Governance Issues for Sustainable Management of Village Irrigation in the Dry Zone of Sri Lanka

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Summary

Village irrigation systems (ViSs) are vital in rural livelihood, food, and water security. VISs include small (minor) tanks and diversions (anicuts). The hydrologically linked tanks with natural drainage patterns form cascades, and beyond food and water security, they play a significant role in mitigating flood and drought impacts on communities in river basins. With anthropogenic changes, many cascades are in depilated states now. This paper finds that policy support with legal recognition to cascade-based community-level institutions promote bottom-up water and natural resources management approaches. They also facilitate investigations of ill-defined subject areas in cascade management and complex socio-political and economic issues and challenges constraining sustainable cascade based VISs operations.

1. Introduction

1.1 The role of village irrigation in water resources management

Village irrigation systems (VIS) were a vital component of the ancient hydraulic civilization of Sri Lanka. Despite the collapse of this civilization in the 13th century, VISs remained the center of social *organization* and management of local resources by the village community at the subsistence level (Kenyon et al., 2004) until the British colonial times. Traditionally, the villagers managed these systems comprised of small reservoirs (*tanks*) and diversions (*anicuts*). The village irrigation systems are also called minor irrigation tanks. VISs are not only production systems, but they are considered social, economic, and cultural systems.

VIS includes isolated *tanks* and those clustered in "cascades." The latter is a chain of small reservoirs connected hydrologically using a natural drainage pattern (Panabokke, 2009). Over 70 percent of small tanks in major river basins in the dry zone are clustered into cascades. This connectivity in a cascade enables the reuse of water several times, which is a good water management strategy for addressing recurring droughts (Madduma Bandara, 2009). The cascade system also helps to maintain groundwater in relatively larger surface areas. Studies also demonstrate their ability to mitigate floods (Perera et al. 2020). Therefore, the cascades have the potential to adapt to current climate change impacts characterized by high-intensity rains and longer dry periods.

Since the cascade systems consisted of hydrologically interconnected tanks, ad-hoc interventions targeting isolated tanks have created many problems in the past affecting the sustainability of the cascade system. This paper proposes measures to improve the sustainability of VIS with a focus on cascades. The proposals are based on analyzing past lessons and the status of VIS and cascade.

1.2 A synopsis of village irrigation systems

There are 14,421 *tanks* and 12,773 *anicuts* in working order (DAD 2023). VISs account for 45% of total lands under irrigation. The total number of farmers benefiting from VIS (excluding small anicuts systems) is little more than 300,000 (DAS, 2000). A database prepared by the UNDP and the Department of Agrarian Development in 2017 indicates a density of about one *tank* per 1.02 km^2 in the Northwestern Province (NWP) and one *tank* per 2.16 km^2 in the North Central Province (NCP), including both working and non-working *tanks*.

About 25% of the paddy lands cultivated in 2021/22 are under minor irrigation (DCS 2023), indicating the input to rural food security. When non-agricultural benefits, including domestic water supply, fisheries, livestock needs, and environmental services are also considered, village tanks perform a significant social and economic function.

Small *tanks* are heavily present in about 70 river basins (Panabokke et al*.,* 2002). 90% of the cascade systems are in 27 river basins (Dharmasena, 2019). Madduma Bandara (1985) defined the cascade as "a connected series of village irrigation tanks organized within a micro- (or meso-) catchment of the dry zone landscape, storing, conveying and utilizing water from an ephemeral rivulet." Panabokke (cited in Sakthivadivel et al. (1997) recommended that 'micro-catchment' be replaced by 'meso-catchment' and ephemeral rivulet be replaced by either 'second-order inland valley' or 'first-order ephemeral stream'. A modification introduced by Dharmasena (2019) describes them as "An ecosystem, where water and land resources are organized within the micro-catchments of the dry zone landscape, providing basic needs to human, floral and faunal communities through water, soil, air, and vegetation with human intervention on a sustainable basis". Perera et al. (2020) focusing on the hydrological principles behind the formation of *tank* bunds in a cascade, define it as" …an autogenic runoff harvesting technique consisting of strategically located series of bunds in shallow valleys of a small catchment for storing water while increasing the ability to regulate peak flows experienced over time." In summary, different definitions of cascades cited above indicate several components serve social, technical, and ecological services.

1.3 Current issues and challenges

1.3.1 Environmental degradation

The ancient land use planning recognized the connectivity among land, water, and human activities with due regard to nature-based solutions. This supported the ecosystem services provided by the cascades. Recent observations show that the erosion of rainfed uplands and home gardens contributes to silting in the tanks and decreases the productivity and water infiltration rates of eroded lands (JICA and Nippon Koei, 2000). Farmers often encroached on tank catchments, spill tail canals, and drainage canals in cascades, thus disrupting the erosion, evaporation, flood, and water-logging control functions of the cascade ecosystem.

Overall, water quality decreases in the dry periods (Cooray et al*.,* 2019). Water-related health issues, including chronic kidney disease of unknown etiology (CKDu) affect climate resilience, reduce the community's engagement in economically productive activities, and increase poverty.

1.3.2 Rehabilitation and maintenance of village irrigation systems

The rehabilitation of irrigation systems has been given prominence since the mid-1980s, and many such projects focusing on specific geographic areas and village irrigation were implemented in the country (World Bank 1981). However, post-rehabilitation maintenance remains a concern and affects the sustainability of investments in rehabilitation. A deteriorated sense of community ownership of the rehabilitated irrigation infrastructure provided little incentives for their maintenance (Abeyratne 1990). The World Bank (1999) raised concerns about the sustainability of the rehabilitation benefits without increased financial support for operation and maintenance (O&M).

Decreased income from the irrigated command and the emergence of alternative sources of income have contributed to the inadequate priority for VIS maintenance. Fragmentation of land, complex land tenure patterns, low profitability of paddy cultivation, and water scarcity in the dry season (sometimes resulting from the unauthorized increase of irrigated command in the wet season compared to the designed command area) are noted to reduce income from the irrigated area. Alternative sources of income include diversified cropping outside the irrigated command supported by agro-wells, livestock, and inland fisheries. A major strategy to cope with the loss of income from village irrigation, especially by male farmers, is engaging in off-farm activities (Aheeyar, 2015, Gunatilake, 2015). Anecdotal evidence shows that such migration results in poor maintenance of irrigation systems.

1.3.3 Inadequacies of the current water governance system

Current governance arrangements are inadequate to address major issues listed above, despite many government institutions providing various services required by the community. Moreover, it is often found that the responsibility for different services such as rehabilitation, water management, and agriculture extension lie with different government organizations and is mandated by different legislation. While inadequate maintenance and environmental degradation of the catchments affect the sustainability of village irrigation, there is no mechanism to engage the whole set of water users to address these issues. Although many rehabilitation projects promise institutional changes, usually prominence is given to infrastructural development during the implementation. One of the lessons learned from rehabilitation is that it should be preceded by institutional and agricultural policy reforms (World Bank 1981).

Considering the relevance of governance to many of the issues challenging the sustainability of village irrigation, we studied the evolution of their governance to learn lessons useful for improving the current situation.

2. Evolution of water governance in village irrigation

Historical Buddhist literature shows that private individuals, the community, and the state-owned irrigation works existed collectively before the 13th century (Gunawardana, 1971, Abeywardana et al., 2018). Particularly, the state was responsible for constructing major irrigation works, though it did not maintain ownership of them. Buddhist monasteries controlled a section of irrigation works obtained through donations and purchases and generally could maintain their irrigation works (Abeywardana et al., 2018).

A powerful bureaucracy guided by numerous rules, customary regulations, and sanctions managed VISs through 'Gamsabawa' (Village Council). The community-led indigenous institutions constructed, operated, and maintained the Tank systems (Panabokke, 2009). Such institutions formulated methods to raise the incomes of the community through fisheries and aquatic plants and mechanisms to share water based on property rights within the tank's command. They managed the ecosystem associated with irrigation infrastructure. The equitable right to water was central in all decisions about irrigation and cropping systems (Leach, 1980).

The ancient cascades contained tanks serving different purposes such as agriculture, groundwater recharge, wildlife needs, silt-trapping, and an ecosystem of several environmental components. The sustainability of the cascade system depended on ensuring these distinct functions of the different tanks and their ecological components. Therefore, it is reasonable to assume that the ancient village irrigation management system extended beyond the *tank* to the cascade. This management system could have been informal, "cellular" rather than centrally administered (Leach, 1959). Although the cascade management system is not well documented, a few inscriptions provide evidence that water management based on the "Cascade Tank-Village System" was introduced in the 3rd century BC and had uninterrupted expansion and development until the 13th Century AD. The fully developed cascades were governed by a hierarchical but durable governance system, under which the King, community, and leaders had different responsibilities, with fees and sanctions for water use (Melles and Perera, 2020).

The hydraulic civilization in Sri Lanka's Dry Zone collapsed after the 13th century and was never restored. The disintegration of the irrigation governance structure due to foreign invasions, the spread of malaria, and climatic reasons (Gunawardana, 1971, Wijesundere and Ramasamy, 2017) have complemented each other in this collapse. However, the ancient irrigation governance depended on several centers of decision-making that were reasonably independent of each other. These polycentric elements in the ancient governance system enabled the continuity of village irrigation infrastructure during the post-hydraulic civilization period (Abeywardana et al., 2018), which may have been administered by the temples, and local nobles (Kenyon et al. 2004).

Sweeping changes to the traditional governance system were implemented during the British rule following the Colebrook reforms (1829-1832), which weakened the traditional governance system and pruned down its judiciary powers (Abeywardana et al., 2018). Although several reasons are cited for these actions, making the traditional institutions dysfunctional without providing an alternative arrangement has significantly contributed to the deterioration of irrigation systems (Roberts, 1980; Silva and Vidanapathirana, 1984), and disrupted the holistic management of the *tank*, paddy, and forest areas including pasture lands, and associated agriculture-based economic activities (Panabokke et al., 2002).

The resulting severe impacts on the rural economy (Perera, 1955) and national economy (Silva and Vidanapathirana, 1984) prompted the authorities to improve domestic peasant agriculture in the later part of the 19th century (Farmer 1957). However, Abeyratne (1990) noted that government interventions in VISs since the mid-19th century adversely affected them being 'farmer-managed'. Although some governance arrangements were introduced occasionally, they did not help improve sustainable cascade management.

The above discussion shows that the polycentric elements in ancient governance helped the continuity of village irrigation when one center of decision-making malfunctioned. However, recent developments did not retain all such elements. An analysis of the current state of governance was carried out to form a base for formulating an improved governance system.

3. Status of governance in cascade systems and opportunities for improvement

3.1 Current state of cascade systems using Social-technical-ecological- systems (STES) approach

The STES primarily consists of three domains:

- The social domain includes institutions, laws, regulations, standards, participation and collaboration, knowledge transfer, and economic mechanisms.
- The technological domain consists of design standards and codes, infrastructure construction, operation and maintenance, and developing and implementing data-driven solutions.

- The ecological domain comprises conservation, preservation, and restoration of ecological systems, green infrastructure, and ecological services (Ahlborg et al., (2019).

Ariyaningsih and Shaw (2022) show that an analysis based on the three domains helps to understand the state of flood management in a city in Indonesia and facilitates the preparation of effective flood risk management solutions. Different definitions of cascades cited above have given prominence to social, ecological, and technical aspects such as hydrological connectivity and flood mitigation potential. Therefore, STES is a convenient concept for analyzing the state of a cascade system and making informed decisions leading to sustainability.

The STES concept in cascade systems is not entirely new. It is noted that traditional technologies formed a part of a more comprehensive ecological and social system, which made the cascades function sustainably, and changes to socio-economical-environmental settings affected the cascade's technical functions (Madduma Bandara, 2009). The STES domains of a cascade system described below will help to understand the domains' current state and interdependencies.

Social Domain:

The laws and regulations include the following:

- **The Agrarian Development Act of 2000** covers issues such as tenant farmers' rights, Agrarian Tribunals (for resolving disputes), use of agricultural lands, formation and registration of farmer organizations (FOs) providing legal authority, holding meetings, minor irrigation development, and management within FO areas. This Act defined irrigation schemes commanding less than 200 acres (80 ha) as "Minor Irrigation Schemes" (FAO, 2023).

- **The Irrigation Ordnance (**LAWNET 2016) addresses matters such as the District Agricultural Committee, meetings of proprietors, construction, and maintenance of irrigation works, special provisions applicable to major irrigation works and minor irrigation, protection of irrigation works, and dealing with offenses, among others.
- **Other laws** applicable to village irrigation cover land administration, environmental management, flood management, provincial statutes, etc.

The institutions relevant to the village irrigation system include the following:

- **DAD** deals with the implementation of matters relating to the Agrarian Development Act
- **Provincial Councils (PC)** were devolved with technical matters such as agriculture and irrigation within the province by the 13th Amendment to the Constitution in 1987. Some PCs have gazetted their irrigation functions and are legally empowered to carry out such functions including disaster risk reduction, irrigation works, agriculture, and water supply.
- **Irrigation Department** when a tank serving a command area larger than 80 ha is in a cascade in an inter-provincial river basin.
- **The District Secretary** (head of district administration) and **Divisional Secretary** (head of divisional administration) are empowered by several laws related to irrigation to carry out functions related to land and conservation of the environment.
- Many other institutions deal with services for the people, including drinking water, groundwater, fisheries, livestock, agriculture, credit, insurance, micro-credit, environmental conservation, disaster management, etc.
- **Community organizations,** including farmer organizations, women's organizations, fisheries societies, and domestic water user organizations.

- **The private sector**, which plays a major role in providing agricultural inputs and markets for the produce,
- **Guaranteed price schemes** such as purchasing paddy at a guaranteed price through the Paddy Marketing Board that stabilize the prices.

The community organizations are affiliated with different government institutions and operate mostly at the village level. The responsibility of community organizations in ecosystem management is vague or given a low priority in their operational arrangements.

Ecological domain:

As per Dharmasena (2010), the traditional tank ecological domain included (among others):

- Upstream tree belt and sediment filter,
- Soil ridges, water holes, and small tanks to trap sediment and provide water for wild animals and cattle,
- Drainage canal,
- Downstream reservation or the interceptor, hamlet buffer, assigned portion of land for protection from birds and pest damage.

The efficient functioning of these ecosystem components, within the constraints imposed by the current socio-economic environment, is a governing factor in addressing the impacts of climate change. For example, the tree belt in the upstream reservation in the traditional VIS acts as a wind barrier and reduces evaporation from the Tank surface. It also facilitates vegetation growth among the trees, controls runoff, and improves groundwater recharge. The vegetation and artificial soil ridges trap sediment inflow to the Tank. Controlling sedimentation helps maintain the Tank's water retention capacity and thereby mitigates the effects of floods and droughts. Aquatic plants in the Tank's upper periphery help trap nutrients flowing with agricultural drainage (Mahatantila *et al*., 2008). The dead storage of a tank retains some water after the irrigation season, helps to recharge groundwater during the dry periods, and maintains the water level of nearby wells. The upstream Tanks in the forest area provide water for wildlife, thereby minimizing human-wildlife conflicts. The reservations provide grazing ground for the livestock as well.

Furthermore, Downstream reservation acts as an interceptor to retard the flow of undesirable salts to the command area. Properly functioning drainage canals prevent waterlogging and soil salinization and facilitate water reuse. The tank and the ecosystem provide fish, fuel wood, fruits, vegetables, and the material for cottage industries (Dharmasena, 2010).

Technical domain:

The technical domain includes the standards to carry out technical functions, such as

- Technical guidelines and design standards provided by the Irrigation Department and other mandated institutions.
- Circulars are issued by government institutions to carry out specific tasks such as de-silting.
- Climate-smart agriculture guidelines and agriculture extension methodologies

- Mathematical models, weather forecasts, and other technical tools that facilitate improved decision-making in water management.

Main infrastructure components include the Tank bund, sluices, spillways, and riprap for large bunds. Operation and maintenance of these infrastructures are generally carried out by the farmers with certain input from the relevant government institutions, especially when the cost of infrastructural improvements is beyond the reach of the community.

3.2. The state of cascade management in the context of three domains

Figure 1 explains how the three domains interact and influence each other in a cascade system in a pluralistic manner. This interconnectedness implies that isolated interventions in any of the domains can be detrimental to the system's efficient functioning, as verified by previous studies. Abeyratne (1990) pointed out that inadequate coordination between the implementing institutions and beneficiaries threatens the sustainability of the benefits of a rehabilitation project. Aheeyar and Smith (1999) noted that adopting a sectoral approach to solving complex irrigation problems has adverse effects on the environment and recommend a multidisciplinary and integrated approach to irrigation development. The Climate Resilient Integrated Water Management Project's (CRIWMP) preliminary investigation surveys in Anuradhapura in 2017 showed that tapping spill water of an upstream tank by downstream farmers without properly designed control structures, water-sharing agreements, and disaster response mechanisms has led to conflicts among farmers and increased flood risk.

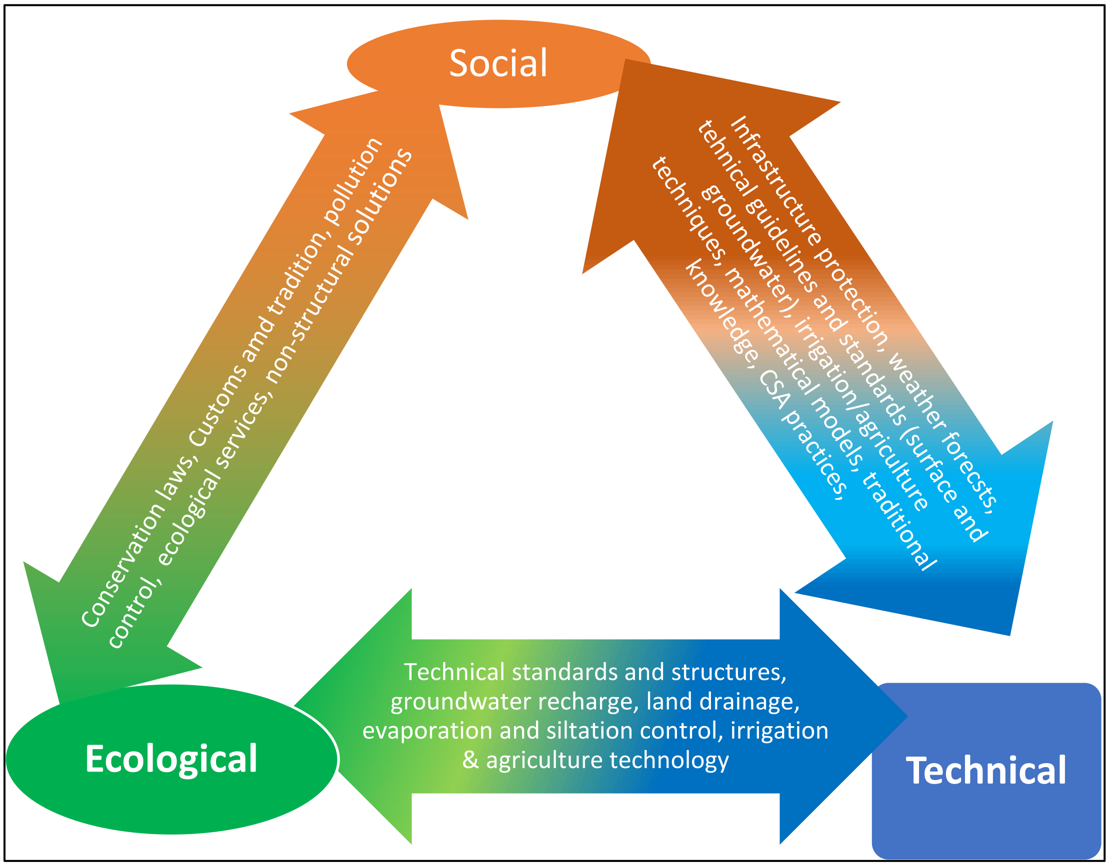

Figure 1: Interactions among different domains of a cascade system

Although technical tools, including computer models are available to make decisions on sharing water equitably among users, there is no institutional mechanism to use such opportunities for the entire population in the cascade. For example, the field observations of CRIWMP showed that four cascades in Vavuniya have been joined by tapping drainage and spill water, enabling increased reuse of water. However, the lack of an institution to use the technical tools and make water-sharing decisions at the cascade level hinders the optimum realization of this potential. Therefore, sectoral decision-making within a complex legal and bureaucratic system with a confusing array of overlaps and gaps continues to be unproductive. It constrains women and youth from contributing to water management and associated resources and different community-based water user organizations to have a collective action for optimal water sharing.

This implies that the current governance modality cannot achieve the cascades' development potential or make them sustainable, and this is one of the root causes of vulnerability.

3.3 . Need for transformative adaptation of cascade systems to climate change

Fedele et al. (2019) describe coping strategies as enabling the community to maintain the affected system in an unchanged state despite the impacts of climate change. Incremental adaptation strategies make small-scale adjustments to the system without altering its fundamental characteristics so that the people are resilient to the current impact. However, the potential for coping strategies or incremental adaptation to reduce future vulnerability is small because the fundamental characteristics of the system do not change. Several irrigation rehabilitation projects implemented since the 1980s contain a heavy proportion of incremental adaptation elements. Although many such projects have achieved their physical targets substantially, whether they have addressed the root causes of vulnerability in village irrigation is questionable.

Furthermore, unpredictability in seasonal weather patterns resulting from climate change increases the reliance on accurate weather forecasts. Many technical standards need modification due to changes in flood frequency and other hydrological parameters. Considering the impact of climate change on crops, climate-smart agriculture practices (CSA) are becoming increasingly relevant. Above all, the cascades need to be managed in an integrated manner.

Conventional coping strategies and incremental adaptation to climate change are unlikely to reduce the vulnerabilities of the communities engaged in village irrigation. Instead, a systemic transformation to adapt to climate change addressing the root causes of vulnerability is required. Fedele et al. 2019 describe "transformative adaptation" as those with restructuring, path-shifting, innovative, multiscale, systemwide, and persistent characteristics.

3.4 Need for polycentric governance.

A polycentric system engages multiple governing authorities that do not possess a hierarchical relationship with each other (Morrison et al., 2019). These authorities may operate at different scales while making mutual adjustments. Oberlack et al. (2018) noted that "governance systems are polycentric if they involve multiple arenas of decision making, which operate with some degree of autonomy but are interlinked through processes of cooperation, coordination, or conflict". Gelcich (2014) notes that a polycentric governance system could reduce the probability of failure throughout a region through smaller-scale successes. This is very relevant to Sri Lanka, as demonstrated by the survival of village irrigation during the failures of the central government due to polycentric elements in ancient governance systems.

In ancient times, cascades operated as mostly isolated and self-sufficient systems, which depended substantially on local resources and were mainly community-managed. They served multiple uses, and village life depended on the complementary services of rain-fed and irrigated agriculture. However, the analysis of the current social domain shows that many government institutions at national, provincial, and district scales are involved in managing the cascades. The essential needs such as drinking water, health, agricultural inputs, marketing, protection from wild animals, land use, etc., are provided by institutions including the private sector. Market forces govern the community's income. The farming community is also affected by human-elephant conflict, and they need the support of government institutions to maintain life and livelihoods.

A polycentric governance system can bring the actors operating at different scales and within social, ecological, and technical domains to a common forum. Abeyratne (1990) and Kekulandala et al. (2020) emphasized the need for an improved governance arrangement considering the multi-functional nature of cascade systems and to avoid potential conflicts in the resource use and management of infrastructure. Madduma Bandara (2009) highlighted the need for a management structure encompassing the entire cascade to achieve the potential benefits of cascade water management. While there could be elements in the ancient governance system that made the cascades function efficiently, the mechanisms such as compulsory labour cannot be reactivated. Therefore, the current situation calls for a systemic transformation of cascade governance.

Accordingly, we examine a few recent interventions for their polycentric governance and transformative adaptation elements and any barriers to their sustainability.

4. Conceptual approach of recent development projects

4.1 Adoption of a "cascade approach"

Panabokke et al. (2002) pointed out that changing the hydrology of a few Tanks in a cascade impacts the entire cascade. As such, a hydrological assessment of the cascade should precede interventions on selected tanks. Sakthivadivel et al. (1997) noted that the shift of emphasis from Tank to cascade took place in the mid-1980s. Meaningful attempts to incorporate this concept into development planning took some more time. One example is the Cascade-based small tanks rehabilitation project in the Anuradhapura district in 2004-2010 implemented by Plan Sri Lanka. Subsequently, Hong Kong and Shanghai Banking Corporation Limited (HSBC), in partnership with the International Union for Conservation of Nature (IUCN) implemented a cascade-focused project to enhance rural livelihoods and environmental Services in Kapirikgama cascade in the Anuradhapura District (MMDE, 2016). This project gave due consideration to the cascade ecosystem, which could be considered a further advancement from the cascade-hydrology model (Dharmasena, 2019).

The Climate Resilient Integrated Water Management Project (CRIWMP), implemented from 2017 to 2024 by the Ministry of Irrigation with technical assistance from UNDP and funding support from the Green Climate Fund (GCF), is a pioneering effort to identify cascade-based village irrigation systems as a planning, development, and water management unit within a river basin. The studies leading to project formulation identified poverty, the incidence of CKDu, and floods and droughts are among the main issues contributing to the vulnerability of the Dry Zone farmers to climate change. The interventions included upgrading irrigation systems, restoring cascade ecosystem components and their maintenance arrangements, converting weather advisories into improved agricultural advisories and using them for cultivation planning, modeling complicated water balance in cascade systems, and promoting CSA, drinking water management, and groundwater management.

The Climate Smart Irrigated Agriculture Project (CSIAP) aims to improve the productivity and climate resilience of the smallholder agriculture sector in selected vulnerable areas (World Bank 2019). The Project is implemented from 2019-2024 by the Ministry of Agriculture with funding support from the World Bank. Novel approaches adopted by the project include river basin level hydrological assessments, considering future climate vulnerability, and identifying "hot spot" areas including cascades. A hotspot area is identified based on the exposure and vulnerability to increasing climate variability determined by drought and flood impacts, and current and future climate vulnerability. The interventions focused on improving agriculture production, marketing, and irrigation systems through rehabilitation, operation, and maintenance.

4.2. Institutional arrangements proposed for cascade management

A common intervention with polycentric governance elements in both CSIAP and CRIWMP is the formulation of a Cascade Management Committee (CMC). The CRIWMP's project proposal recommends cascade-level water management committees to enhance climate resilience, optimally utilize water resources, multi-stakeholder planning, promote conflict resolution, and improve water-sharing between individual tanks and *anicuts* for multiple uses (MMDE, 2016). The CSIAP intends to create the CMC to ensure that individual tanks are managed in the wider context of the system. The committees comprising key stakeholder agencies and users are expected to be the main entry point for water management within a watershed (World Bank, 2019). The CMC has the potential to bring in production entities in a cascade such as a command area, home gardens, livestock, and fisheries to a common forum so that the resources available for the maintenance of water infrastructure are increased. The committee can facilitate the participation of women and youth in the resources management process. When fully implemented, it will promote polycentric governance through the engagement of actors at national, provincial, district, and local levels into one forum and has the potential to resolve issues arising from different institutions managing water within a cascade. However, this institutional framework is only partially implemented at present due to several reasons including inadequate legal and policy support.

4.3 Integrated management model proposed by the CRIWMP

A unique feature of the CRIWMP is developing an integrated plan to manage water resources and the associated natural resources at the cascade level. The thinking of several scholars in the field of Tank-cascade development influences this plan. The main thematic areas of the plan include (a) Upgrading the village irrigation system in a climate-resilient manner, (b) an agriculture development plan with CSA principles, (c) operation, maintenance of VIS and disaster response, (d) environmental management and catchment conservation, (e) drinking water management (f) groundwater management, and (g) an institutional framework for cascade management.

The concept of the integrated management plan of CRIWMP, which facilitates linkage between social, environmental, and technological domains of a cascade, is schematically described in Figure 2.

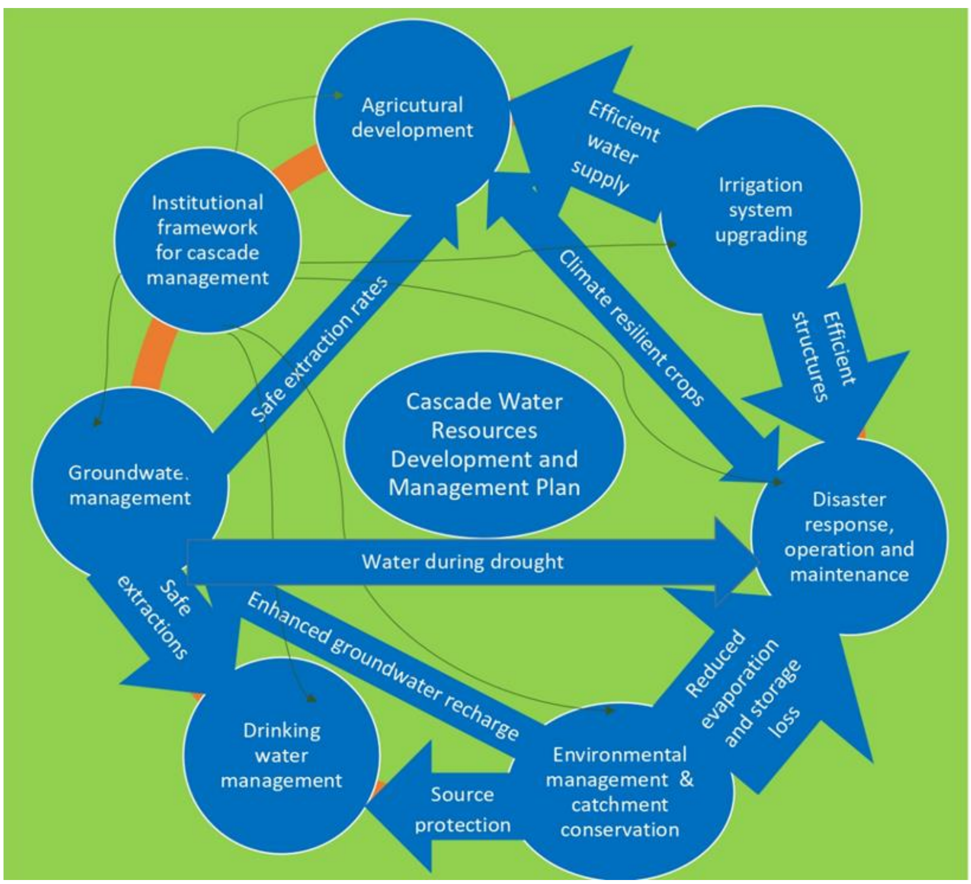

Figure 2: The concept of the integrated management plan of CRIWMP

4.4 Barriers to Implementing Transformative Adaptation Options

An inadequate enabling environment (policy and legal backing) was one of the major barriers to establishing functional CMCs. Although making the participation of key actors in the agriculture sector through existing mechanisms such as seasonal cultivation meetings and the District Agriculture Committee is possible, current policies do not support the participation of different water users outside agriculture in such forums. Some potential barriers among different tank-based communities to facilitate transformative adaptation in village irrigation are many government institutions providing services to the community, administrative boundaries not coinciding with hydrological boundaries, competition within the community for scarce resources, inefficient village-level community organizations, and inadequate social cohesion.

5. Conclusions and policy recommendations

The discussion demonstrates that a cascade has inherent advantages to be used as an integrated management model, as its hydrological linkages make it a suitable unit for water management. As an ecosystem providing multiple services, it has the potential to promote integrated water resources management with a "bottom-up" approach. The scientific basis of some traditional elements of a cascade implies that sustainable development of cascades must be carried out using an appropriate mix of traditional knowledge and modern technology. Analyzing the cascades in an STES framework enables an understanding of the status, its functional gaps, and overlaps. It facilitates making the more specific and targeted inputs from social scientists, economists, environmentalists, engineers, etc.

We have observed some transformative adaptation elements in current interventions. They include the development and management plans that incorporate surface and groundwater resources, multiple water uses, new technologies, including CSA, and restoration of selected traditional features, into integrated solutions. A new institutional setup should encourage interested members of the community, especially the youth, to engage in commercial farming and to introduce improved business practices and partnerships with due regard to environmental management and user rights of other farmers. It has the potential to address issues such as the inadequate representation of women in decision-making, improved vertical and horizontal linkages across the community and government institutions, and the under-representation of tenant farmers and non-agricultural water users in the current institutional setup. Grouping the production of a larger number of smallholders can influence the markets better, and it would be easier to achieve the cascade’s potential to mitigate droughts and floods. The feasibility of linking off-farm incomes and attracting external financial support to cascade system management should be further studied.

The formal recognition of the cascade-based community institution by government policies and legislation will directly address some of the barriers to sustainability and facilitate detailed investigations into achieving the full potential of a cascade system. Setting the goals, objectives, scope, and accountability aspects of such an organization should be designed with the involvement of government institutions handling matters such as agriculture, irrigation, forestry, wildlife, and drinking water. This will lead to a polycentric governance model at the cascade level, in which the community's role will increase with their economic development. Different development projects have attempted different models such as producer groups, cooperatives, and farmer companies and their suitability for economic empowerment of the community at the cascade level should be studied for adoption.

It is noted that a considerable number of isolated tanks exist, and they should not be left out of the development process. Besides, the impact of interventions such as improved water management, cropping patterns, and groundwater recharge and utilization extends beyond the cascade boundaries. As such, any water resource developments should be carried out with a proper hydrological assessment extending beyond the cascade. A sub-basin (consisting of several cascades, isolated tanks, and *anicuts*) can be used as a development planning unit. In contrast, the cascade can be used as a water and agriculture management unit. Such an arrangement can optimize in-basin water resource use and reduce adverse impacts on downstream users and the environment due to excessive utilization of cascade water resources.

Eventually, a cascade's hydrology, livelihoods, and natural resources should be recognized in river basin management plans. Understanding cascade hydrology will help river basin planners assess the potential for in-basin water resource development. Suppose the conceptual model for cascade management described above is successful and recognized in river basin management. In that case, it will constitute a bottom-up approach to river basin management and integrated natural resources management.

This will, however, require strong policy and legal support. Besides, the political will to opt for long-term, sustainable solutions is also essential for success. It will be challenging because the current global economic downturn can make immediate and short-term solutions more attractive. Meaningful discussions among the researchers, decision-makers, donors, and subject-matter specialists to formulate strategies to overcome the identified barriers are also essential. However, the preceding discussion highlights that the cascade systems will not be sustained without addressing the root causes of vulnerability through a transformative adaptation approach. Therefore, the commitment of all the interested parties is required. Therefore, the accountability of implementing the governance changes envisaged at the planning stage of development projects should be asserted.

Considering the above analysis, the following recommendations can be made to the policymakers:

1. Policy support followed by legal recognition should be provided to establish community-based institutions at the cascade level. This will enable increased bottom-up approaches in water and natural resources management and facilitate investigations into ill-defined subject areas in cascade management and complex socio-political and economic issues and challenges.
2. Water resources development is to be planned with due consideration of a river basin level water resources assessment, which can show the cumulative impacts of any modification to water use

anywhere in the basin. Such an analysis can identify whether there is a need for inter-basin water transfers.

3. If the entire river basin cannot be taken up as the spatial unit for water resources planning and development, a sub-basin (sub-watershed) can be selected. The cascade shall be the primary spatial unit for water management in river basins where cascades are predominantly present.
4. Water resources management policies should recognize the importance and relevance of polycentric governance and transformative adaptation to make cascade systems sustainably climate-resilient managed by empowered communities.

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