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

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Abstract
Small Tank Cascade Systems (STCS) are interconnected small reservoirs constructed in shallow valleys in the dry zone of Sri Lanka. STCS have assumed heightened significance for their potential contribution to climate adaptation of agricultural systems. Local communities managed STCS to store water by capturing seasonal rain and cultivating crops that suited local conditions over millennia. The British colonial centralisation of STCS governance led to the degradation and deterioration of STCS. Contemporary water governance literature identifies STCSs as complex multifunctional systems. Adaptive co-management (ACM) approaches can reconcile complex resource governance issues by combining co-management with co-governance. We studied Palugaswewa STCS in North Central Sri Lanka to explore farmer and government officials' views, perceptions, knowledge, and experiences about agricultural decision-making including current governance, issues, and proposed improvements seeking evidence for ACM in practice. We interviewed eleven farmers and four extension officials selected from the analysis preceding this research. Our results show that an informal decision process (pre-cultivation meeting) precedes and informs the formal decision process (cultivation meeting), farmers use their collective knowledge and experience to anticipate seasonal weather and plan cultivation, and government officials facilitate a community-led decision process with institutional limitations. We concluded that the informal process compensates for the lack of timely meteorological information, allows space for sharing and co-development of knowledge and facilitates ACM. Future governance interventions in STCS need to recognise informal processes that drive decision-making, provide timely user-centred meteorological information, and rethink legal frameworks at local and national levels to provide flexibility for local farmers.

Keywords Adaptive governance · Agricultural decisions · Adaptive co-management · Climate change adaptation · Informal decisions · Small tank cascades

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 [1, 2]. Monsoon rains over South Asia are projected to increase over the twenty-first century with higher annual variation [3]. In Sri Lanka, the climate pattern

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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 [4–6]. 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 [7]. An undulating plain and a bi-modal rainfall pattern characterise the dry zone of Sri Lanka [8]. The northeast monsoon (October to February) is the primary source of water for the dry zone, with the remainder of the year relatively dry [8, 9]. Historical records and rainfall projections indicate that the monsoon rains are currently variable and projected to be more so in the future. Therefore, agriculture in the dry zone will need to become better adapted to high levels of seasonal weather variability [10, 11].

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 [8]. 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" [12]. 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 the 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 [8, 13]. Several national policies identify the development of STCS as a strategy to enhance the rural economy and food and livelihood security [14]. These policies created a new impetus, through investment from the Sri Lankan Government and Green Climate Fund (The Irrigation Department of Sri Lanka implements this project, see details at https://www.greenclimate.fund/project/fp016 & https://criwmp.lk/) for the rehabilitation and development of tank cascade systems, to improve the climate resilience of Sri Lankan farming communities and establish new governance arrangements for their management over the next decade [14].

Internationally, the institutional structures governing local water resources have received considerable attention in the literature [15–19]. 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" [18]. 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" [15]. 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 [15, 18].

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 [13]. These top-down decision processes often disregard local farmers' place-based knowledge in the context of a changing climate [20, 21]. The gradual centralisation of management responsibility and decision processes that focus on irrigation and engineering efficiency led to the deterioration of STCS [13]. However, governance variations exist, and institutional structures for agricultural decision-making in some STCSs 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 [13, 22].

The primary agricultural decision-making process in STCS is the 'cultivation meeting', which involves farmers, agricultural extension officials and government administrators determining a range of seasonal management tasks such as cropping calendar, water release dates, subsidized fertiliser access and dates of water allocation [8, 23]. 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 [13]. 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 [24–26].

Adaptive Co—Management (ACM) has received attention in the literature as an approach to reconciling governance-related problems in complex social-ecological systems like STCS [27]. ACM combines adaptive management with co-management [28]. 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 [27, 29, 30]. The emphasis on trust-building, institutional development and collaborative and social learning are essential elements in ACM that facilitate inclusive and sustainable governance [29]. A framework for diagnosing evidence of ACM practice proposed by Plummer et al. [31] 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 decision process 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 [22, 23, 32]. However, the role of informal actors, such as farmers, is unclear. 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 [21, 33–37]. 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 [33, 34, 36, 38].

This study aims to explore and analyse the knowledge, views, understanding, interpretations and experiences of farmers and agricultural extension officials about the agricultural decision-making process in the Globally Important Agricultural Heritage System (See details at Globally Important Agricultural Heritage Systems) in Palugaswewa STCS, Northcentral Sri Lanka to diagnose evidence of and options for ACM [31].

2 Materials and methods

2.1 Study area

The study site was the Palugaswewa STCS in the Anuradhapura district of North Central Sri Lanka (see Fig. 1). The study site encompasses three tanks in the main valley and smaller tanks in the side valleys of the cascade within Palugaswewa, Udakadawala and Horiwila villages. The Irrigation Department of Sri Lanka manages the medium scale "Horiwila Wewa" and the Department of Agrarian Development manages all other small tanks in the cascade (tanks with an irrigation command area of 80 ha or less are considered as small tanks). FAO listed Palugaswewa STCS as a Globally Important Agricultural Heritage System due to its irrigation and cultural significance [14, 39]. Palugaswewa STCS covers 2353 ha and the cultivable area is around 570 ha. The cascade is situated in the DL1b agroecological zone of Sri Lanka. The cascade area is characterised by an annual rainfall (75% expectancy) of 900 mm with two distinct rainy seasons and undulating terrain with low ridges and valleys [39, 40]. The two rainy seasons correspond to the northeast and southwest monsoons. The northeast monsoon (October to January) is the predominant rainy season and the primary cultivation season for local farmers. Late onset of this monsoon, an extended dry season, increased intensity of rainfall events and a reduction of rainy days are projected climate changes for the region [39]. 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 [39].

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 [36].
2. Diagnosing the agricultural decision-making process by exploring and analysing key actors' knowledge, views, understandings, interpretations, and experiences to diagnose evidence of and options for ACM (reported here).

In component one, we used Key Player Analysis [41] algorithm in UCINET6 software to identify 11 farmers and four government officials as key actors that drive and facilitate the decision process [36]. 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). The research reported here focuses on the second component, which entailed qualitative data collection through 15 semi-structured interviews (SSI) with the key actors identified through the component 1 (reported in [36]).

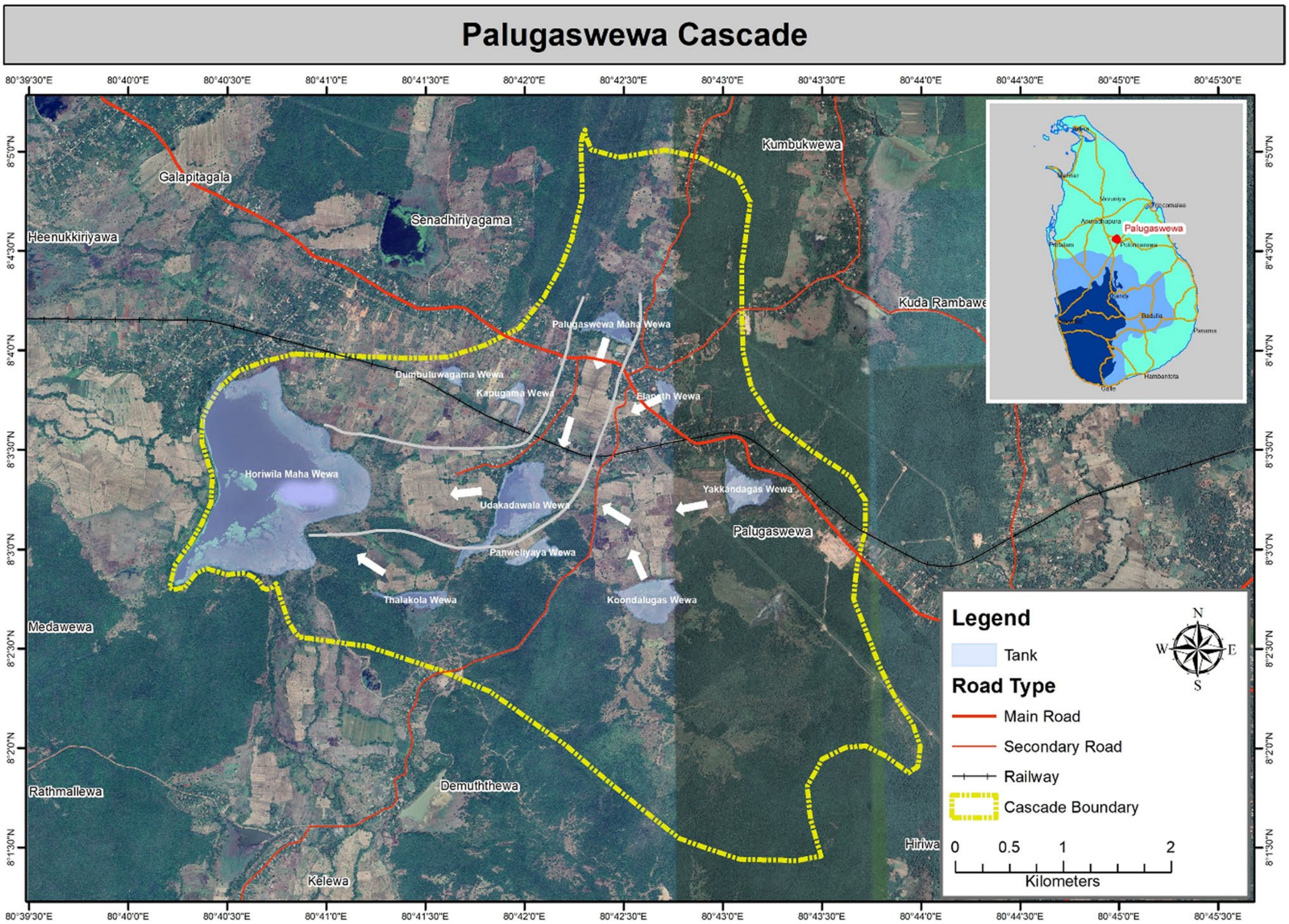

Fig. 1 Palugaswewa tank cascade system (for Interpretation- The two grey lines that encompass the main tanks in the cascade show the main axis other tanks in the side valleys discharge into the main axis. White arrows show the flow direction

2.2.1 Sampling method and data collection

We used SSI to collect data from 15 participants. 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 the interviewee [42]. The SSIs were helpful in eliciting information from farmers on tacit knowledge and traditional practices about a context that the interviewer organises as a series of questions in a sequence [43]. 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 [44].

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 do 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.

2.2.2 Analysis

The interviews were audio-recorded with the informed consent of the interviewee and transcribed. Transcripts were de-identified and coded in NVivo 12 [45, 46]. 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 [31] for analysing evidence and options for ACM. Participants were informed about the research, and written informed consent was obtained before commencement, following ethics approval (UTS Human Research Ethics Committee No. ETH18-2825) and all methods were carried out in accordance with relevant guidelines and regulations.

3 Results

We analysed and organised the interview data into three themes; agricultural decision processes, how cultivation and climate/weather information is accessed and used, and options for improving the current decision process (see individual graphs in Fig. 2). Then, we divided each theme into sub-themes/primary codes (see Fig. 2). The sub-themes within the agricultural decision process and how cultivation and climate/weather information are accessed and used were divided further into secondary themes/codes to facilitate a detailed investigation of participant responses.

The sub-themes that appeared most frequently have been emphasised in analysing the qualitative data (Fig. 2).

3.1 Key actors

Antecedents such as actors, activities, and practices may indicate an ACM process in a specific setting [31]. The key actors involved in the agricultural decision process included government officials, Farmer Organization officials (FO), Yaya Representative (YR), and farmers. These actors and their roles in the agricultural decision process within Palugaswewa STCS are summarised in Table 1.

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 meetings 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, tanks 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:

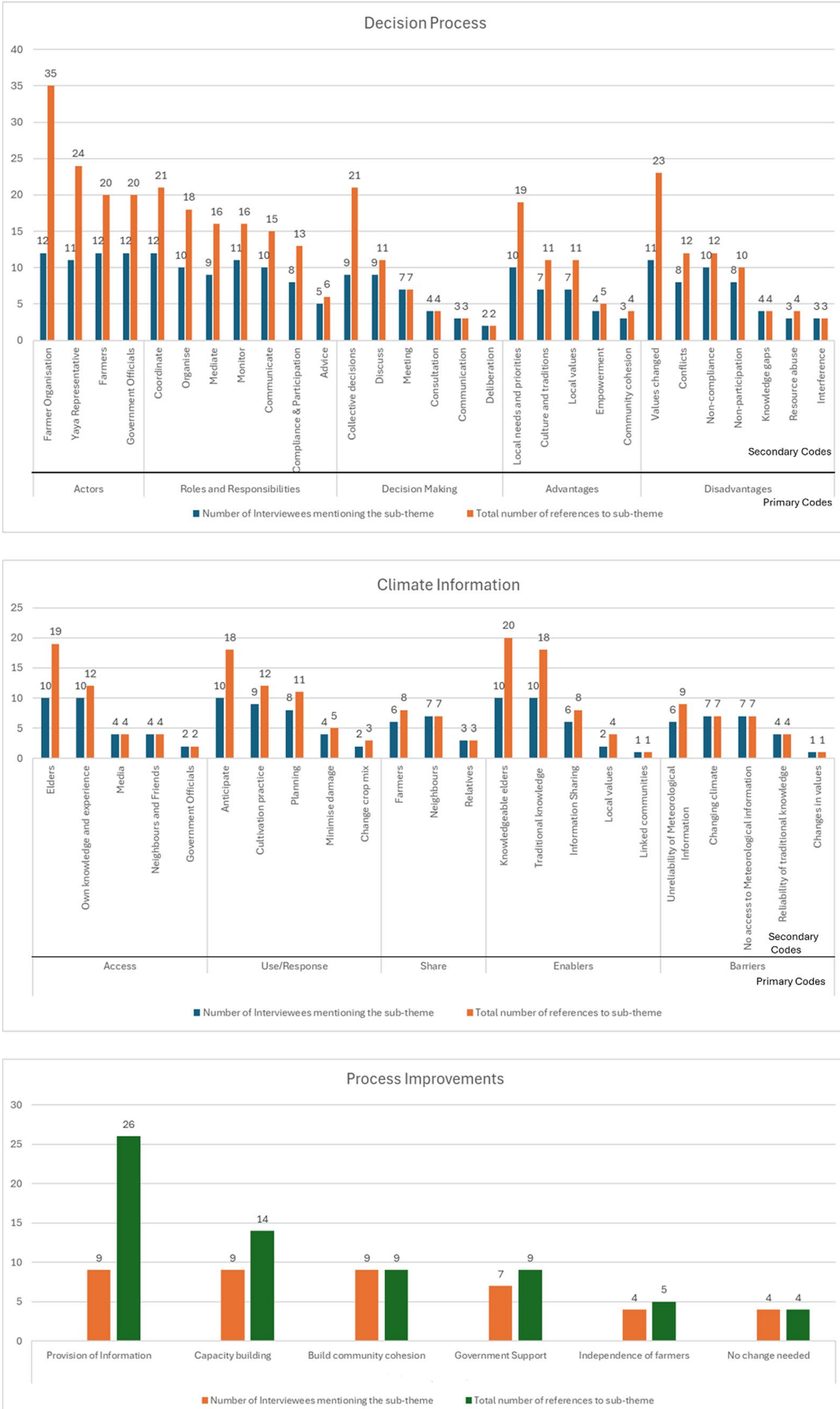

Fig. 2 Themes, sub-themes/primary codes and secondary codes (For interpretation; each graph corresponds to a theme in the figure. The X-axis shows the sub-themes/primary code and their secondary codes, Y-axis represents the number of responses received for each secondary code)

Table 1 Key actors in Palugaswewa Tank Cascade and their role in the decision process

Actor/s	Role
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
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 the 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. Their primary role 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

Yaya Representative 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,and 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 YRs 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 experiences and are involved in conflict resolution.

3.2 Decision process

There are several steps in the decision process within Palugaswewa STCS (Fig. 3). The cultivation meeting is the formal decision-making platform for cultivation planning in the Palugaswewa cascade system but is the second of two

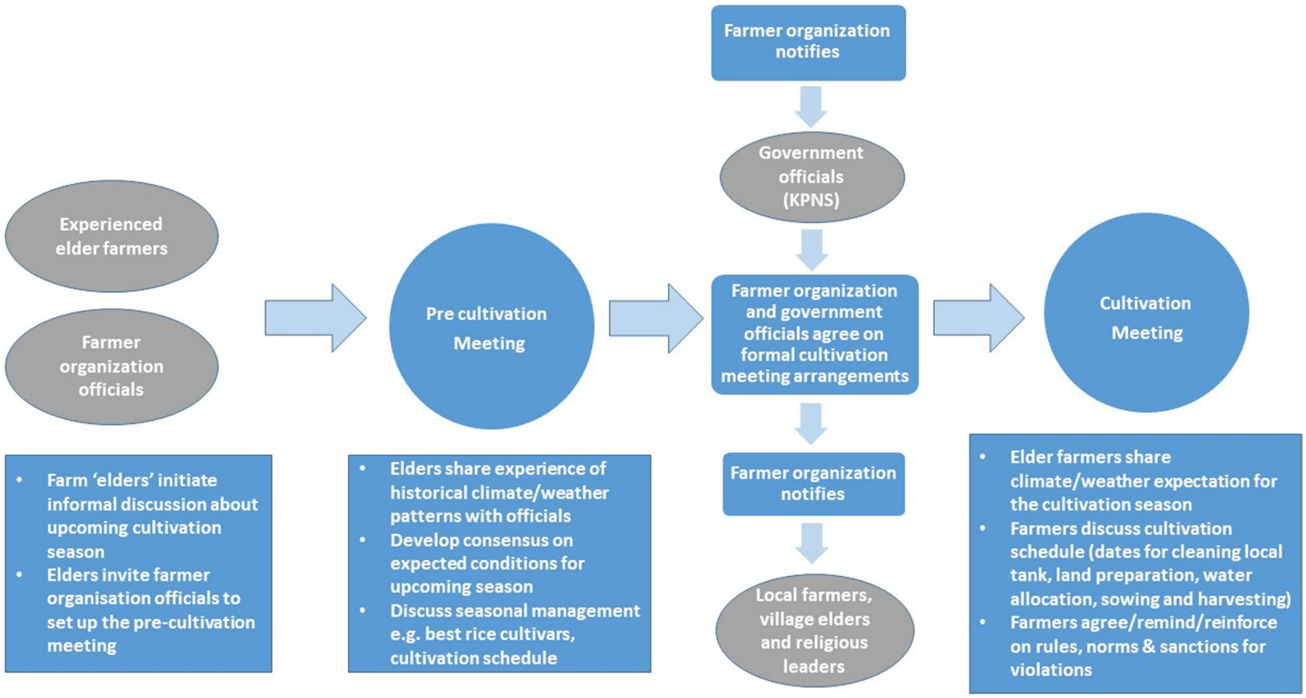

Fig. 3 Agricultural decision-making process in Palugaswewa Tank Cascade System—blue circles represent key decision processes (informal and formal), grey ovals represent key actors, and blue rectangles represent key actions

decision-making platforms. Interviews indicated an informal pre-cultivation meeting that determines the formal decision process.

The informal pre-cultivation meeting, convened by experienced farmers, is the decision process that underpins the formal decision-making at the cultivation meeting (Fig. 3). 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 [13, 22].

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 are 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. The 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 on the extent of 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 are challenging in medium to large-scale irrigation systems with similar top-down governance processes [22, 47, 48].

The above participant statement also indicates some flexibilities within the prescribed formal decision process. The thematic analysis (Fig. 2) 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 needs 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 make 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).

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 Fig. 3). 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 (Fig. 2) 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 (Fig. 3). 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's 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 indicates 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 into 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 rain (P10).

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 the 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 rainfall 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. If anything goes wrong, we cannot get any compensation. We have to use seeds provided by the government (P4).

4 Discussion

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. [31], who suggests 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 [15, 16, 49] as described in Table 2. 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.

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 [27, 50, 51].

4.2 Limitations to ACM practice

Despite appropriate institutional and governance structures Table 2, that resemble polycentric governance, there are inherent issues that limit the flexibility of management and practice. These issues 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 [13].

STCS are multifunctional landscapes that can support diverse food and ecological systems, local livelihoods and the local economy [13, 52] and show the potential to buffer agriculture from climate variability to sustain local communities [53]. 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 [54]. The cultural significance of rice in Sri Lankan society [55], preference for rice cultivation, and institutional and legal barriers that limit diversification [23, 56] 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 [34, 37]. In Palugaswewa, the rice-focused decision process has alienated farmers who cultivate upland crops (such as vegetables, and 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

Table 2 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 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: labour, material or money requirements)	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 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 the 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 arenas to resolve a conflict between users or between users and officials)	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 community fails to resolve disputes, they forward the matters to 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 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)

Table 2 (continued)

Ostrom's design principle	Institutional characteristics of Palugaswewa STCS
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

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 [57, 58]. However, centralised irrigation bureaucracy and its agents at the local level can act as barriers that prevent communities' effective participation in decision processes [48, 59]. In Palugaswewa, we found evidence of considerable government oversight limiting the activities of FOs about fertiliser access and crop diversification (formally enabled under The Agrarian Development Act 2000, no 46). This situation constrains the FO's capacity to act as an independent institution [60, 61] by granting oversight and discretionary powers to government officials to override farmer decisions [13]. 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, and a district-level bureaucracy leads the decision process with 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 the particular time frame is determined by a technical agency (Irrigation Department). This predetermination by a technical 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 [48, 59].

The changing nature of the political, social and cultural landscape has impacted the agricultural societies of Sri Lanka [62]. 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. 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 [37, 63].

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 [8, 22, 23, 32]. 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, FOs 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 [33]. 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 gaining their acceptability, trust and confidence in the information [21, 64]. 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 [65]. 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 [5, 6, 66]. 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 the 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 [34]. 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 [38]. 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 [24, 34, 38].

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 [67]. The tank cascade systems such as Palugaswewa are multifunctional, offering ecosystem services beyond food production and involving multiple stakeholders [13]. 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 [68, 69]. 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 [24, 34, 70]. 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 [1, 71, 72]. 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 [13].

4.3 Conclusions

We aimed to explore evidence for ACM in the agricultural decision process associated with Palugaswewa STCS, following the ACM diagnostic framework of [31]. 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. However, variations in governance arrangements between parts of the STCS were found that influenced seasonal decision-making. 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). While farmers recognised the need to adapt to climatic conditions, 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 [63, 73].

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 the 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) is 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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Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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