AGENT-BASED MODELING FOR SUSTAINABLE WATER RESOURCE PLANNING: INSIGHTS FROM THE VILLAGE TANK CASCADE SYSTEM

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Abstract: Village Tank Cascade Systems (VTCSs) in Sri Lanka represent long-standing, community-managed irrigation systems that operate through tightly coupled hydrological, agricultural, and governance interactions. This study applies an Agent-Based Modelling (ABM) approach as an analytical framework to examine water-sharing dynamics within a representative VTCS in Sri Lanka, using a selected tank cascade as a case-based illustration for identify the complexity of the system. Rather than generating predictive estimates for modelling, the study focuses on hypothetical case for application of ABM through the understanding of the complexity of the VTCS. The analysis compares non-sharing and proportional water-sharing arrangements under identical climatic conditions to explore how governance rules influence storage distribution and cultivation outcomes. Increasing climatic variability, particularly during the Yala season, intensifies water scarcity within cascades, while the results show that governance-based redistribution of upstream storage reduces downstream vulnerability during water-scarce periods through adaptive and sustainable decision-making. The findings highlight the central role of governance in shaping how scarcity is managed within VTCSs and demonstrate the usefulness of ABM for exploring adaptive, people-centred water-sharing arrangements which highlights Sri Lanka's traditional irrigation system's sustainable use of water governance and demonstrates how interaction-based analysis can support adaptive, equitable water-sharing governance in interconnected tank cascade systems.

Keywords: *Village Tank Cascade System, Agent-Based Modeling, Water Governance, Socio-Hydrological Systems, Climate Variability*

1. Introduction

Village Tank Cascade Systems (VTCS) constitute one of the most advanced forms of traditional water resource management in Sri Lanka's Dry Zone. A VTCS is composed of a series of small, human-made reservoirs that are hydrologically interconnected within a micro-catchment and typically arranged in an upstream–downstream sequence. These systems were historically developed to capture seasonal monsoonal rainfall, regulate runoff, and redistribute water across spatially and temporally in an environment which marked by prolonged dry periods and high climatic uncertainty (Panabokke et al., 2001). Crucially, tanks within a cascade do not function as isolated irrigation units that instead, it operates as an integrated system in which storage, release, and overflow processes at upstream tanks directly influence water availability in downstream tanks. This cascading configuration has enabled Dry Zone agrarian communities to sustain agricultural production and livelihoods over centuries despite persistent water scarcity (Bandara, 2009).

The hydrological functioning of a VTCS is governed by complex surface and subsurface interactions. Rainfall received in upper catchments is first stored in head-end tanks, after which controlled releases and overflow transfers convey water to midstream and tail-end tanks. In addition to surface flows which seepage and return flows contribute to groundwater recharge and baseflow, strengthening water availability across the cascade landscape (Jayatilaka et al., 2003). Consequently, water storage at any given tank is shaped not only by local rainfall but also by upstream storage behaviour and release decisions. This strong hydrological connectivity creates spatial interdependencies, whereby interventions at one location can generate cascading effects throughout the system (Indika et al., 2024). Beyond irrigation, VTCSs function as multifunctional socio-ecological systems that provide a wide range of ecological, economic, and social benefits that tanks support groundwater recharge, sediment retention, nutrient cycling, and biodiversity conservation, effectively acting as landscape-scale ecological infrastructure (Geekiyanage & Pushpakumara, 2013). At the same time, VTCSs underpin diverse livelihood activities which including paddy cultivation, inland fisheries, livestock rearing, and domestic water use, making them central to food security and rural well-being (Ratnayake et al., 2021). The distribution and sustainability of these benefits are shaped by locally embedded governance arrangements which includes customary water-sharing practices and collective maintenance systems, which regulate access to a shared and finite resource base (Sirimanna & Prasada, 2021).

The importance of VTCSs is further intensified by the climatic characteristics of Sri Lanka's Dry Zone where rainfall is highly seasonal, with the Maha season delivering the majority of annual precipitation and the Yala season frequently characterised by acute water scarcity. Climate change has amplified this variability which increases the frequency of droughts, altering rainfall timing, and heightening uncertainty in water availability (Ranasinghe et al., 2023). Under such

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conditions, water-related risks are unevenly distributed within cascades which often disadvantaging downstream users and smallholder farmers which these pressures expose vulnerabilities in existing water-sharing arrangements and challenge the long-term capacity of VTCSs to maintain equitable and reliable access to water (Vidanage et al., 2022). Taken together, VTCSs exhibit a high degree of socio-hydrological complexity where water availability and use emerge from interactions among hydrologically connected tanks, heterogeneous users with differing landholdings and demands, seasonal variability, and governance rules that regulate allocation (Bandara, 2009). These interactions generate feedbacks and non-linear outcomes which cannot be adequately captured through conventional, top-down analytical approaches that focused solely on aggregate water balances and addressing this challenge first requires a clear conceptual articulation of system complexity, highlighting how biophysical connectivity, multifunctional use, and governance processes that jointly shape water outcomes across the cascade (Sirimanna & Prasada, 2021).

To analytically engage with this complexity, this study adopts an agent-based modelling (ABM) approach which is particularly suited to systems in that collective outcomes arise from the interactions of individual actors operating within shared environmental and institutional constraints. In water resource planning, ABM has been widely recognised for its ability to represent heterogeneous users, spatial interdependencies, and governance-dependent decision-making within a unified analytical framework (Akhbari & Grigg, 2013). For VTCSs, where water flows, institutional arrangements, and farmer behaviour are tightly coupled which ABM provides a means of translating conceptual understanding of system complexity into a formal, interaction-based representation (Berglund, 2015).

Accordingly, this research objective is to apply an agent-based model to a Village Tank Cascade System located in Sri Lanka's Dry Zone, using a single cascade as a case study to generate methodological insights. The emphasis is not on optimisation or broad generalisation, but on demonstrating how the complexity of VTCSs can be conceptually framed and analytically represented through bottom-up modelling of interconnected tanks, heterogeneous water users, and governance-dependent allocation processes. By integrating hydrological dynamics, seasonal variability, and community decision-making within an agent-based framework, the study illustrates the potential of ABM to support sustainable water resource planning in cascade-based systems facing increasing climatic and socio-institutional stress.

2. Literature review

Village Tank Cascade systems (VTCS) are one of ancient systems in societies which are increasingly understood as complex socio-hydrological systems in human decision-making, institutional rules, and biophysical processes are tightly coupled and evolve over time and such systems are characterised by heterogeneous actors, spatial interdependencies, feedback loops, and non-linear responses to climatic variability which mainly be adapted in dry and semi-arid regions (Brown et al., 2015). When discussing about the conventional hydrological or optimisation-based models which have been effective in representing physical water balances but are limited in their ability to capture behavioural diversity, negotiation processes, and adaptive decision-making under uncertainty. Consequently, recent water governance research emphasises the need for analytical approaches which can explicitly represent interactions among multiple actors operating within shared and dynamic environments (Akhbari & Grigg, 2013).

VTCS in Sri Lanka represent a clear example of a socio-hydrological system and it consist of a series of hydrologically linked small tanks arranged along a micro-catchment, where water flows sequentially from upstream to downstream tanks and is reused multiple times through spills, seepage, and return flows (Indika et al., 2024). These cascades function as integrated water-reuse systems rather than independent reservoirs which is optimising highly seasonal rainfall in the Dry Zone through collective storage and redistribution (Bandara, 2009). Decisions taken at upstream tanks directly influence downstream water availability which creating strong spatial interdependencies across the cascade (Jayatilaka et al., 2003). Also, eco-hydrological landscape components within the cascade such as "Gasgommana", "Kattakaduwa", "Perahana", and "Wew-thavula" play critical roles in reducing evaporation, filtering sediments, regulating salinity intrusion, and maintaining ecological stability. These features highlight that VTCS operate as adaptive, nature-based socio-ecological systems which have been built as irrigation infrastructure (Dharmasena, 2020).

Historically, VTCS operated through community-based institutional arrangements that aligned water-sharing practices with cascade hydrology, enabling farmers to adjust cultivation decisions in response to seasonal variability and collective water availability (Ariyawanshe et al., 2023). However, contemporary governance fragmentation which have weakened coordination across hydrologically connected tanks, and ongoing land-use and ecological changes have disrupted these adaptive mechanisms, intensifying upstream–downstream inequalities which have increased the vulnerability during dry-season cultivation (Ratnayake et al., 2023). While existing studies have examined that VTCS's hydrology, ecology, and policy dimensions in depth, comparatively limited attention has been given to explicitly which representing community behaviour, governance rules, negotiation processes, and their combined effects at the cascade scale. This gap is significant because VTCS outcomes emerge from interactions among heterogeneous actors operating under shared environmental constraints—conditions that cannot be adequately captured through aggregate indicators or single-tank analyses. Consequently, this interaction-driven complexity points to the relevance of analytical approaches that can explicitly represent individual actors, their interactions, and environmental feedbacks when examining its dynamics (Brown et al.,2015)

When talking about Agent-Based Modelling (ABM), it has emerged as a powerful framework for analysing complex socio-hydrological systems where outcomes arise from interactions among multiple actors operating within shared and dynamic environments (Bousquet & Le Page, 2004). In contrast to conventional hydrological or optimisation-based approaches that primarily focus on aggregate water balances, ABM enables the representation of distributed decision-making processes, interaction-driven dynamics, and adaptive behaviour under uncertainty. Within water resources planning, ABM has been increasingly applied to examine allocation conflicts, institutional arrangements, and decision-making processes shaped by environmental variability, demonstrating its capacity to explore trade-offs between efficiency, equity, and resilience in shared water systems (Fartassi et al., 2025).

ABM is a bottom-up modelling approach which has developed to analyse complex systems by representing them as collections of individuals, autonomous components. It's a system which is designed around a set of agents, an explicit environment, defined interaction mechanisms, and rule-based decision logic and each agent is modelled individually, with its own attributes, behaviours, and constraints, allowing heterogeneity to be explicitly represented (Berglund, 2015). Agents interact with one another and with their environment according to specified rules, and these interactions may evolve in response to internal decisions or external conditions and through repeated local interactions and feedback processes, system-level patterns such as cooperation, inequality, conflict, or resilience emerge without being directly imposed by the model structure (Bousquet & Le Page, 2004). Unlike aggregate, equation-based, or optimisation models, this ABM does not rely on equilibrium assumptions or representative behaviour which makes it particularly suitable for systems characterised by non-linearity, uncertainty, and path dependency (Berglund, 2015).

The modelling framework of ABM closely aligns with the operational characteristics of VTCS which function as complex socio-hydrological systems rather than as isolated hydraulic units and it involve multiple interacting components, including hydrologically connected tanks, heterogeneous water users, seasonal climate variability, and governance arrangements that shape allocation and sharing decisions (Brown et al., 2015). According to the reviewed literature, existing studies have largely relied on aggregate indicators, single-tank analyses, or static representations of system behaviour which those approaches often overlook how heterogeneous actors, spatial interactions, and governance rules jointly shape cascade-level outcomes that are particularly under seasonal variability and water scarcity (Berglund, 2015). This gap highlights the relevance of ABM as an analytical framework for VTCS which has its core components of heterogeneous agents, explicit environments, rule-based decision-making, interactions, and feedback loops, correspond closely to the operational realities of tank cascades. By enabling the exploration of how micro-level behaviours and institutional arrangements generate system-level patterns of equity, reliability, and stress, ABM offers a theoretically grounded approach for representing VTCS complexity and examining water-sharing dynamics that cannot be adequately captured through aggregate or single-tank analyses (Fartassi et al., 2025).

By integrating socio-institutional behaviour with hydrological processes, ABM offers a structured means of analysing VTCS as coupled human–natural systems. Rather than prescribing optimal solutions, ABM enables systematic exploration of interactions and emergent outcomes, supporting learning and decision-making for sustainable water resource planning in Sri Lanka's Dry Zone and comparable smallholder irrigation systems.

3. Methodology

3.1 CASE STUDY CONTEXT

The methodology is applied to a single VTCS located in Sri Lanka's Dry Zone which namely the Padipanchawa Village Tank Cascade System in the Galgamuwa area. The region experiences high seasonal rainfall variability, extended dry periods, and the cascade functions within a micro-catchment where water is stored, reused, and redistributed through hydrologically connected tanks via surface flows, seepage, and return flows. Both literature and local understanding have used to identify this system. This study adopts an exploratory and demonstrative methodological approach to examine how Agent-Based Modelling (ABM) can be applied to Village Tank Cascade Systems (VTCS) as an analytical demonstration that identifies key system interactions and illustrates how these interactions can be structured within an agent-based framework. As VTCS evolve dynamically across space and time, the analysis is situated within a clearly defined spatial and temporal case, representing a specific cascade during a particular seasonal period, to ground the conceptual and modelling exercise. and scenarios are used to demonstrate how ABM can be applied to explore water-sharing dynamics under varying conditions.

As shown in Figure 1, the Padipanchawa VTCS exhibits a clear upstream–downstream hydrological structure where Henwalagama Maha Wewa functions as an upstream tank, with flows progressing through a sequence of intermediate tanks to Medawachchi Wewa, which acts as a collector tank receiving inflows from multiple upstream sources. Water from Medawachchi Wewa, together with contributions from other upstream tanks within the cascade and selected adjacent cascades, is conveyed to Padipanchawa Wewa, which serves as a major receiving and redistribution tank. From

Padipanchawa Wewa, flows continue downstream to Pahalagama Wewa, after which water is transferred to another cascade, reflecting the interconnected and non-isolated nature of tank cascade systems in Sri Lanka's Dry Zone.

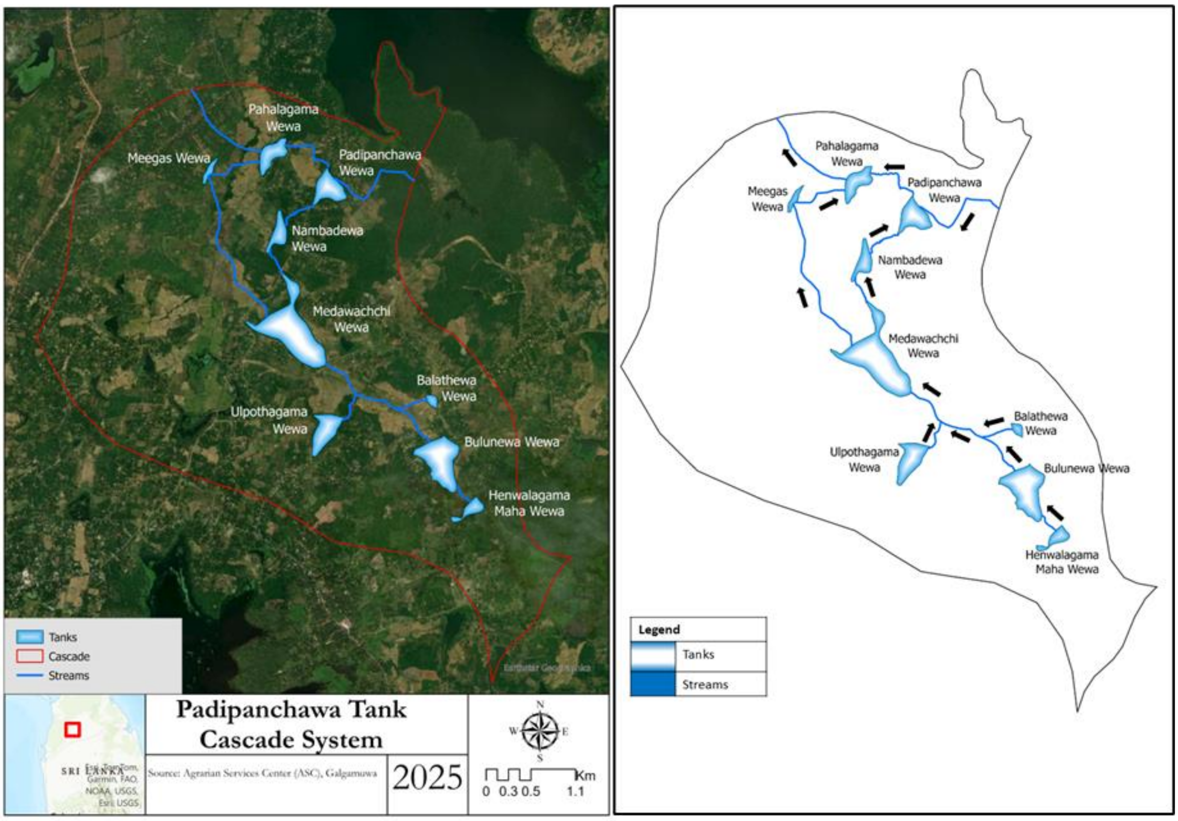

Figure 1: Study area *(Source: Compiled by author)*

3.2 CONCEPTUAL FRAMEWORK: FRAMING SYSTEM COMPLEXITY

The conceptual framework developed in this study identifies the core components that structure within a VTCS which the framework is organized around five interconnected system elements as climate, the tank system, agricultural water use, non-agricultural (household and livelihood) water use, and governance arrangements which these elements collectively define the boundaries of the system considered in the analysis. Table 1 summarizes the system components and their associated sub-components, providing a clear conceptual foundation for the agent-based modelling framework developed in the subsequent section.

Table 1: System components and sub-components *(Source: Compiled by author)*

Main Component	**Key Agent / System**	**Sub-Components**
Climate	Climatic System	Rainfall, seasonal variability, drought periods
Tank System	Village Tank Cascade	Storage capacity, water levels, inflows and outflows, upstream–downstream connectivity, flow paths, infiltration, evaporation
Agriculture	Farmers / Paddy Cultivation	Irrigation demand, farmer water allocation, crop choice, cultivated extent, Maha season, Yala season, seasonal decision-making
Citizens	Non-agricultural Users	Domestic water use, drinking and washing needs, livestock watering
Governance	Water Institutions	Water-sharing rules, allocation priorities, coordination mechanisms, seasonal adjustments, sustainability considerations

3.3 AGENT-BASED MODELLING FRAMEWORK

This framework represents the VTCS as a collection of interacting components operating within a shared environment where ABM enables a bottom-up representation of systems in which collective outcomes emerge from local interactions among heterogeneous actors.

3.3.1 Agents and Environment

The model represented through several agent categories which are tank agents represent individual reservoirs and its character. Agricultural (paddy) agents represent irrigation demand. Community (citizen) agents represent non-agricultural water demand. A governance agent represents water-sharing and allocation rules which influences the entire system. All agents operate within a shared environment defined by seasonal time steps and the hydrological connectivity of the cascade.

3.3.2 Hydrological Representation and Water Balance

Tank storage dynamics within the ABM are represented using a simplified seasonal water balance formulation. For each tank agent, storage at the next time step is calculated as:

$$S_{t+1} = S_t + R_t + Q_t^{in} - Q_t^{out} - E_t - I_t \quad (1)$$

where $\boldsymbol{S_t}$ is the storage at time $\boldsymbol{t}$, $\boldsymbol{R_t}$ is the rainfall contribution, $\boldsymbol{Q_t^{in}}$ represents inflow from upstream tanks, $\boldsymbol{Q_t^{out}}$ represents releases to downstream tanks and water users, $\boldsymbol{E_t}$ denotes evaporation losses, and $\boldsymbol{I_t}$ denotes infiltration and seepage losses.

3.3.3 Agricultural Water Demand Representation

Agricultural water demand within the model is represented using evapotranspiration-based seasonal requirements for paddy cultivation which is crop evapotranspiration is estimated as:

$$ET_c = ET_0 \times K_c \quad (2)$$

where $\boldsymbol{ET_0}$ is the reference evapotranspiration and $\boldsymbol{K_c}$ is the crop coefficient corresponding to paddy cultivation where total seasonal irrigation demand for each agricultural agent is calculated as:

$$W_{agri} = A \times ET_c \quad (3)$$

where $\boldsymbol{A}$ represents the cultivated paddy area.

3.3.4 Allocation Rules and Agent Interactions

Interactions among agents are governed by rule-based decision logic, with tank agents exchanging water according to the hydrological connectivity of the cascade. Storage and release decisions at upstream tanks directly influence downstream availability shapes how water is distributed among competing uses.

3.3.5 Scenario Design

Two illustrative scenarios were developed to demonstrate the application of the agent-based modelling framework under contrasting water-sharing arrangements. Both scenarios use the same cascade structure, climatic inputs, hydrological assumptions, and agricultural demand parameters, as summarised in Table 2. The simulations are implemented for both Maha and Yala seasons using monthly time steps, with Yala representing conditions of heightened water scarcity.

Table 2: Parameters of the ABM scenario *(Source: Compiled by author)*

Parameter	**Value**	**Notes**
Cultivation type	Paddy	Yala and Maha seasons
Cultivation duration	120 days	Seasonal
Crop coefficient (Kc)	1.10	Standard FAO value
Agricultural allocation	20%	Of available tank water
Annual infiltration loss	11%	Mean Dry Zone assumption
Seasonal focus	Maha, Yala	Maha (Oct- Mar), (Yala (May–Sep)
Data basis	Observed rainfall, ET_0, pan evaporation	Irrigation Dept.

The cascade is represented as a simplified, hypothetical system informed by the Padipanchawa VTCS, comprising upstream tanks (A and B), a collector tank (C), and downstream tanks (D and E). Tank surface areas, storage depths, and connectivity are defined using realistic Dry Zone ranges (Table 3), while rainfall, evapotranspiration, and infiltration parameters are derived from Irrigation Department hydrological records. In both scenarios, 20% of available tank storage is allocated for paddy cultivation, and domestic water requirements are prioritised before agricultural allocation.

Scenario 1 (Non-Sharing Scenario) assumes that no explicit downstream sharing rule and paddy cultivation at each tank is supported solely by locally available storage. Scenario 2 (Sharing Scenario) introduces a simplified downstream sharing rule, whereby a fixed proportion of 10% available storage from each tank is released to downstream tanks and to demonstrate the output of study, cultivation index was introduced here as:

$$\textbf{Cultivation Index} = \frac{\textbf{Paddy cultivated area (Scenario 2)}}{\textbf{Paddy cultivated area (Scenario 1)}} \qquad (4)$$

This scenario represents coordinated allocation under scarcity without implying optimisation or policy prescription. By holding structural parameters and demand constant across scenarios, the analysis isolates the role of sharing rules in shaping interaction pathways and cascade-level outcomes.

Table 3: Defined dimensions of hypothetical VTCS *(Source: Compiled by author)*

Tank ID	Functional role	Surface area (m^2)	Avg. water depth (m)	Max. storage volume (m^3)	
A	Upstream tank	22,000	3.0	66,000	
B	Upstream tank	35,000	3.0	105,000	
C	Collector tank	150,000	4.5	675,000	
D	Downstream tank	60,000	3.5	210,000	
E	Downstream tank	55,000	3.5	192,500	

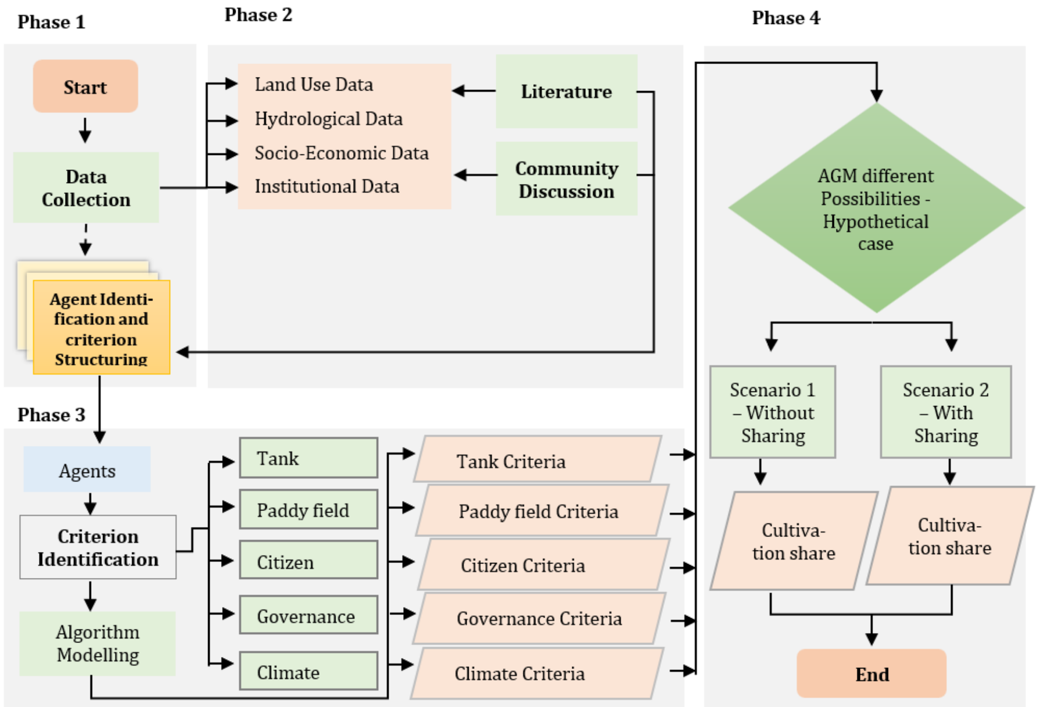

Figure 2: Detailed Research Design *(Source: Compiled by author)*

4. Analysis and results

This section analyses the behaviour of the VTCS using the conceptual and agent-based frameworks developed in the preceding sections and the analysis focuses on understanding how interactions among climatic forcing, storage dynamics, governance rules, and user behaviour shape system-level outcomes under contrasting allocation arrangements.

4.1 SYSTEM COMPLEXITY AND AGENT INTERACTIONS

Figure 3 presents a simplified interaction network of the VTCS where it illustrating the core agents and dominant interaction pathways that structure the system behaviour. The diagram intentionally extracts internal processes in order to foreground the relational logic of the system and to clarify how interactions are organised prior to agent-based implementation which represent five primary agents as Climate, Tank System, Agriculture, Citizens, and Governance.

Based on the representation the Tank System occupies a structurally central position, mediating all interactions between climatic forcing, water users, and governance controls. Climatic influences affect the system exclusively through their impact on tank storage, while both agricultural and domestic users access water only via the tank system. Governance does not interact directly with climate or users which instead, it influences outcomes by regulating how storage is allocated, retained, or transferred across tanks. As a result, interactions among users are indirect and occur through shared dependence on storage.

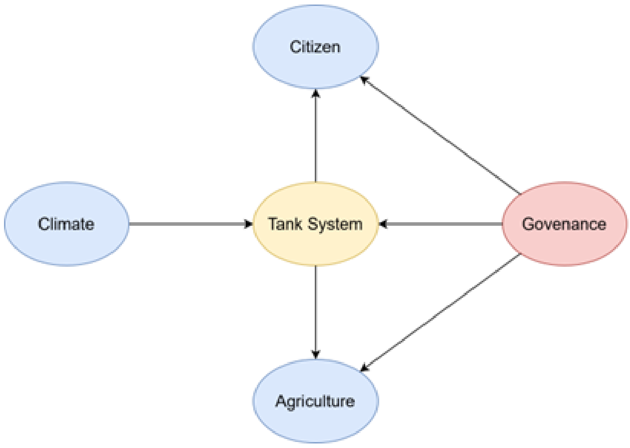

Figure 3: Interaction behaviour of agents *(Source: Com-piled by author)*

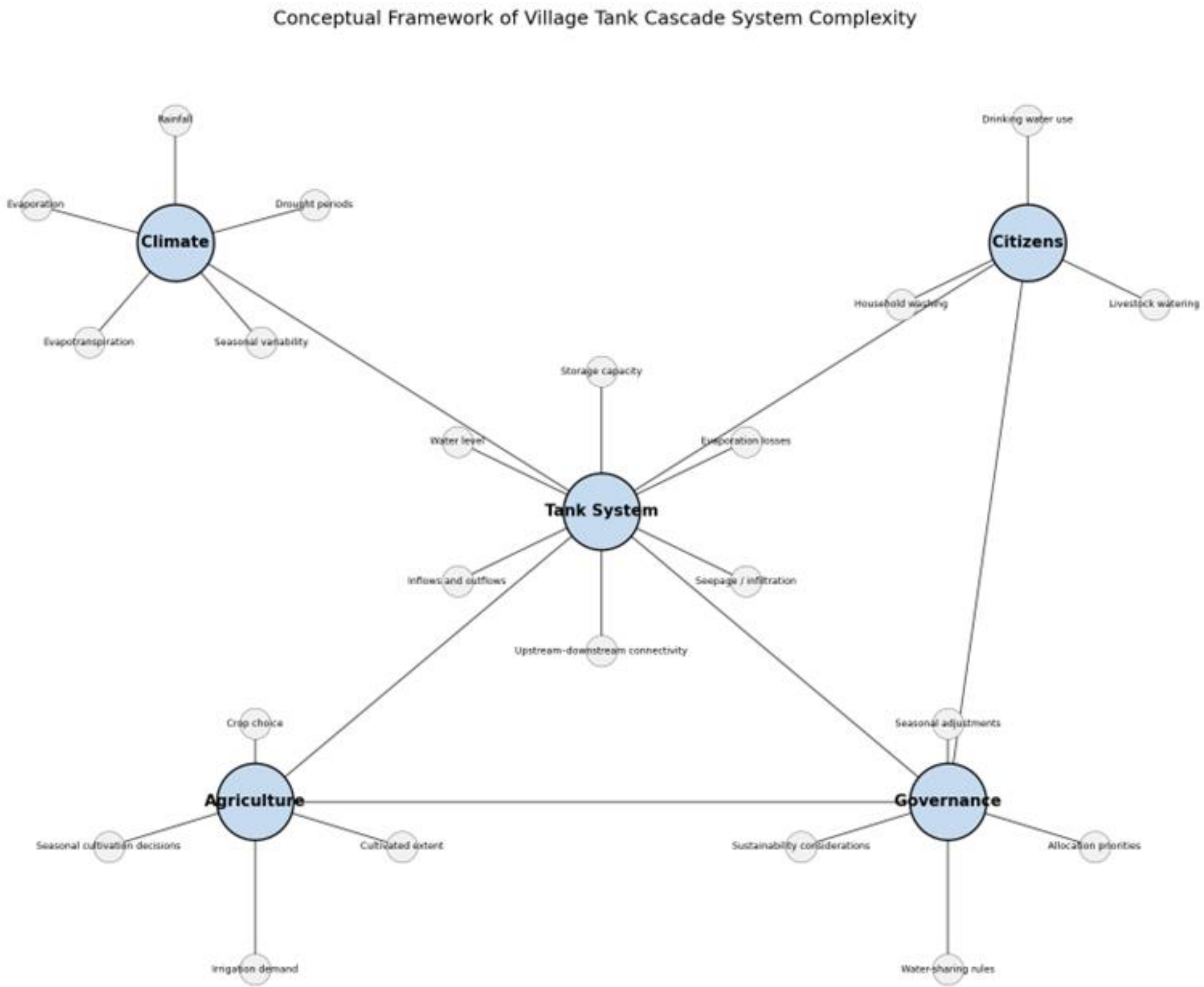

Figure 4: Conceptual Framework of VTCS *(Source: Compiled by author)*

From a network-analytical perspective, this structure implies high betweenness centrality of the tank system, as it lies on all critical interaction paths connecting otherwise weakly linked agents (Freeman, 1977). Nodes with high betweenness centrality function as bridges within a network, exerting disproportionate influence over system dynamics by controlling interaction pathways (Bodin & Tengö, 2012). In the VTCS, the tank system performs this bridging role by transmitting climatic variability, enabling or constraining water use, and operationalising governance decisions. Figure 4 extends this simplified network into a full conceptual framework by unpacking each primary agent into its associated attributes and internal state variables which these secondary elements (e.g., rainfall, evapotranspiration, irrigation demand, allocation priorities) define how agents perceive constraints and make decisions. Interactions therefore occur between agents, while sub-components shape behavioural responses within the shared environment. Together, the two figures demonstrate that VTCS complexity emerges from feedbacks between hydrological constraints and human decision-making rather than from physical processes alone which storage dynamics link climate, users, and governance in a tightly coupled system where small changes can propagate across the cascade and generate non-linear outcomes. This interaction structure provides a clear analytical justification for the use of an Agent-Based Modelling approach, which is uniquely suited to representing heterogeneous agents, indirect interactions, and emergent system behaviour under alternative governance scenarios.

4.2 COMPARATIVE EFFECTS OF WATER-SHARING GOVERNANCE

The agent-based simulation was executed under identical climatic forcing derived from observed rainfall data from the Irrigation department, Sri Lanka, with rainfall acting as a shared environmental driver across both governance arrangements. The simulation was initialized with all tanks assumed to be full capacity at the beginning which simulation has run for 2020-2021 water year for water balance of the VTCS.

Then come to the 2021–2022 water year which VTCS have run for post-Maha recharge conditions which as shown in Figure 6, initial storage levels across all tanks exceed approximately 90% of capacity, providing a common baseline for comparison. Rainfall patterns exhibit strong seasonal variability, with substantial inputs during the Maha season and markedly reduced rainfall during Yala and this seasonal contrast is critical for system behaviour. During Maha, rainfall replenishment partially offsets water withdrawals, allowing tanks to retain relatively high storage levels despite agricultural use.

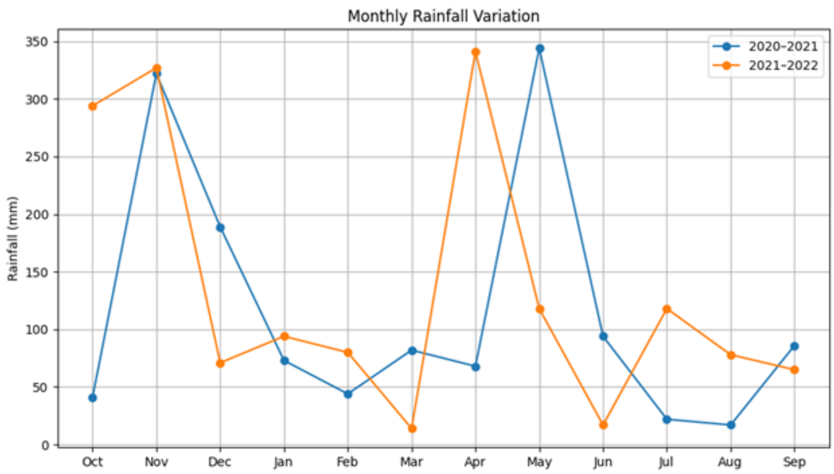

Figure 5: Rainfall variation (2020-2021& 2021-2022 *(Source: Compiled by author)*

By the end of the Maha season, tank storage converges to approximately 70% of capacity across the cascade, reflecting the combined effects of evaporation, infiltration losses, and the allocation of 20% of available storage for agricultural use (table 4). Then scenarios have run for the Yala season where it represents the primary stress period in the simulation where rainfall inputs decline sharply, and water availability becomes dominated by carry-over storage rather than contemporaneous recharge. Under the non-sharing arrangement (Scenario 1), tanks continue to operate independently, with each tank allocating 20% of its remaining storage for agriculture. As a result, water use during Yala draws down storage without compensating inflows, leading to a progressive reduction in available water across all tanks. Although end-of-season storage percentages of tanks appear broadly similar, absolute storage volumes differ substantially (table 4). Larger tanks retain significantly greater volumes of water, while downstream tanks experience volumetric scarcity that is not evident from percentage indicators alone. This disparity is reflected in cultivation outcomes where under non-sharing conditions, agricultural activity remains concentrated in larger upstream and collector tanks, while downstream tanks support comparatively limited cultivation which despite having similar percentage storage levels.

Table 4: Tank storage percentages and end-of-Yala storage volumes under different scenarios *(Source: Compiled by author)*

Tank	**Baseline (%)**	**After Maha (%)**	**End of Yala – S1 (%)**	**End of Yala – S2 (%)**	**Storage Volume – S1 (m^3)**	**Storage Volume – S2 (m^3)**
A	94.23	72.49	62.00	55.80	40,922.4	36,830.1
B	94.23	72.49	62.00	55.80	65,103.7	58,593.4
C	92.49	71.19	58.79	54.48	396,818.2	367,739.0
D	93.49	71.94	60.63	73.46	127,313.4	154,263.9
E	93.49	71.94	60.63	67.24	116,703.9	129,435.3

The introduction of proportional water sharing during Yala (Scenario 2) alters this dynamic were following the end of Maha, a fixed proportion (10%) of available storage is released downstream prior to agricultural allocation which this transfer redistributes water volumes across the cascade, reducing retained storage in upstream and collector tanks while increasing absolute water availability in downstream tanks. Although total system storage declines slightly due to conveyance and infiltration losses, the spatial distribution of water changes has been illustrated from figure 8. These changes are clearly reflected in cultivation outcomes where downstream tanks exhibit a substantial increase in agricultural water availability, allowing a greater cultivated area to be supported during Yala which has been shown by an increase in the cultivation index above unity for downstream tanks, indicating a net gain in agricultural opportunity relative to the non-sharing case (table 5). Conversely, upstream tanks experience a reduction in cultivated area, reflecting the redistribution of water rather than an expansion of total availability.

Graphical analysis of storage routes (Figure 6) reinforces this interpretation where under sharing conditions, downstream tank storage curves diverge upward during Yala relative to the non-sharing case, while upstream curves converge downward. These differences arise despite identical rainfall inputs, confirming that governance-mediated transfers, rather than climatic variability which drive the observed outcomes.

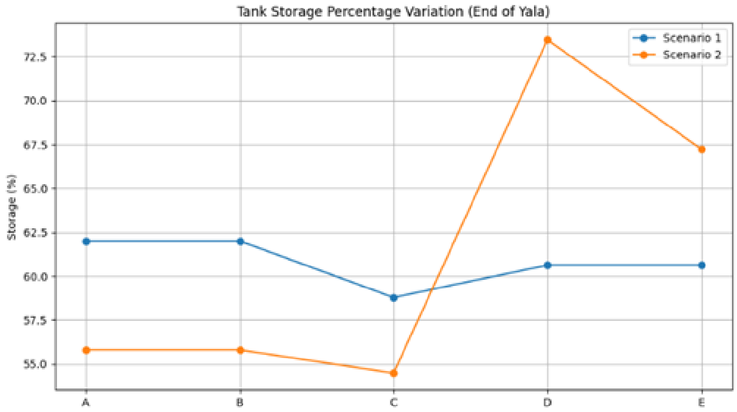

Figure 6: Tank storage variation – End of Yala season *(Source: Compiled by author)*

Overall, the comparative analysis demonstrates that water sharing does not increase total water availability, but it can significantly reduce experienced scarcity within the Village Tank Cascade System. By redistributing stored water spatially across the cascade through governance arrangements, sharing mechanisms moderate downstream vulnerability during the water-scarce Yala season. This illustrates how adaptive governance can manage scarcity more effectively under unchanged climatic conditions by shaping how water stress is distributed and absorbed across the system.

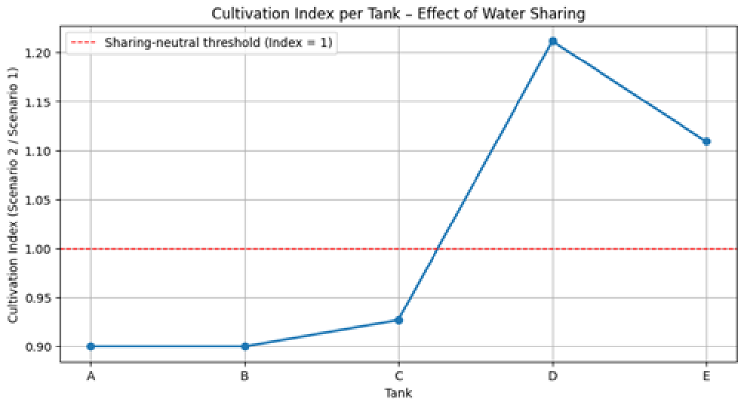

Figure 7 : Cultivation index per tank *(Source: Compiled by author)*

Table 5: End-of-Yala - paddy cultivation outcomes under non-sharing and sharing scenarios *(Source: Compiled by author)*

Tank	End-Yala Storage (%) – S1	End-Yala Storage (%) – S2	Paddy Area (m^2) – S1	Paddy Area (m^2) – S2
A	62.00	55.80	89,000.33	80,100.30
B	62.00	55.80	141,591.44	127,432.29
C	58.79	54.48	863,023.54	799,780.36
D	60.63	73.46	276,888.59	335,502.09
E	60.63	67.24	253,814.54	281,503.40

5. Conclusion and Recommendations

This research approached the Village Tank Cascade System (VTS) as a dynamic socio-ecological system in which water availability, agricultural livelihoods, and institutional arrangements are deeply interlinked. The research adopted a system-oriented perspective that recognises the cascade as a connected and adaptive water-sharing landscape which shaped by both environmental variability and human decision-making. The study highlights that water outcomes within a VTCS are not determined by hydrological conditions alone which is seasonal rainfall variability sets the boundary conditions of the system, but the way scarcity is experienced and managed depends fundamentally on how water is allocated, shared, and governed across the cascade. Allocation decisions influence not only storage levels but also cultivation patterns, livelihood security, and downstream resilience, particularly during the water-scarce seasons. A central insight of this study is that governance arrangements play a critical role in managing scarcity through redistribution and coordinated sharing practices allow water to be reallocated spatially in response to demand and stress, moderating vulnerability at the tail end of the cascade while requiring upstream users to accept reduced individual benefits. This logic closely aligns with long-standing indigenous practices such as *Bethma* and *Mura Wathura*, which prioritise collective risk reduction and system stability over individual maximization. Overall, the study demonstrates that sustainable management of VTCSs depends on recognizing both hydrological constraints and socially negotiated allocation mechanisms. Effective responses to increasing climatic uncertainty therefore require governance frameworks that are adaptive, season-specific, and sensitive to spatial inequalities within cascades. By framing VTCS management as a problem of interaction and coordination, this research provides a conceptual and analytical foundation for more resilient and equitable water-sharing strategies in Sri Lanka's Dry Zone and similar traditional irrigation systems elsewhere.

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