACM research has the potential to provide insights into existing natural resource governance mechanisms and identify conditions that support and disrupt climate adaptation in Sri Lanka.

A social network approach to governance recognizes that resource users are connected through information flow pathways, and it supports the development of ACM (Janssen et al., 2006; Olsson, Folke, & Berkes, 2004; Plummer et al., 2017). This research demonstrated that a combination of SNA and semi-structured interviews could provide insights into a resource governance system to identify its vulnerabilities and possible remediation actions. In Palugaswewa STCS, SNA identified an informal or shadow network that drives the formal decision process (cultivation meeting). The empirical evidence on shadow networks shows that identifying and engaging these shadow networks are critical for understanding the governance environment, identifying its vulnerabilities and developing measures to mitigate those vulnerabilities (Cooper & Wheeler, 2015; Crona et al., 2011; Schmidt, 2017). Climate change will impact the food and livelihood securities of farming communities in Sri Lanka (Ahmed & Suphachalasai, 2014; Esham et al., 2017; Marambe et al., 2015). These impacts will be exacerbated due to predominantly top-down NRM governance mechanisms that fail to identify local-level issues and the need for rapid response (Kekulandala et al., 2021; Reid & Huq, 2014). Therefore, the social network approach to characterising NRM governance research in Sri Lanka may provide insights into informal/shadow networks/actors crucial for local decision-making and new governance mechanisms.

Women account for nearly 43% of the agricultural workforce in developing countries (Davidson, 2016). Female farmer roles are invisible in farming as male farmers dominate agricultural organisations (Athukorala, 1996; Davidson, 2016). The control of decision-making processes by women largely depends on their access, rights, and control over resources (Meinzen-Dick & Zwarteveen, 1998). In Sri Lanka, female farmers are accepted to farmer organizations if they own paddylands (Quealy & Yates, 2021). Women farmer organizations are established throughout Sri Lanka to promote kitchen and backyard farming (Quealy & Yates, 2021). In Palugaswewa STCS, there were two strong women farmer organizations through the support of female agricultural extension officers. The interviews with the women farmers provided some insights into their role in the cultivation decision process. However, there is a dearth of research on the roles of women farmers in the agricultural decision-making process, and they remain an untapped resource in support of climate change adaptation (e.g. Khalil & Jacobs, 2021). As rice farming becomes challenging due to variable seasonal weather and climate, diversification of farming practices will minimize food and income vulnerabilities (Davidson, 2016; Esham & Garforth, 2013). Women are often marginalized from governance processes due to rules, membership costs, time constraints, and other conflicting gender roles and restrictions (Meinzen-Dick & Zwarteveen, 1998). Therefore, further research into understanding their role in farming (not limited to rice) at the local level may provide insights for creating institutional prescriptions and rules (Vermeulen et al., 2010) to facilitate women's participation in agricultural decision processes.

The top-down command and control paradigm associated with water governance failed to adequately consider human dimensions and struggles to adapt to changes and uncertainties (Akamani, 2016). Climate change will pose risks that are difficult to manage through top-down governance mechanisms (Lemos, 2015). Resource use systems (water, forestry, fisheries) are complex systems that require cross-disciplinary integration (Lemos, 2015; Olsson, Folke, & Hahn, 2004). In Palugaswewa STCS, reliable seasonal weather information was crucial for planning the cultivation season, and farmers did not receive seasonal forecasts from government agencies. Therefore, elderly farmers in the villages are engaged to generate a seasonal weather expectation to guide the cultivation meeting. Evidence from Sri Lanka (Esham & Garforth, 2013; Senaratne, 2013) suggests that farmers cultivating under small tanks develop seasonal weather expectations based on their collective knowledge. My research findings showed that these types of local knowledge generation had not received the attention of the Sri Lankan research community. Collaboration, co-learning and co-designing knowledge can enable adaptive governance and build resilience against changes and uncertainties (Baird et al., 2014; Folke et al., 2005; Olsson, Folke, & Berkes, 2004). Seasonal climate/weather forecasts struggle with legitimacy, salience, access and understanding due to data scarcity issues (Hansen et al., 2011). Combining meteorologically-driven seasonal forecasts and farmer generated seasonal weather expectations could address legitimacy and salience issues (Hansen et al., 2011; Roncoli et al., 2002; Ziervogel & Calder, 2003). Therefore, research into how local farmers design seasonal weather expectations, co-designing seasonal weather advisories by combining meteorological data and farmer generated knowledge, and creating feedback mechanisms with meteorological agencies and farmers may provide evidence for good practices for incorporating seasonal forecasts into agricultural decision processes.

My research findings showed that STCS are complex social-ecological systems (SES). SES governance requires coordinated transformative response (Berkes, 2017; Folke et al., 2005). The broader NRM governance framework of Sri Lanka caters towards a centralized bureaucracy. Centralized bureaucracies often lack the specific resource management expertise, and general administrators (civil servants) set policies or take decisions for resource governance (Rahman et al., 2021). Furthermore, the design of these centralized agencies prevents them from rapidly responding to changes in local resource management contexts (Reid & Huq, 2014). Place-based knowledge systems evolve through continuous interactions with the biophysical environment and respond to its changes (Asante et al., 2021; Fazey et al., 2005; Reed et al., 2010). These knowledge systems can inform the NRM policies to respond to local resource use contexts (Jacobs & Brown, 2014). The participation of diverse actors in designing NRM governance ensures resource users, experts and administrators share their perspectives (Webler et al., 2001). Therefore, creating space for local resource users to participate in NRM policy processes in Sri Lanka is a priority. I experienced first-hand the challenges of creating multi-stakeholder platforms for sharing knowledge for policy development during my involvement in developing national wetland, national species conservation and national climate change adaptation strategies in Sri Lanka. The dearth of research on NRM policy processes and their impacts is a significant barrier that impedes advocacy for cohesive policy development processes in Sri Lanka and must be addressed to support climate change adaptation into the future.

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Appendices

CONSENT FORM

Adaptive Co-management of Small Tank Cascade Systems of Sri Lanka in a Changing Climate UTS HREC APPROVAL NUMBER – ETH18-2825

I ____agree to participate in the research **Adaptive Co-management of Small Tank Cascade Systems of Sri Lanka in a Changing Climate UTS HREC APPROVAL NUMBER - ETH18-2825** being conducted by Bhathiya Kekulandala,Institute of Sustainable Futures, Level 10, UTS Building 10, 235 Jones Street, Ultimo NSW 2007, Australia, Tel+61 2 9514 4950, email - Bhathiya.kekulandala@uts.edu.au

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet. I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney.

I understand that I will be given a signed copy of this document to keep.

I agree to be: *[delete what is not applicable]* ☐ Audio recorded ☐ Video recorded ☐ Photographed

I agree that the research data gathered from this project may be published in a form that: *[delete what is not applicable]*

☐ Identifies me

☐ Does not identify me in any way

☐ May be used for future research purposes

I am aware that I can contact *Bhathiya Kekulandala* if I have any concerns about the research.

____ ____/____/____

Name and Signature [participant] Date

____ ____/____/____

Name and Signature [researcher or delegate] Date

____ ____/____/____

Name and Signature [witness*] Date

*** Witness to the consent process**

If the participant, or if their legally acceptable representative, is not able to read this document, this form must be witnessed by an independent person over the age of 18. In the event that an interpreter is used, the interpreter may not act as a witness to the consent process. By signing the consent form, the witness attests that the information in the consent form and any other written information was accurately explained to, and apparently understood by, the participant (or representative) and that informed consent was freely given by the participant (or representative).

Participant Interview Guide

Research on Adaptive Co-management of Small Tank Cascade Systems of Sri Lanka in a changing climate

UTS HREC APPROVAL NUMBER - ETH18-2825

MAIN AIMS OF THE INTERVIEWS

The main objectives of the interview process is to identify,

A. Key cultivation decisions making processes

Cultivation decisions (village, community or individual) will determine what to be cultivated, start of the cultivation season, extent of cultivation and how local water resource is managed.

B. Access and use of climate information

The access and use of climate information for making cultivation decisions (community collectively / individually) will indicate what types of climate information is used

C. How to improve current process/es

This is important to understand the issues of the current management system and opportunities to improve the process

A. CULTIVATION DECISION MAKING PROCESS

1. How cultivation decisions are made at your community (Collective decision making process at community level)
   - Is it as per standard government process?
   - Collective process by government officials and community member

2. Who are the key actors in the decision process
   - Are they government appointed officials?
   - Are they elected by community members?

3. What are their roles and responsibilities
   - Who convenes?
   - Who coordinates?
   - Who is responsible decisions taken?

4. What are the advantages and disadvantages in the process
   - What are the advantages/benefits of the current process?
   - What are the disadvantages/problems of the current systems
   - What should be changed/altered/introduced to improve the current process

(Try to draw a network diagram with the participant to identify hierarchy and how information flow through various actors)

B. ACCESS AND USE OF CLIMATE INFORMATION

1. Do you use climate information for cultivating your fields
   - What climate information you use (Forecasts by government institutions, experienced farmers, your own observations, information provided by another villager)
   - How do you currently access that information and knowledge? [Channels of communication i.e. TV, radio, farmer organisation meeting, etc]
   - What/who are the key climate information and knowledge sources inside and outside the village? [i.e. Met Depart, farmer organizations, extension officer, elders in the village…]

2. In what stages of cultivation cycle you use climate information
   - When do you look for climate information (before cultivation season, land preparations stage, seeding stage, harvesting stage)
   - Do you look for different types of climate information at different stages of cultivation

3. What is your opinion/experience/learning about climate information that you access or use?
   - Adequacy, precision, reliability, timeliness, easy to understand, credibility

4. Do you share what you access/learn with anyone else
   - With whom you share
   - How and when, how often

5. How climate information is used at village level /in the cultivation meeting
   - What climate information you use (Forecasts by government institutions, experienced farmers, your own observations, information provided by another villager)
   - How do you currently access that information and knowledge? [Channels of communication i.e. TV, radio, farmer organisation meeting, etc]
   - What/who are the key climate information and knowledge sources inside and outside the village? [i.e. Met Depart, farmer organizations, extension officer, elders in the village…]

(Try to incorporate climate information flow pathways in the diagram)

C. HOW TO IMPROVE CURRENT PROCESSES

1. What needs to be done to improve the cultivation decision-making process (if any) - Managing water and cultivations (at the cultivation meeting and individually

   - What is your opinion on cultivation meeting
   - If changes are to be made what are your top three suggestions
2. In your opinion what needs to be done to improve the access/use of climate information (if needed)
   - Would you like to receive or like to see climate information is used at cultivation meeting
   - Would you like to receive climate information individually (seasonal outlook, bulletin, advisory)
   - How would you like to receive climate information (forecast, bulletin, text message

D. Any other comments

Survey Form - Social Network Analysis

1. Participant Information

i. Name	
ii. Address	
iii. Farming Type	Rice/Upland/Chena/Vegetable
iv. Water access	Tank (Wewa)/ Well/Tube Well/ Other………………………………….
v. Date	

2. Access to agricultural/cultivation information
   I. Do you access or get agricultural/cultivation information – Yes/No
   II. How do you get information – Verbally/ letter / other (…………………………………..)
   III. If Yes, from whom (name at least 5 sources from most important to least important)

      a. ……………………………………………………………….
      b. ……………………………………………………………….
      c. ……………………………………………………………….
      d. ……………………………………………………………….
      e. ……………………………………………………………….

3. Access to climate information
   I. Do you access or get climate information – Yes/No
   II. How do you get information – Verbally/letter/notice/other (……………………………………..)
   III. If Yes, from whom (name 5 sources from most important to least important)

      a. ……………………………………………………….
      b. ……………………………………………………….
      c. ……………………………………………………….
      d. ……………………………………………………….
      e. ……………………………………………………….

4. Passing on Information
   I. Do you pass on information that you get (climate information / agricultural information / both) – Yes/No
   II. If yes to whom (name 5 sources)

      a. …………………………………………………………
      b. …………………………………………………………
      c. …………………………………………………………
      d. …………………………………………………………
      e. …………………………………………………………