# Agricultural Systems

## Ancient Irrigation Systems in Asia and Africa: Typologies, Degradation and Ecosystem Services

--Manuscript Draft--

| | |
|---|---|
| **Manuscript Number:** | |
| **Article Type:** | VSI:Ancient Irrigation Systems |
| **Keywords:** | Agriculture; Climate Change; Hydrology; Village tank cascade system; Tank irrigation; Watershed |
| **Corresponding Author:** | Jeevika Weerahewa, PhD<br>University of Peradeniya<br>Peradeniya, Central SRI LANKA |
| **First Author:** | Jeevika Weerahewa, PhD |
| **Order of Authors:** | Jeevika Weerahewa, PhD |
| | Jagadish Timsina, PhD |
| | Chamali Wickramasinghe, BSc |
| | Sithuni Mimasha, BSc |
| | Dasuni Dayananda, BSc |
| | Gamini Puspakumara, PhD |
| **Abstract:** | Highlights<br><br>• Ancient irrigation systems (AISs) found largely in Asia and Africa provide a multitude of benefits to mankind but are at a threat of degradation.<br><br>• A systematic review conducted to identify typologies, status and causes of degradation of, and ecosystems services provided by, AISs.<br><br>• 3 typologies (rainwater harvesting based, groundwater based, surface water based) and 4 ecosystems services (provisioning, regulating, cultural, supporting) identified.<br><br>• Cascade tanks in Sri Lanka and India provide irrigation water for surrounding farming communities and various ecosystem services for local communities and societies.<br><br>• Rehabilitation of AISs needs urgent attention by governments, private sector, and development partners. |
| **Suggested Reviewers:** | Hemasiri Kotagama, PhD<br>A/Professor, Sultan Qaboos University<br>hemkot26@gmail.com<br>Knowledgeable on tank irrigation systems and qanats. |
| | Jeetendra Aryal, PhD<br>CGIAR<br>jeetenaryal@gmail.com<br>Research interests: Climate change policy, Poverty and inequality, Adoption and Impact analysis |
| | Sebak Jana, PhD<br>Professor, Vidyasagar University<br>sebakjana@yahoo.co.in<br>An agricultural Economist knowledgeable in tank irrigation system in India. |
| | MIM Mowjood, PhD<br>Professor, University of Peradeniya<br>mowjood2010@gmail.com<br>Agricultural Engineer with a specialization in hydrology |

University of Peradeniya
Department of Agricultural Economics
and Business Management
Faculty of Agriculture, University of Peradeniya,
Peradeniya 20400, Sri Lanka
Phone: +94812395010 (Office), +94714933591 (Mobile); Fax: +94812388041
Email: deanagri@pdn.ac.lk; ngpkumara63@gmail.com
Web: http://agri.pdn.ac.lk

CELEBRATING 70 Faculty of Agriculture - University of Peradeniya 1948 - 2018 Years of Agriculture Higher Education in Sri Lanka

September 14, 2022

Editor-in-chief
Agricultural Systems

Dear Madam,

**Submission of Manuscript for VSI – Ancient Irrigation Systems**

On behalf of all couthors, I am pleased to submit a manuscript titled '**Ancient Irrigation Systems in Asia and Africa: Typologies, Degradation and Ecosystem Services**' for your consideration of publication in the Virtual Special Issue on «Ancient Irrigation Systems» of Agricultural Systems.

The manuscript is based on a systematic review of peer-rviewed journal articles, conferrence proceedings, book chapters, and supplemented by and grey literature about several types of ancient irrigation systems broadly groupe under three main systems: rainwater harvesting based, groundwater based, and surface water based in several Asian and African countries. It provides description of various systems and typologies, status and causes of degradation, and four types of ecosystems services (provisioning, regulating, cultural, supporting) provided by the same. The review revealed that among the various systems, cascade tanks in Sri Lanka and India were the most studied systems. All ancient irrigation systems have provided various ecosystem services for local communities and societies in addition irrigation water for surrounding farming communities though there were more published studies of proving such services by cascade tanks of Sri Lanka and India. The review highlights the importance and urgent need of rehabilitation of AISs through a system approach.

I am looking forward for a favourable response from you.

Thank you,

Jeevika Weerahewa
Professor of Agricultural Economics

Corresponding author

**Highlights:**

- Ancient irrigation systems (AISs) found largely in Asia and Africa provide a multitude of benefits to mankind but are at a threat of degradation.
- A systematic review conducted to identify typologies, status and causes of degradation of, and ecosystems services provided by, AISs.
- 3 typologies (rainwater harvesting based, groundwater based, surface water based) and 4 ecosystems services (provisioning, regulating, cultural, supporting) identified.
- Cascade tanks in Sri Lanka and India provide irrigation water for surrounding farming communities and various ecosystem services for local communities and societies.
- Rehabilitation of AISs needs urgent attention by governments, private sector, and development partners.

Graphical Abstract

# Community Managed Ancient Irrigation Systems in Asia and Africa: Typologies, Degradation and Ecosystem services

## Objective

To synthesize the research knowledge on AISs on their typologies, status and causes of degradation, and ecosystem services and functions provided by them in Asia and Africa.

## Methodology

Systematic review
↓
46 Peer reviewed journal articles
↓
Develop typologies
Investigate causes of degradation
Identify ecosystem services

## Causes of Degradation

| | |
|---|---|
| Natural causes | High intensity rainfall, Dry spell, Natural disasters, Global environmental changes |
| Physical causes | Infrastructure changes, Human settlements, Forest degradation |
| Social causes | Urbanization, Changes in land use pattern, Increase population, Neglecting maintenance |

## Ecosystem services

| | |
|---|---|
| Provisioning | Water for irrigation and domestic purposes, food, fuelwood, fiber, medicinal plants |
| Regulatory | Flood control, water purification, ground water recharges |
| Cultural | Spiritual, religious and aesthetic, place for meeting people |
| Supporting | Wildlife habitat, carbon sequestration |

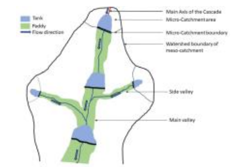
## Conclusions and Recommendations

Proper coordination and management of AISs jointly by the local communities and government organizations would be required to preserve the ecosystems and provide various types of ecosystem services.

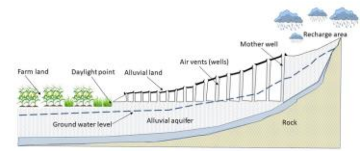
## Typologies and physical structures

Ancient Irrigation Systems

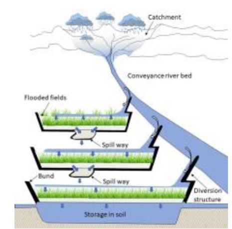
- Rainwater harvesting systems with reservoirs
  - Tank Cascade Systems
  - Pond or Minor Tanks
  - Small Dam
- Groundwater Based Systems
  - Qanats
  - Karez
  - Falaj/Aflaj
- Floodwater Based Systems
  - Flood Plain
  - Flood Inundation
  - Spate
  - Depression



Tank Cascade System



Karez system



Spate irrigation system

| | Rainwater based Irrigation Systems | | | Groundwater Based Irrigation Systems | | | Floodwater Based Irrigation Systems | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cascade Tanks | Ponds or Minor Tanks | Small Dams | Qanats | Karez | Aflaj/ Falaj | Flood Plain | Flood Inundation | Spate | Depression | |
| Asia | 34 | 6 | 3 | 4 | 4 | 1 | 1 | 1 | 0 | 2 | 56 |
| Africa | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 7 |
| Total | 34 | 6 | 6 | 4 | 4 | 1 | 2 | 2 | 1 | 3 | 63 |

**Abstract:**

*Context*: Ancient irrigation systems (AISs) with various types and names are used for millennia in Asian and African countries with arid and semi-arid dry climate with low rainfall. They have been providing a multitude of benefits to local communities and to the larger societies. Many AISs are however degraded due to inadequate government support and lack of farmer/community participation in management. A systematic documentation of such AISs in terms of their typologies, causes of degradation, and their ecosystem services and functions is lacking.

*Objective*: The objective of this review was to synthesize the knowledge on AISs on their typologies, status and causes of degradation, and ecosystem services and functions provided by them in Asia and Africa.

*Method*: A systematic literature review of published papers in peer-reviewed journals, conference proceedings and book chapters was conducted. The review was supplemented by grey literature such as unpublished technical reports, Ph.D. dissertations and country report wherever required. Qualitative and quantitative information from journal papers were used to identify and develop the typologies and analyse the status and causes of degradation and ecosystems services and functions provided by the AISs.

*Results and Conclusion*: Based on the review, we categorized AISs into three groups by the source of irrigation water: Rainwater harvesting systems (RHSs) with small reservoirs, ground water based systems, and floodwater based systems. The review showed that the causes of degradation of AISs are multi-faceted. The RHSs such as tanks or ponds which used to receive reliable rainfall and managed by well cohesive social organizations for their maintenance and functioning in past have now been difficult to maintain due to erratic rainfall pattern and breakdown of such organizations in recent decades. As a result, siltation of tanks has become a common issue in all RHSs. In systems that use ground water, indiscriminate development of deep tube wells causing siltation of channels has been a major challenge. Lack of maintenance and increased soil erosion, and inadequacies of skilled manpower and support from the government for repair and maintenance were the main causes of degradation of all AISs. In floodwater irrigation systems irregular rainfall in the highlands and the breaking of the irrigation structures by destructive big

floods were the main causes of degradation. Lack of implementation of floodwater management rules, techniques and practices, and inappropriate interventions used on head works, canals and distribution structures also led to degradation.

The main eco-system service provided by all AISs is water for agriculture. In tank cascade and pond systems, fish farming is also practiced. Various types of provisioning, regulatory, cultural and supporting services are provided by the tank cascade systems since they were intrinsically connected to ancient civilization particularly in India and Sri Lanka. Ground water sourced systems provide water for domestic purposes in addition to irrigation and various cultural services while floodwater based systems for power generation and for wildlife habitat maintenance, and help in flood control.

*Significance*: The knowledge generated on typologies and causes of degradation of, and ecosystem services provided by, AISs will provide evidence-based information and awareness to the governments, private sectors and development agencies in planning and policy making and prioritizing the restoration, rehabilitation, and management of various AISs.

# Ancient Irrigation Systems in Asia and Africa: Typologies, Degradation and Ecosystem Services

Jeevika Weerahewa[a*], Jagadish Timsina[b], Chamali Wickramasinghe[c], Sithuni Mimasha[d], Dasuni Dayananda[e], Gamini Puspakumara[f]

[a,d,e] Department of Agricultural Business and Management, Faculty of Agriculture. University of Peradeniya (email: [a]jeevika.weerahewa@agri.pdn.ac.lk, [d]sithunim@agri.pdn.ac.lk, [e]dasunid@agri.pdn.ac.lk)

[b] Institute for Study and Development Worldwide, Sydney, Australia (email: timsinaj@hotmail.com)

[c] Postgraduate Institute of Agriculture, University of Peradeniya, Sri Lanka (email: chamaliwick93@gmail.com)

[f] Department of Crop Science, Faculty of Agriculture, University of Peradeniya (email: ngpkumara@agri.pdn.ac.lk)

[*]**Corresponding author**

**Highlights:**

- Ancient irrigation systems (AISs) found largely in Asia and Africa provide a multitude of benefits to mankind but are at a threat of degradation.
- A systematic review conducted to identify typologies, status and causes of degradation of, and ecosystems services provided by, AISs.
- 3 typologies (rainwater harvesting based, groundwater based, surface water based) and 4 ecosystems services (provisioning, regulating, cultural, supporting) identified.
- Cascade tanks in Sri Lanka and India provide irrigation water for surrounding farming communities and various ecosystem services for local communities and societies.
- Rehabilitation of AISs needs urgent attention by governments, private sector, and development partners.

Keywords: Agriculture, Climate Change, Hydrology, Village tank cascade system, Tank irrigation, Watershed

**Abstract:**

*Context*: Ancient irrigation systems (AISs) with various types and names are used for millennia in Asian and African countries with arid and semi-arid dry climate with low rainfall. They have been providing a multitude of benefits to local communities and to the larger societies. Many AISs are however degraded due to inadequate government support and lack of farmer/community participation in management. A systematic documentation of such AISs in terms of their typologies, causes of degradation, and their ecosystem services and functions is lacking.

*Objective*: The objective of this review was to synthesize the knowledge on AISs on their typologies, status and causes of degradation, and ecosystem services and functions provided by them in Asia and Africa.

*Method*: A systematic literature review of published papers in peer-reviewed journals, conference proceedings and book chapters was conducted. The review was supplemented by grey literature such as unpublished technical reports, Ph.D. dissertations and country report wherever required. Qualitative and quantitative information from journal papers were used to identify and develop the typologies and analyse the status and causes of degradation and ecosystems services and functions provided by the AISs.

*Results and Conclusion*: Based on the review, we categorized AISs into three groups by the source of irrigation water: Rainwater harvesting systems (RHSs) with small reservoirs, ground water based systems, and floodwater based systems. The review showed that the causes of degradation of AISs are multi-faceted. The RHSs such as tanks or ponds which used to receive reliable rainfall and managed by well cohesive social organizations for their maintenance and functioning in past have now been difficult to maintain due to erratic rainfall pattern and breakdown of such organizations in recent decades. As a result, siltation of tanks has become a common issue in all RHSs. In systems that use ground water, indiscriminate development of deep tube wells causing siltation of channels has been a major challenge. Lack of maintenance and increased soil erosion, and inadequacies of skilled manpower and support from the government for repair and maintenance were the main causes of degradation of all AISs. In floodwater irrigation systems irregular rainfall in the highlands and the breaking of the irrigation structures by destructive big floods were the main causes of degradation. Lack of

implementation of floodwater management rules, techniques and practices, and inappropriate interventions used on head works, canals and distribution structures also led to degradation.

The main eco-system service provided by all AISs is water for agriculture. In tank cascade and pond systems, fish farming is also practiced. Various types of provisioning, regulatory, cultural and supporting services are provided by the tank cascade systems since they were intrinsically connected to ancient civilization particularly in India and Sri Lanka. Ground water sourced systems provide water for domestic purposes in addition to irrigation and various cultural services while floodwater based systems for power generation and for wildlife habitat maintenance, and help in flood control.

*Significance*: The knowledge generated on typologies and causes of degradation of, and ecosystem services provided by, AISs will provide evidence-based information and awareness to the governments, private sectors and development agencies in planning and policy making and prioritizing the restoration, rehabilitation, and management of various AISs.

## 1. Introduction and methodology

Global irrigated agriculture is highly diverse. Globally, irrigation extracts water from surface water (e.g., rivers, lakes) and groundwater (e.g., aquifers) sources. About 188 million ha, Mha (62%) of the global irrigated area receives water from surface water sources, while about 113 Mha (38%) from the groundwater sources (Thenkabail et al., 2008). The predominant irrigated systems practised worldwide are large-scale public systems (e.g., low-lying fields for rice production in humid areas or for staples and cash crops in dry areas), small and medium-scale community-managed systems such as tank irrigation in Sri Lanka and South India, commercial private systems for cash crops, and farm-scale individually managed systems producing for the local market (Molden et al., 2007). In these systems, water conveyance and distribution may be by gravity or through pressure, and management and institutional set-up could be public, user-run, private, community-based, or in any combinations (FAO, 2011).

Of the above systems, the small and medium-scale community-managed ancient irrigation systems (AISs) have immensely supported local communities to meet their food and domestic water needs from ancient times and continue to enhance livelihoods and alleviate rural poverty and food insecurity in many countries even now. Small- to medium-scale AISs are prevalent across all continents, and particularly in developing countries of Asia, Africa, Europe, and Southern America. The irrigation unit may range from a small individual farm up to massive integrated schemes such as the Rohri canal system in Pakistan, which covers 1.04 Mha (Dubois, 2011). There are ample evidence showing that such systems have potential to improve crop and animal productivity and maintain ecosystems services providing various provisioning, regulatory, supporting and cultural services to the communities who reside in and around the irrigation systems and to the society at large. Over time, due to lack of effective and efficient water governance at local level due to poor national water legislations, poor management or maintenance, or climate change, a degradation of these systems in many countries has now become evident. Many structures of the AISs have fallen into disrepair or disuse resulting in siltation of the structures and salinity of irrigation water and surrounding fields (Pandey et al., 2003). In addition, such irrigation systems are being adversely affected by climate change. As a result, governments and community organizations responsible for maintenance and management of such systems are facing difficulties in restoring such irrigation systems worldwide (Saatsaz, 2020; Sirimewan et al., 2021).

The objective of this review is to synthesize the research knowledge on community managed AISs paying special attention to their typologies, causes and extent of their degradation, and their role in providing various types of ecosystem services. We conducted a systematic review of literature covering peer reviewed journal papers and grey literature to synthesize the knowledge and identify gaps and priorities for research in these areas. Due to our prior knowledge and experience about the existence, dominance and importance of the AISs in Asia and Africa, the review focuses on these two continents. Moreover, our prior knowledge revealed that tank cascade irrigation systems (TCSs) are the major types of AISs in South India and Sri Lanka (Panabokke, 2009; Panabokke et al., 2002). Hence, the review emphasizes on the TCSs in these countries but also giving due importance and enough coverage to other community managed AISs and countries in both continents. Further, we decided not to include hydrological modelling studies on AISs since they have been subject of review and investigations by many others (Palanisami & Flinn, 1988; Jayatilaka et al. 2003; Satiskumar et al., 2010; Unami et al., 2015). Private tube wells have rapidly spread in all South Asia countries since early 1980s with assistance by both governments and private sectors and with donors' interest (e.g., Hasan et al., 2021; Haque et al., 2022; Panabokke et al., 2002). However, since these are generally managed by individual users they are not included in this review.

We used a pragmatic methodological approach to conduct this literature review. We searched published peer-reviewed papers from Science Direct, Scopus and Web of Science using relevant keywords. In addition, we used Google Scholar, Research Gate and Academia to identify relevant papers, reports, and working papers. The studies included were published as journal papers, books or conferences proceedings papers, or unpublished materials such as technical reports, discussion papers, country project reports, Ph.D. dissertations, etc. during 1985 to 2022. Out of various materials reviewed from various sources, only papers published in peer reviewed journals were used to identify and develop typologies, investigate causes of degradation, and analyze ecosystems services and functions. Only the journal papers that devoted to investigation of at least one AIS covering at least one of the countries in Asia or Africa were included in the summary tables. Some papers addressed more than one AIS in more than one Asian or African countries and hence the number of cases of AISs extracted from those papers exceeded the number of papers (Tables 1-5). We also noted that scientific evidence related to some important AISs (for example dams in Yemen) have not been published in journal papers. Therefore, information on such systems were obtained from grey literature and included in the review where appropriate but not included in the preparation of summary tables. Supplementary Table 1 provides the list of journal papers included in the preparation of various summary tables.

## 2. Typologies of AISs

The review identified diverse types of AISs, which differ by management type (solely by community, or community and government together), water harvesting techniques (rainwater, groundwater, or floodwater), or storage mechanisms (aboveground or underground; connected or individual), etc. Different authors have adopted different classification systems for AISs. For example, Hoanh et al. (2009) reported six systems in Lower Mekong Basin countries. They include (i) reservoir-gravity, (ii) off-river-gravity, (iii) off river-pumping, (iv) conjunctive groundwater – surface water, (v) integrated management, and (vi) small-scale water storages. In contrast, Takeshima & Edeh (2017) divided households into four irrigation user types (mechanized, stream, pump, and temporary irrigators) using a cluster analysis in Nigeria. Based on various AISs used in Asia and Africa, this review classified AISs into three systems based particularly on source of irrigation water namely rainwater harvesting system (RHSs) with small to medium reservoirs, groundwater based system, and floodwater based system while recognizing that there exists connections between RHSs with groundwater (Chowdhury & Behera, 2018 and Kumari et al., 2019). Figure 1 shows the typologies of AISs developed and adopted in this review.

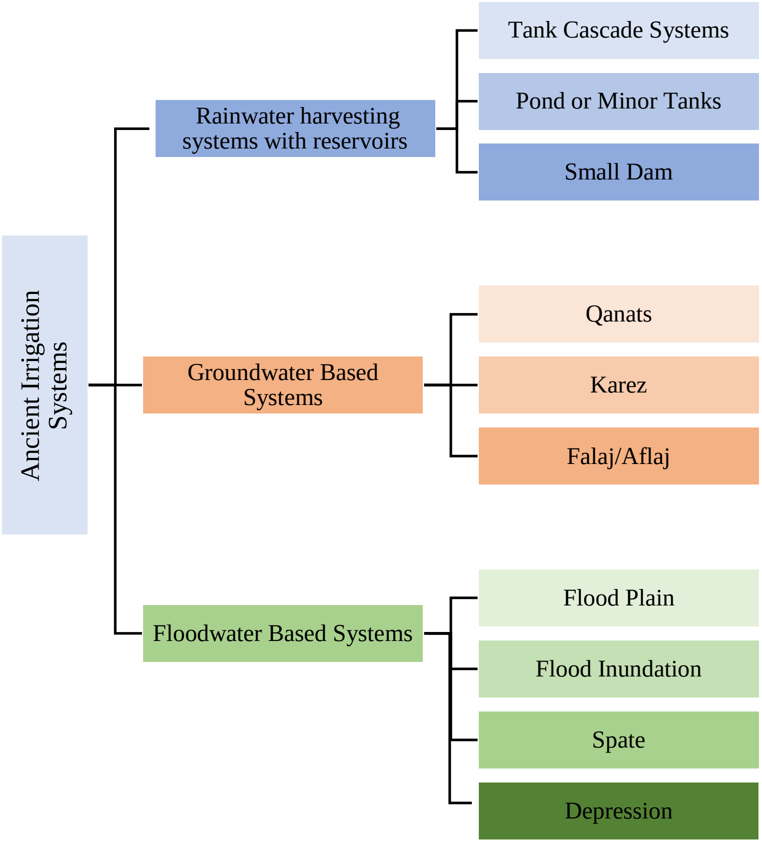



Figure 1: Typology of ancient irrigation systems (Source: authors' developed)

Of the 46 journal papers examined (Table 1), there were 20 studies related to Sri Lanka discussing TCSs (Mahatantila et al., 2008; Geekiyanage & Pushpakumara, 2013; Abeysingha et al., 2021; Nanthakumaran et al., 2021; Sirimanna & Prasada, 2021; Kahathuduwa & Prasada, 2022). Similarly, most of the 19 studies in India (13) were related to tank irrigation systems (for example, Bitterman et al., 2016; Chowdhury & Behera, 2018; Chinnasamy & Srivastava, 2021). One study discussed about the cascade tanks in Indonesia (Darma et al., 2011). Most studies (72.7%) in Middle East were however related to ground water based systems (Ambler, 1994; Khan and Nawaz, 1995; Lightfoot, 1996; Jayasena & Gangadhara, 2014; Himat & Dogan, 2019; Angelakıs et al., 2020; Azami et al., 2020). There were two studies on pond irrigation from China and one on Karez system from Pakistan (Khan & Nawaz, 1995; Chai & Zeng, 2018; Angelakıs et al., 2020). Spate irrigation was mentioned in one study in Sudan, and by dams in three studies in Tunisia, Nigeria and Mozambique (Turner, 1994; Abdelgalil & Bushara, 2018; Angelakıs et al. 2020; dos Anjos Luis & Cabral, 2021).

Table 1: Distribution of ancient irrigation systems across Asia and Africa[1]

| | Rainwater based Irrigation Systems | | | Groundwater based Irrigation Systems | | | Flood based Irrigation System | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cascade Tanks | Pond or Minor Tanks | Small-dams | Qanats | Karez | Afalaj/ Falaj | Flood plain | Flood inundation | Spate | Depression | |
| **Sri Lanka** | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **20** |
| **India** | 13 | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | **19** |
| **Indonesia** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| **China** | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | **3** |
| **Pakistan** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| **Nepal** | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| **Middle East** | 0 | 0 | 2 | 4 | 3 | 1 | 0 | 0 | 0 | 1 | **11** |
| **Sudan** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **1** |
| **Tunisia** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| **Mozambique** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| **Egypt** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **1** |
| **Nigeria** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| **Ethiopia** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | **2** |
| **Total (AISs)** | **34** | **6** | **6** | **4** | **4** | **1** | **2** | **2** | **1** | **3** | **63** |

Source: Authors' calculations

[1]The total row count and the column count exceed the number of journal papers reviewed since some articles cover multiple AISs and countries.

### *2.1 Rainwater Harvesting Systems with Reservoirs*

Small to large reservoirs used to store water for irrigation are commonly known as tanks or ponds, which in cascade system are interconnected with various canals. The number, size and spread of tanks across the globe have not been adequately documented. Mady et al. (2020) reported that globally there are about 3 million small-sized reservoirs (<0.1 $Km^2$) in operation in semi-arid climatic regions in USA, Brazil, Spain, Italy, Morocco, Nigeria, India, Myanmar, China and Australia, with a total water surface area of 17 800 $Km^2$ and seasonal storage of 37 $Km^3$, supporting 15% of the world's population. Furthermore, compared to large reservoirs, water storage in small reservoirs is small (Mady et al., 2020). Nevertheless, small reservoirs due to their high density are reported to have a high socio-economic value (Mady et al., 2020).

#### *2.1.1 Tank cascade irrigation systems*

TCSs are predominant in dry zone of Sri Lanka and in arid and semi-arid regions of the Southern Indian peninsula. The tanks are constructed across the slope of a valley to catch and store water during the rainy season. In such systems, small or large tanks are interconnected with each other by a common stream flowing under gravity from the upstream tank thereby feeding the downstream tank. The underlying principle behind tank operation is the reuse and recycling of water from a series of tanks. The tank catchments capture and conserve rainwater runoff, which would otherwise flow down as streams and mostly dissipated as evaporation. The captured rainwater is used for irrigation of agricultural lands, drinking and other households uses, ground and sub-surface water recharge, nutrient and sediment retention, flood and drought control, soil erosion avoidance, phyto-remediation, water purification, evapotranspiration reduction, salt filtration, and conservation of macro and micro aquatic fauna, etc. (Deivalatha and Ambujam, 2011).

**Sri Lanka:** TCSs in Sri Lanka were developed by the ancient kings as the water conservation strategy for the dry zone during the Rajarata hydraulic civilization. Perera (2017) provided a good account on the evolution of tanks and Kakulandala et al. (2021) provided a detailed description on the issues related to management of TCSs in Sri Lanka. In the TCS, rainwater is harvested and conserved for irrigation of surrounding fields. Tanks, paddy fields, watersheds and canals are integrated and interwoven with the natural environment (Marambe et al., 2012). Figures 2 and 3 provide a spatial setting of the TCS using an aerial photograph and a sketch respectively. Figure 2 depicts several interconnected ecological land use components of a tank with micro-catchments and purpose, functions and environmental services provided by those components in a TCS (Ratnayake et al., 2021). The stability, sustainability and resiliency of the tank or the TCS depends on the presence or absence of those components and their configurations and functions.

Bandara (1985) reported that the TCSs in Sri Lanka have evolved as a network of hydraulic structures for conservation and recycling of harvested rainwater, whereas the hydraulic civilization has harnessed the availability of surface and groundwater for their consumption. Thennakoon (2017) argued TCS is not an isolated entity but a creation in response to the limitation imposed by the physical, climatological and environmental factors whereas Jayasena & Gangadhara (2014) suggested physical setup of an irrigation system in dry environment be the main platform for an effective water management planning and designing process. The TCSs provide multifarious roles in water management and delivery especially in dry season, help meet food security of tank dependent communities, and provide multiple ecosystems services and functions. Due to these reasons, the TCSs of Sri Lanka were identified by the Food and Agriculture Organization (FAO) as a Globally Important Agricultural Heritage System (GIAHS) in 2017 (FAO, 2017).

The TCSs are classified based on arrangement of tanks in cascade as linear (Panabokke, 1999), crescent (Bandara, 1985), dendritic (Thennakoon, 2004), and fan formation (Panabokke, 1999). The number and size of the tank in a cascade varies widely, with average of eight tanks (Panabokke, 1999). TCSs exist throughout the dry zones in north-western, northern and southern provinces in Sri Lanka. However, the estimates regarding the number of tanks whether in operation or not vary widely. Panabokke et al. (2002) reported that by 1300 A.D., around 15,000 small tanks were in some state of existence and were either fully or partly operational. Geekiyanage & Pushpakumara (2013) reported that each tank of the cascade delineates a distinct small watershed or meso-catchment ranging in extent from 13 to 26 $Km^2$ and averaging 20 $Km^2$. Panabokke (2009) reported the total number of both functioning and abandoned tanks of about 18,387. On the other hand, IUCN (2015) reported approximately 14,200 small tanks and 13,000 anicuts, feeding an extent of approximately 246,000 ha (~ 39% of the total irrigable area of the country). TCSs provide water for approximately 200,000 ha (Personal Communication with Kadupitiya, 2022) out of 775, 846 ha of paddy lands (Department of Census and Statistics, 2022). However, an estimated 15,958 minor tanks with a command area of 188,310 ha have been supporting the livelihood of 386,860 families (IUCN, 2015). Recent estimates by Abeywardena et al. (2019) and Bebermeier et al. (2017) include around 10,000 small village tanks which are in use in the country.

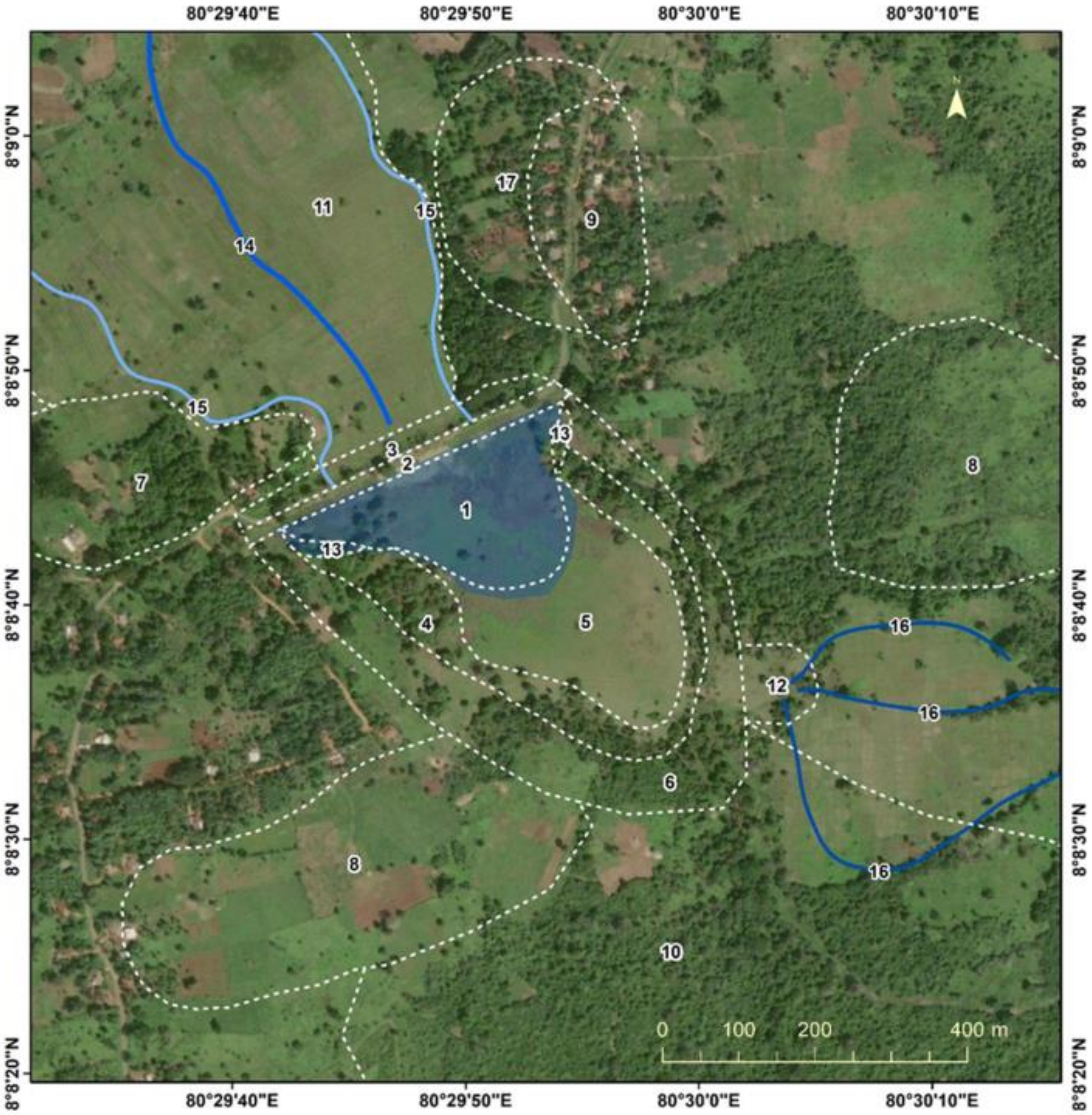



Figure 2: The spatial setting of tank with catchment and associated micro-land use components within a selected micro-catchment in the Mahakanumulla TCS (Adapted from: Ratnayake et al., 2021). 1 = tank and its bed; 2 = *Wew kandiya* (tank bund); 3 = *Kattakaduwa* (interceptor); 4 = *Gasgommana* (upstream tree belt); 5 = *Wew-thaulla* (upstream shallow tank bed); 6 = *Wew-ismaththa* (upstream immediate catchment); 7 = *Landa* (shrubland); 8 = *chena*, *hena* (rainfed farmland); 9 = *Gangoda* (hamlet); 10 = *diyabethme* (upper catchment forest); 11 = paddy fields (command area); 12 = *Godawala* (upstream water-hole); 13 = *Iswetiya* (soil ridge); 14 = *Kiwul-ela* (common drainage); 15 = irrigation canal; 16 = *Ela* (stream); 17 = *Tis-bambe* (backyard reservation around hamlet).

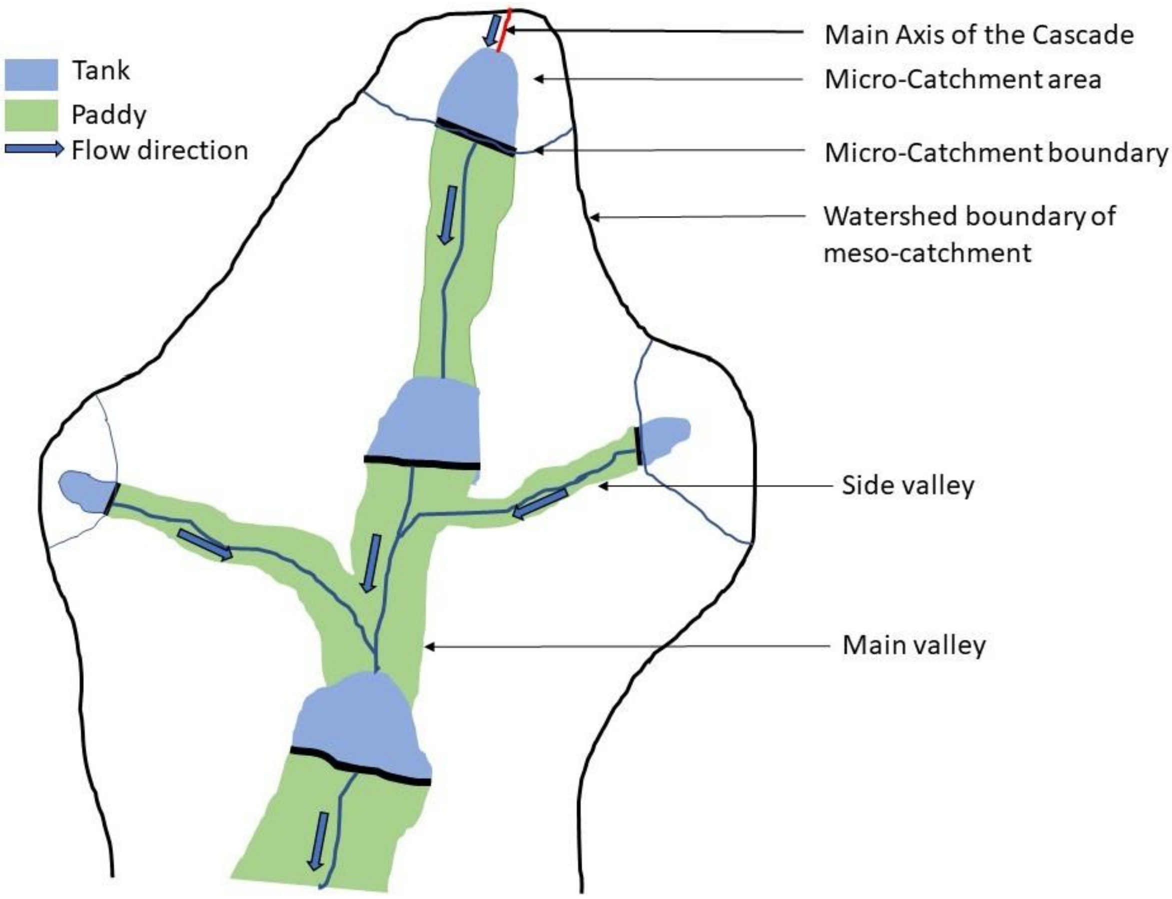



Figure 3: Schematic illustration of tank cascade system showing interconnected tanks, paddy fields, catchment area, and valleys (Adapted from: Panabokke et al., 2002).

**Southern India:** Arid and semi-arid regions of Southern Indian peninsula experience frequent droughts and high temperature. Watersheds in these regions are characterized by hot climate, scanty water availability, and erratic rainfall. Similar to the definition, structure and functions of TCS in Sri Lanka, Srivastava et al. (2021) defined the TCS in Southern India as a network of surface water holding structures in which a chain of tanks in the cascade forms a micro-watershed, with individual tank having its own catchment, tank bed area, and command area. Palanisami & Flinn (1988) reported that the tank irrigation systems of Tamil Nadu, Karnataka and Andhra Pradesh account for over 30% of the irrigated rice area. Van Meter et al. (2016) reported that more than 39,000 of RWH tanks exist in Tamil Nadu only. These RWH tanks each of 20–40 ha in size, which commonly take the form of earthen impoundments, are built from natural depressions in the landscape and have historically been designed to meet the water needs of subsistence farmers for rice production (Van Meter et al., 2016).

As in Sri Lanka, TCSs in India were constructed historically primarily to take care of the water needs for agriculture and for use by humans and livestock (Debnath et al., 2020, Chowdhury

& Behera, 2021). Such tanks are popular especially among farmers of South Indian states (Andhra Pradesh, Telangana, Karnataka, and Tamil Nadu). Readers are referred to Palanisami & Flinn (1988), Chinnasamy & Srivastava (2021), Krishnaveni et al. (2011), and Oppen (1987) for further details about the status and functions of TCSs in South India.

**Indonesia:** Darma et al. (2011) reported that the TCSs in the mountainous areas of West Sumatra, Indonesia have become the main source of water to irrigate large areas of terraced rice fields. As for TCSs in Sri Lanka and Southern India, water flows from upper to lower rice terraces carrying soil particles (sediments and nutrients) and thus provides continuous water flow to rice fields within and between the tanks in the TCS of West Sumatra too. Agus et al. (2006) found that sediment gain in terraced rice fields in Indonesia ranges from 2 to 5.4 Mg $ha^{-1}$ per cropping season with significant amount of nutrients.

### *2.1.2 Pond irrigation systems*

Ponds are water storage devices similar to, but generally smaller and shallower than, tanks. Ponds are predominant in Nepal (Bastakoti et al., 2016; Egloff et al., 2013), Bangladesh (Huq, 2017), China (Chai & Zeng, 2018) and India (Das et al., 2021; Debanath et al., 2020; Reddy et al, 2018), but are also important in Yemen in West Asia and Africa.

**Nepal**: In Nepal, ponds (or tanks) are locally known as *pokharis* and most often are found as the stand-alone water resources, although in some areas cascades of several ponds are also common. Ponds in Nepal vary considerably in size. Larger ponds (>5 ha) are generally natural ponds but many have been subjected to modernization for productive use, while smaller ponds are built and managed by the local people. Pond irrigation system generally comprises of the following components: intakes for one or several water sources, HDPE (High Density Polyethylene) pipes conveying the extracted water, flow-regulating chambers distributing water to one or several ponds, and water taps connected to the ponds serving as irrigation outlets (Egloff et al., 2013). Such ponds are replenished by floodwater in rainy season.

Ponds are primarily used for irrigation and fisheries, though their use varies across the geographical regions. Bastakoti et al. (2016) reported that many small to medium-sized community ponds are in most parts of the Terai region and could be a feasible alternative to surface irrigation. Despite potential, the large-scale uptake of pond irrigation is limited in Nepal owing to poor planning and implementation, poor functioning of input and output markets, lack of farmers' skill to use the ponds effectively, and poor institutional arrangements including unclear property rights.

**Yemen**: The Cisterns of Tawila, a well-known historic site in Aden in Yemen consists of ponds, varying size, shape and capacity, and can store enough water to last several months. For thousands of years, a network of aqueducts and basins has helped Yemen cope with both floods and drought. However, in recent years, the channels are mostly blocked with garbage (Baquhaizel et al., 2011).

**Africa**: Dixon et al. (2020) reported that RWH and small-scale irrigation systems in ancient times were common across North Africa and more recently, they have been growing much faster than the large-scale irrigation systems. For example, in Rwanda, government and non-governmental organizations introduced RWH ponds in 2007 to mitigate the effects of erratic rainfall in the arid and semi-arid areas and since then promoting the small-scale irrigation systems in the country (Zingiro et al., 2014). McCartney (2021) reported that small-scale storage structures, RWH and groundwater all play an important role in ensuring water supply at the household level and are widely perceived as critical irrigation systems for adaptation to climate change in the Volta basin. Many small reservoirs are constructed in the semiarid regions of northern Ghana and Burkina Faso too, with almost 70% with <1 ha and the remaining typically ranging from 1 to 35 ha. The reservoirs are hydrologically linked by the streams that have been dammed and are used as multipurpose water sources for irrigated agriculture and gardening, livestock watering and fishing, as well as personal hygiene, domestic uses, income-generation, and brickmaking (McCartney, 2021).

### 2.2 *Ground Water based Irrigation Systems*

Ground water based irrigation systems comprise of a physical structure that pumps groundwater to the surface for domestic and agriculture use. These systems in South Asian and Middle Eastern countries are quite large and complex and are either privately or community managed. Ground water based systems are referred to in different countries by different names even though they have very similar hydrological structure. For example, structures in Iran, Yemen, Jordan and Romania are called qanats and in Afghanistan and Pakistan are known as karez. A similar structure located in Ghail Bawazeer in Yeman is called as Ma'aayeen system (Baquhaizel et al., 2011). The structures in many Arabian countries are called Aflaj or Falaj.

**Qanat system**: Qanat is a gently sloping underground canal for transport of water from groundwater aquifer or water well to surface for irrigation and drinking (Fig. 4). Historical records indicate its presence in Asian and African countries as far as 3000 years back (Alemohammad & Gharari, 2017; Jayasena & Gangadhara, 2014). Alemohammad & Gharari (2017) reported that qanat systems exist in over 30 countries in Asian, African, European and American continents. Countries where qanats are popular include Afghanistan, Bahrain, China, India, Iran, Iraq, Jordan, Pakistan, Palestine, Russia, Syria, Saudi Arabia, Oman, Turkey, United Arab Emirates (Abu Dhabi) and Yemen in Asia, and Algeria, Egypt, Libya, Morocco and Tunis in Africa`. Today there are about 32,000 Qanats in Iran alone which provide about 10,000 million cubic meters (MCM) water per year (Alemohammad & Gharari, 2017). However, over time qanats have undergone many technological, social, moral, economical, and legal changes (Alemohammad & Gharari, 2017).

The qanat system in Iran is operated with successive wells joined by a horizontal conveyance canal and fed by the groundwater in the foothills (Jayasena & Gangadhara, 2014). In ancient times, a special (marginal) class of people were involved in their maintenance, which used extraordinary water measuring systems and adopted local water institutions or local laws (Jayasena & Gangadhara, 2014).

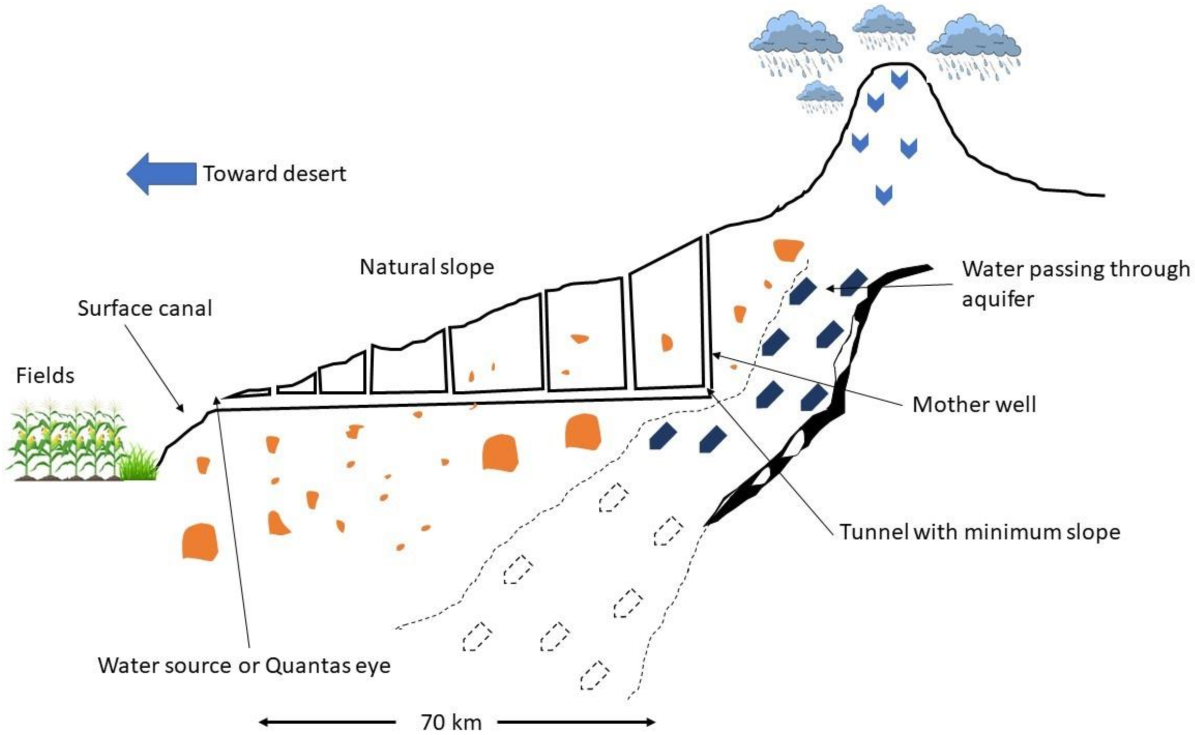



Figure 4: Schematic diagram of a qanat system. (Adapted from: Jayasena and Gangadhara, 2014). Mother well-This is the main water source and located at the extreme end along the series of wells; Shaft/wells- sunk at regular intervals along the route of the tunnel to access the tunnel for construction and maintenance (extraction of debris, soil, dredging and ventilation); Subterranean canal/ qanat tunnel- constructed by approaching through a series of wells or shafts dug and water is carried by gravity flow

**Karez system**: Karez system in Pakistan is similar to qanat system. The physical components of a typical Karez system commence with a mother well, constructed to tap groundwater upwards, often in an alluvial fan, and near the base of hills or mountains. The mother well serves as an outlet point for the upstream groundwater that then discharges into a gently sloping subsurface, sub-horizontal channel and flows under gravity to the village, where it is routed through above-ground channels for various uses (Ashraf & Hasan, 2020) (Fig. 5). This system extracts groundwater to surface by gravity without using any pumping equipment (Himat & Dogan, 2019). UNESCO and PCRWR conducted a cultural mapping of karezes in Pishin, Pakistan to assess its relevance for inclusion in the world heritage listing. It has been reported that some of the karezes were built in Balochistan before the arrival of the Mughals in 1525 A.D. (Ashraf & Hasan, 2020; UNESCO, 2021).

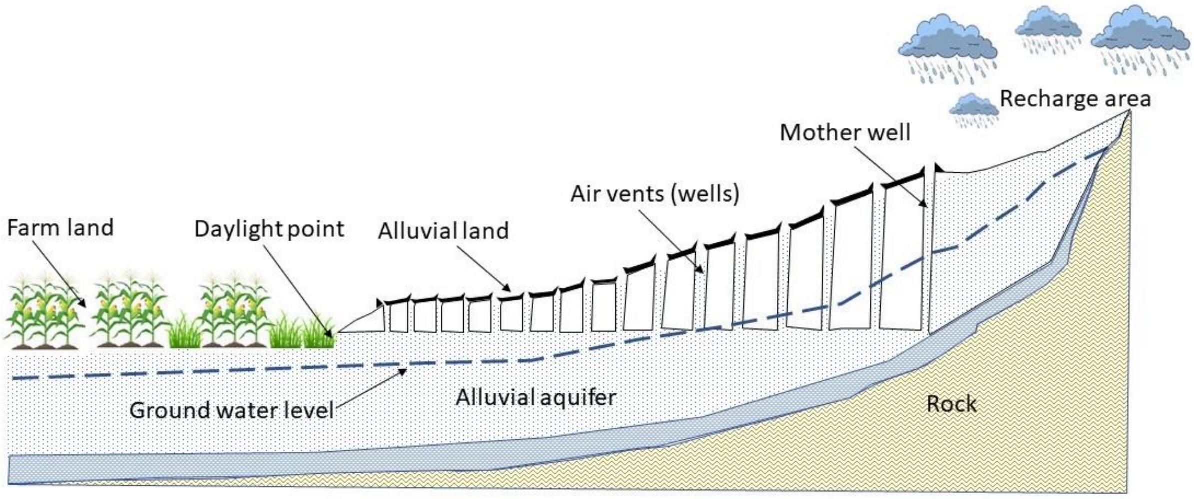



Figure 5: Schematic diagram of a typical Karez system. (Adapted from: Kahlown et al., 1987) Mother well – this well is the source of water located at the upstream; Air vent - to undertake operation, maintenance and removal of accumulated debris and gases, ventilation, fetching of water through bucket and pulley systems; Daylight point - point where water comes out from the subsurface channel.

**Aflaj/ Falaj system**: Omanis have developed the Aflaj irrigation system through surface and tunnel conduits as deep as 50m underground extending over long distances to transfer water from its sources to agricultural lands. The horizontal wells of aflaj assure holistic use of water for human consumption and ecological sustenance in the desert environment. Aflaj is managed collectively by village organizations with strong and cohesive social leadership institutions. It is managed in such a way that at the head end of the channels water is used for domestic uses and at the tail end for agricultural uses. Water in its channel flow is first used for drinking and then for mosques and forts, men's followed by women's bathing, washing clothes, irrigating perennial crops followed by seasonal crops, and a balance drained (Kotagama, 2021).

## 2.3 *Floodwater based Irrigation Systems*

Floodplain agriculture dates back to more than 5000 years in Pakistan and Yemen (Zenebe et al., 2022). Floodwater based irrigation systems rely on temporary floods and provide livelihoods for nearly 50 million smallholder farmers across water-stressed African basins (Zenebe et al., 2022). There are four widely practiced flood irrigation systems: (i) floodplain agriculture (flood recession and rise) in which cultivation occurs using receding and/or rising floodwater, (ii) flood inundation canals, which are fed by temporarily high-water levels in rivers to irrigate adjacent low-lying fields, (iii) spate irrigation, which makes use of short duration floods generated from mountain catchments, and (iv) depression agriculture, where shallow, seasonally waterlogged depressions retain sufficient moisture for dry season grazing and crop production (Kool et al., 2017).

Of four types, spate irrigation is quite popular in middle eastern and some African countries. Spate irrigation is defined as a pre-planting system of irrigation where water use is made of seasonal rivers (wadis) producing flash floods of short duration from highlands and mountainous areas (Hadera, 2001). These floods are diverted by structures (flow diversions, canals and control structures) to irrigate the lowlands (Tesfai & Stroosnijder, 2001) (Fig. 6). Spate irrigation is practised traditionally for rainfed cropping in arid and semi-arid areas where rainfall is too low such as the Middle East (Yemen, Pakistan, etc.) and African countries (Northern Africa, Sudan, Somalia, Eritrea) (Hadera, 2001; Tadesse & Dinka, 2018). However, in recent decades, the headworks, canals, and distribution structures of the spate irrigation system have been subjected to unsuccessful modernization interventions. These failures are due to heavy sedimentation, severe floods, or new designs that weren't compatible with local customs (Tadesse & Dinka (2018).

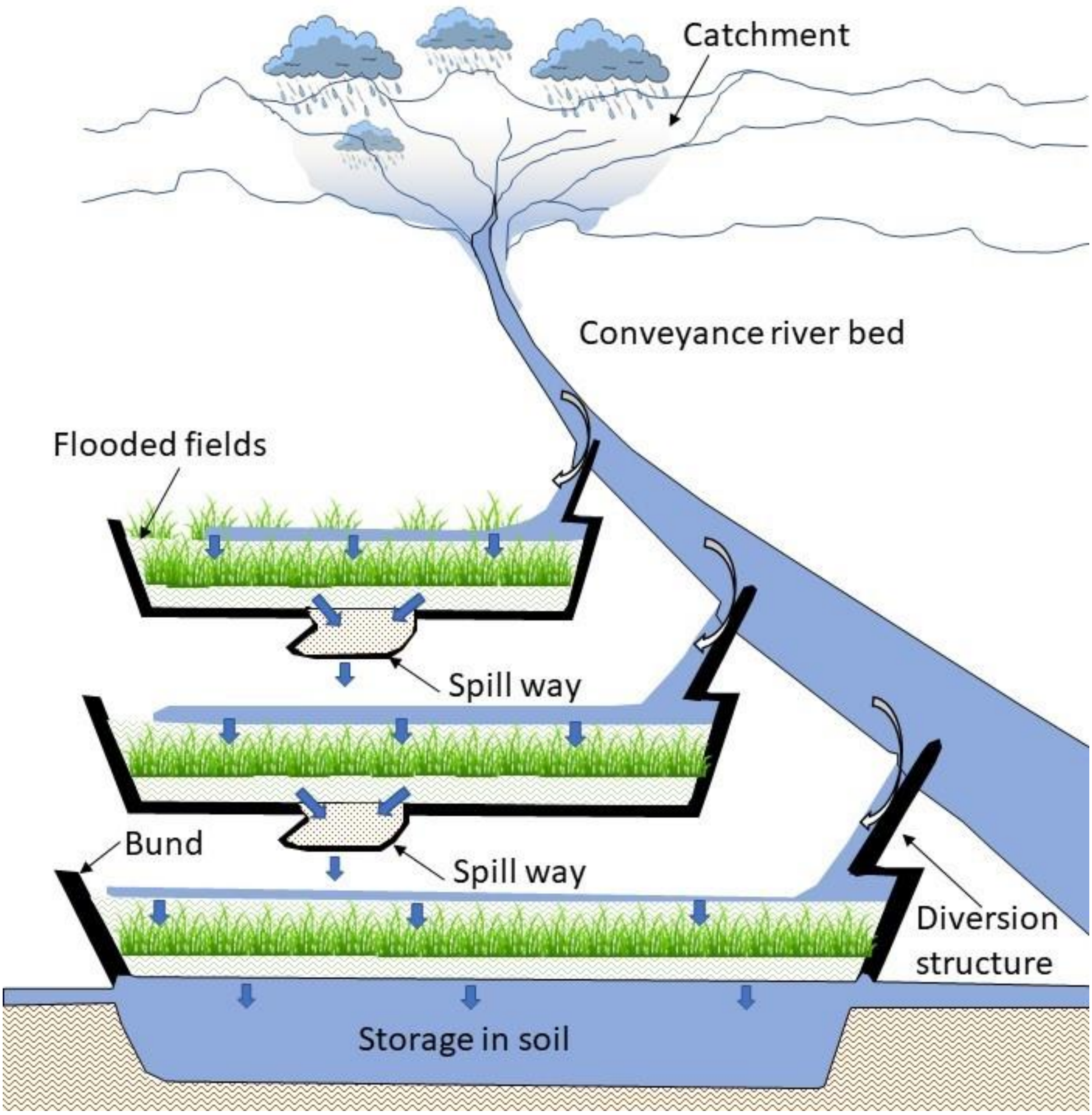



Figure 6: Schematic diagram of spate irrigation system (Adapted from: Mekdaschi & Liniger, 2013). Conveyance river bed flood water from mountain catchments is diverted by diversion structures to the fields by free intakes, diversion spurs, or bunds that are built across the river bed. Then water is channelled through a network of primary, secondary, and sometimes tertiary flood channels.

Spate irrigation has been used traditionally in Southern Tigray and in some semi-arid areas in Oromia region of Ethiopia (Mehari at al., 2011; MoA, 2011). Such irrigation systems were traditionally developed and managed by water users' associations but headed by individuals for construction, water allocation, and operation and maintenance (Belay and Bewket, 2013). These associations comprise of up to 20 to 30 groups each with 200 users who share a common main canal and its branches (MoA, 2011). The traditional floodwater management practised in Africa has promoted some fairness in floodwater sharing. It, however, has lacked critical agricultural floodwater management rules and practices, and has remained at a low level of production with subsistence livelihood system (Zenebe et al., 2022).

## 3. Degradation of AISs: Status, Causes, and Restoration Efforts

Tables 2 and 3 provide an account of studies related to status and causes of degradation, restoration efforts, and ecosystem services by country and typology respectively.

### *3.1 Status of Degradation*

Most of the 46 studies examined have discussed the indications of degradation of AISs in Sri Lanka and India accounting for 42.9%% (12) and 32.1%% (9) respectively, while no such cases were reported for Indonesia and China. In most cases, degradation was due to the combination of adverse natural factors (e.g., heavy and stormy rainfall) and social causes (e.g., human neglect). In one study for Pakistan, dry spells have led to the eventual downfall of the irrigation systems (Khan & Nawaz, 1995) (Table 2).

Table 2: Categorization of the status and causes of degradation, restoration efforts, and ecosystem services provided by various ancient irrigation systems (by country)[1]

| | **Indication of Degradation** | **Causes of Degradation** | | | **Restoration** | **Total** |
|---|---|---|---|---|---|---|
| | | **Natural causes** | **Physical causes** | **Social causes** | | |
| **Sri Lanka** | 12 | 3 | 2 | 10 | 9 | 36 |
| **India** | 9 | 2 | 4 | 8 | 7 | 30 |
| **Indonesia** | 0 | 0 | 0 | 0 | 0 | 0 |
| **China** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Pakistan** | 1 | 1 | 1 | 2 | 1 | 6 |
| **Nepal** | 1 | 0 | 0 | 1 | 1 | 3 |
| **Middle East** | 3 | 2 | 1 | 4 | 4 | 14 |
| **Sudan** | 1 | 0 | 0 | 0 | 0 | 1 |
| **Tunisia** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Mozambique** | 1 | 1 | 0 | 0 | 0 | 2 |
| **Egypt** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Nigeria** | 0 | 0 | 0 | 0 | 1 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Ethiopia** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | 28 | 9 | 8 | 25 | 23 | 93 |

Source: Authors’ calculations

[1]The total row count and the column count exceed the number of journal papers reviewed since some articles cover multiple aspects of causes of degradation and multiple countries.

Few studies reported that the degradation was due to the imbalance of water availability and requirement. Furthermore, the rapid change in socio-economic environment also led to the disruption of the AISs (Bandara, 1985; Khan & Nawaz, 1995; Reddy et al., 2018; Abeysingha et al., 2021). A common issue among the various irrigation schemes across Asia and Africa was the lack of user-based maintenance (Bastakoti et al., 2016; Reddy et al., 2018). Analysis of degradation based on the type of irrigation system showed highest number of studies conducted on rainwater-based TCS (21; 72.4%) followed by groundwater based karez system (3; 10.3%), while one study was reported for floodwater based spate irrigation system (Abdelgalil & Bushara, 2018).

Studies on TCSs in India and Sri Lanka have discussed aspects related to system degradation, impact of climate change, water balance and water quality, irrigation efficiency, rehabilitation strategies, etc. Those studies have shown that the systems are getting deteriorated, though considerable attention is being paid to rehabilitation (Turner, 1994; Reddy et al., 2018). Abeysingha et al. (2021) and Chinnasamy & Srivastava (2021) thoroughly discussed the degradation and rehabilitation of the hydrological structures in all systems in India and Sri Lanka. Water quality studies were only reported for TCSs and qanats whereas water wastage was discussed for TCSs, dams, and qanats (Jayasena & Gangadhara, 2014; Abeysingha et al., 2021). Van Meter et al. (2016) reported that a large fraction of the tank water was being wasted and that efficient management of structures in tanks was necessary. On the otherhand, in qanats evaporation losses are minimal and their underground coverage protects against sediment deposition from windstorms (Ashraf & Hasan, 2020). Water losses from small reservoirs in semi-arid regions are attributed primarily to evaporation, where up to 40% of the tank stored water could be lost through this process but could be reduced significantly (by 70-85%) using floating covers (Mady et al., 2020).

In Yeman, most of the dams have been abandoned are mostly broken or reused as terraces these days (Charbonnier, 2009). In Pakistan, Ashraf & Hasan (2020) reported the key factors that resulted in the threatening of the karez system. These were: (a) mining of groundwater and lowering of water tables resulting from indiscriminate development of deep tube wells, (b) reduction in flow because of siltation of channels due to deferred maintenance, (c) soil erosion affecting the mother well and the vertical shafts, (d) lack of skilled manpower, and (e) lack of support from the government regarding repair and maintenance of the systems. Today, 60–70% of the karezes in Pakistan are not in use due to drought and low groundwater recharge. Out of total 5887 karezes in Afghanistan, 600 (11%) were identified as being active while 5276 (89%) as inactive (Himat & Dogan, 2019).

### *3.2 Causes of Degradation*

The review revealed that the causes of degradation (natural, physical, and social) of the AISs varied among the countries (Table 2). Analyzing the degradation studies by country, twenty-five studies (52.5%) mentioned social causes such as urbanization, population rise, and other socio-economic changes as the main causes of degradation (e.g., Khan & Nawaz, 1995; Satishkumar et al., 2010; Abeysingha et al., 2021). Investigation of individual countries revealed that in Sri Lanka, there were three cases of degradation caused by natural factors (Geekiyanage & Pushpakumara, 2013; Ratnayake et al., 2021; Kumari et al., 2019). In contrary, in China, there was no indication of the causes of degradation (Chai & Zeng, 2018).

Table 3: Categorization of the status and causes of degradation, restoration efforts, and ecosystem services provided by various ancient irrigation systems (by typology)[1]

| | | Indication of Degradation | Causes of Degradation | | | Restoration | Total |
|---|---|---|---|---|---|---|---|
| | | | Natural Causes | Physical Causes | Social Causes | | |
| **Rainwater Based Irrigation Systems** | Cascade Tanks | 21 | 5 | 6 | 18 | 16 | 66 |
| | Ponds or Minor Tanks | 2 | 0 | 1 | 2 | 2 | 7 |
| | Small Dams | 1 | 1 | 0 | 0 | 1 | 3 |
| **Groundwater Based Irrigation Systems** | Qanats | 1 | 0 | 1 | 2 | 1 | 5 |
| | Karez | 3 | 3 | 1 | 4 | 3 | 14 |
| | Aflaj/ Falaj | 0 | 0 | 0 | 0 | 0 | 0 |
| **Floodwater Based Irrigation Systems** | Flood Plain | 0 | 0 | 0 | 0 | 0 | 0 |
| | Flood Innundation | 0 | 0 | 0 | 0 | 0 | 0 |
| | Spate | 1 | 0 | 0 | 0 | 0 | 1 |
| | Depresssion | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | | 29 | 9 | 9 | 26 | 23 | |

Source: Authors' calculations

[1]The total row count and the column count exceed the number of journal papers reviewed since some articles cover multiple aspects of causes of degradation and multiple AISs.

The analysis of causes of degradation by type of AIS showed large number studies on rainwater based irrigation system. The most prevalent cause of deterioration of cascade tanks was related to social issues such as negligence and lack of participatory maintenance (Hakeem & Raju, 2009; Kekulandala et al., 2021). In Sri Lanka, natural causes such as high intensity and erratic rainfall patterns, resulting in large fluctuations in tank water availability, have contributed to the degradation of cascade tanks (Geekiyanage & Pushpakumara, 2013; Srivastava & Chinnasamy, 2021).

Many studies in India and Sri Lanka have reported that the reduction in tank recharge capacity due to tank siltation and improper maintenance has resulted in declining number and performance of village tanks (Nanthakumaran et al., 2021; Kekulandala et al., 2021; Geekiyanage & Pushpakumara, 2013; Abeysingha et al., 2021). Factors such as variation in rainfall, siltation, encroachment of tank beds and catchment areas, and channel obstructions have reduced the tank-irrigated area over the years (Chowdhury and Behera, 2018). Hakeem and Raju (2009) stressed that years of neglect and indifference in tank maintenance and management have eroded their functional efficiency and jeopardized their multifarious benefits. All these factors have caused many tanks in India and Sri Lanka starting to deteriorate and underperform in terms of delivery of irrigation water and groundwater recharge (Debnath et al., 2020). Likewise, social and natural causes have led to the degradation of karezes in Pakistan and Afghanistan (Ashraf & Hasan, 2020).

### 3.2.1 *Changes in climate and natural environment*

Climate change has an impact on AISs in numerous ways (Chinnasamy & Srivastava, 2021; Ratnayake et al., 2021). The erratic rainfall pattern has been a major cause for large fluctuations in water depth inside tanks. Chinnasamy & Srivastava (2021) reported 0–50% fluctuations in tank water depth in India. Similarly, increasing climate variability has been identified as one of the key causal factors for the reduction of ecological and socio-economic productivities of the TCSs in Sri Lanka and reduced karez system's efficiency due to low precipitation during 1997-2017 in Pakistan (Macpherson et al., 2017; Ratnayake et al. (2021)). In the past, the maintenance of the karez system was carried out by workers which ensured sustainable water use for the communities but now the karezes have been impacted by poor maintenance, overcrowding, war, and insecurity (Himat & Dogan, 2019).

For spate irrigation in African countries, increasing soil erosion caused by erratic rainfall in highlands and breakage of the irrigation structures by destructive floods in downstream areas have been the main problems. The eroded soil from highlands is however high in available phosphorus and potassium. Hence, the eroded soil transports these nutrients together with some nitrogen and eventually gets deposited on spate irrigated lowland fields in the downstream. This results in soil nutrient enrichment which enables farming without or with reduced application of chemical fertilizer (Hadera, 2001).

#### 3.2.2 *Lack of maintenance of irrigation infrastructure*

The karez irrigation system may not be used effectively if construction and maintenance processes are not carried out properly and regularly, and this could adversely affect the agricultural production, water supply and social life. For these reasons, Himat & Dogan (2019) suggested that the associated organizations involved in karez systems in Afghanistan be encouraged for rehabilitation of karez infrastructures and water supply system. Azami et al. (2020) also suggested for restoring ancient karez tunnels in Afghanistan and upgrading them using modern sustainable technologies such as redesigning canals to make water distribution more efficient. Likewise, most of the dams in Yemen have been abandoned, which today are either mostly broken or reused as terraced walls (Charbonnier, 2009). Vermillion & Al-Shaybani (2004) suggested using strategies to facilitate the building of local institutions to govern, manage and finance operation and maintenance of dams and water delivery networks.

Extraction or mining of ground water through indiscriminately developed and used deep tube wells in qanat system in Pakistan can lower water tables and reduce water flow. This is further aggravated by siltation and degradation of channels due to deferred maintenance, soil erosion affecting the mother well and the vertical shafts, and lack of skilled manpower and support from the government for repair and maintenance (Ashraf & Hasan, 2020).

In Eritrea, spate irrigation systems were developed and managed by water users' associations while water allocation, operation and maintenance activities were headed by individuals (Tadesse & Dinka, 2018). Spate systems however have been the subject of inappropriate modernization interventions such as heavy investments on head works and canals and distribution structures with an aim for improving floodwater diversion efficiency.

Consequently, in many cases, the modernization interventions were not successful due to heavy sedimentation, occurrence of high floods, local water distribution rules, or the new designs not coherent with indigenous practices (Tadesse & Dinka, 2018). Hence, spate irrigation is prone to high risks and uncertainties such as too little or no floodwater, structural damage by large floods, and increased sedimentation of canals and fields.

### *3.2.3 Land use change, inappropriate external interventions, and lack of proper management*

During the early stages of irrigation development, communal management was innovative, sustainable and resilient with cooperation and long-term relationships between the irrigators within the community. Overtime, cooperation became more challenging, demonstrating the tragedy of commons in irrigation management in many countries in Asia (Takeshima & Edeh, 2017). Palanisami (1991) reported that long-term poor management of tanks resulted in tank siltation, foreshore encroachment and poor tank structures, resulting in reduced tank storage capacity (by 15-20%) in Southern India. In addition, shifting away from community management also led to the waning of the irrigation system in India (Debnath et al., 2020).

One of the factors that resulted in the degradation of the TCSs in Sri Lanka was the removal of *Rajakariya*, a semi-feudal system, by the British administration in 1832 without providing any alternative system for maintenance and repair of the village tanks. This resulted in negligence in management and repair and maintenance of many AISs, including the TCSs, ultimately resulting in their degradation. Furthermore, improper maintenance of tank bunds and canals, tank siltation, improper structural repairs, intensive agricultural practices using excessive chemical fertilizer usage, climatic change, incidence of malaria, depletion of soil fertility, foreign invasions and famine were some reasons for collapse of the TCSs. Thus, Dharmasena & Kadupitiya (2021) suggested for further studies to understand how changes in cascade ecology impact the capacity of the system to supply ecosystem services.

Excessive ground water extraction from tube wells has become a serious threat in areas where tank cascades (Srivastava & Chinnasamy, 2022) and qanats (Ashraf & Hasan, 2020) are located. Lack of skilled manpower and support from the government for repair and maintenance of qanats led to their degradation in Iran (Alemohammad & Gharari, 2017). Likewise, thousands of karezes in Afghanistan were destroyed due to drying up, over-exploitation of groundwater, increased demand for deep wells, and poor protection and maintenance (Azami et al., 2020).

Land use change has also impacted on water delivery and availability from the AISs. For example, Srivastava & Chinnasamy (2021) reported that increased urbanization resulting from change in land use was the primary cause of high runoff (40-60% of rainfall) from tank catchments in Southern India. This resulted in variable (0–15%) seasonal water availability from the tank across catchments, with summer season recording the least tank storage (0–8%) (Srivastava & Chinnasamy, 2021). Sirimanna et al. (2022) found that with the expansion of home gardens and farmlands, the tank components of some TCSs in Sri Lanka have changed over time causing an ecological imbalance and deterioration of tank structures, and reduced efficiency, effectiveness and resource footprint. Kulasinghe & Dharmakeerthi (2022) evaluated the extent to which land management practices affect sustainability of tank watersheds in Sri Lanka. They observed that the use of scrub/shrub lands has degraded the soil organic matter reserves and soils in lower position of the tank would continue to degrade. They recommended for introducing policies on land use and input management for improving the sustainability and resilience of the TCSs. Studies on floodwater based systems in Africa and qanat and karezs system in Afghanistan, Pakistan and middle east have also shown evidences of neglect or poor management resulting in their deterioration and low crop productivity and profitability (Baquhaizel et al., 2011; Macpherson, et al., 2017; Vermillion & Al-Shaybani, 2004; Zenebe et al., 2022).

### *3.3 Restoration of AISs*

The review revealed that most studies on restoration efforts were focused on Sri Lanka and India accounting for 9 (39%) and 7 (30%) respectively. In Indian studies, introducing policy initiatives and intervention measures were discussed (Reddy et al., 2018). Use of satellite data was identified as an initiative for restoring the irrigation systems (Hakeem & Raju, 2009) and of remote sensing, GIS and GPS for rehabilitation of tank cascades in India (Krishnaveni et al., 2011). In middle east countries, sustainable management of irrigation systems was suggested as an effective restoration approach (Himat & Dogan, 2019; Azami et al., 2020).

The restoration efforts by AISs showed most studies (16; 69.6%) focused on TCSs. Reddy et al. (2018) and Srivastava & Chinnasamy (2021) suggested that building ownership of TCSs could aid in their restoration. Furthermore, proper management of TCSs in Sri Lanka was reported as an effective restoration effort (Abeysingha et al., 2021). There were also cases of rehabilitation efforts for degenerated karezes in Afghanistan (Azami et al., 2020). One such instance discussed the possibility of encouraging the existing farmers' or irrigators' organizations for their rehabilitation and improved water supply in Pakistan and Afghanistan (Himat & Dogan, 2019).

Johnson et al. (2004) argued that relatively more attention needs to be paid to developing and strengthening locally controlled organizations for reforming irrigation institutions compared to restructuring public agencies and required supporting services. They suggested for maintaining a balance between the local organizations and public agencies as the pressure for institutional reform increases globally. Albinson & Perry (2002) highlighted the importance of using a structured design with clear operational rules and the transparent monitoring system in developing a participatory management of an irrigation system.

Abeysinghe et al. (2021) reported that the satisfaction on the quality of water for drinking influenced the participatory decision of the community for rehabilitation of Thirappane TCS in Sri Lanka. Paranage (2018) noted the importance of treating the relationship between water management infrastructure and society as a complex socio-material assemblage for a surface irrigation system and a TCS, also in Sri Lanka. Likewise, Dayananda et al. (2021a, 2021b) reported that the restoration of TCSs needs to be coupled with market interventions to promote high value agriculture as cost for desiltation cannot be covered with returns from paddy cultivation alone.

## 4. Ecosystem Services Provided by ancient irrigation systems

Ecosystem services can be defined broadly as the conditions and processes through which natural ecosystems and species that make them up sustain and fulfill human life (Daily, 1997). Costanza et al. (1997) defined ecosystem services as the benefits human populations derive, directly or indirectly, from ecosystem functions. Four types of ecosystem services have been distinguished by the scientific body: provisioning, regulating, cultural, and supporting (Millennium Ecosystem Assessment, 2005; Xiofei et al., 2020). Provisioning services include goods produced by the ecosystems while regulatory services are benefits from regulation of ecosystem processes. Cultural services are non-material benefits from ecosystems which include the spiritual, recreational, aesthetic and educational values. Supporting services are factors necessary for producing ecosystem services. Collectively, ecosystem services can be described as provisioning of food, water, fiber and fuel; regulating droughts, floods and water purification; providing humans with recreational, spiritual and aesthetic values, and supporting basic ecological properties/processes (Biswas et al., 2022; Haines-Young & Potschin, 2018; Millennium Ecosystem Assessment, 2005; Ojha et al., 2022).

Tables 4 and 5 provide the distribution of studies on ecosystems services and functions by country and typology, respectively. Annex 2 of supplementary material provides the detailed account of ecosystem services provided by various AISs. The review demonstrated that as compared to other countries, more detailed information about the ecosystems services have been reported for Sri Lanka followed by India (Table 4). Most studies (40; 47.6%%) dealt with AISs providing provisioning services such as water for agriculture and fishery in Sri Lanka (Paranage, 2018). Studies on regulatory services were mostly from Sri Lanka and India (Jayatilaka et al., 2003; Chinnasamy & Srivastava, 2021). One of the most important regulatory services was flood prevention and control, although other services such as erosion control, groundwater recharge, and evaporation minimization were also reported (Geekiyanage & Pushpakumara, 2013; 2018; Melles & Perera, 2020). Likewise, cultural services such as religion specific rituals or chanting, or start of certain activities based on auspicious times (e.g., movement of the moon), and such practices passed through generations were reported in studies from Sri Lanka (Marambe et al., 2012). A study from a middle east country also reported presence of cultural services, such as providing solidarity in social life, cultural diversity, and spiritual and religious values (Himat & Dogan, 2019). Bandara (1985) & Geekiyanage & Pushpakumara (2013) emphasized that AISs have paved the way for cultural customs and development of civilizations and Abeysingha et al. (2021) on irrigation schemes' contribution to scenic views and aesthetic functions in Sri Lanka. Finally, Geekiyanage & Pushpakumara (2013) and Ratnayake et al. (2021) discussed supportive services such as establishing habitats for flora and fauna in Sri Lanka, and Jayasena & Gangadhara (2014) and Abdelgalil & Bushara (2018) on water cycling in middle east and African countries.

Table 4: Ecosystem services provided by various ancient irrigation systems (by country)[1]

| | **Ecosystem Services** | | | | **Total** |
|---|---|---|---|---|---|
| | **Provisioning Services** | **Regulatory Services** | **Cultural Services** | **Supporting Services** | |
| Sri Lanka | 16 | 11 | 9 | 9 | 45 |
| India | 11 | 4 | 0 | 0 | 15 |
| Indonesia | 0 | 0 | 0 | 1 | 1 |
| China | 1 | 0 | 1 | 0 | 2 |
| Pakistan | 2 | 0 | 0 | 0 | 2 |
| Nepal | 1 | 0 | 0 | 0 | 1 |
| Middle East | 5 | 2 | 4 | 1 | 12 |
| Sudan | 1 | 0 | 0 | 1 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| Tunisia | 0 | 1 | 0 | 0 | 1 |
| Mozambique | 1 | 0 | 0 | 0 | 1 |
| Egypt | 0 | 0 | 0 | 0 | 0 |
| Nigeria | 1 | 0 | 0 | 0 | 1 |
| Ethiopia | 1 | 0 | 0 | 0 | 1 |
| Total (AISs) | 40 | 18 | 14 | 12 | 84 |

Source: Authors' calculations

[1]The total row count and the column count exceed the number of journal papers reviewed since some articles cover multiple ecosystem services and multiple countries.

Table 5: Ecosystem services provided by various ancient irrigation system (by typology)[1]

| | | Ecosystem Services | | | | Total |
|---|---|---|---|---|---|---|
| | | **Provisioning Services** | **Regulatory Services** | **Cultural Services** | **Supporting Services** | |
| **Rainwater Based Irrigation Systems** | Cascade Tanks | 26 | 15 | 9 | 10 | 60 |
| | Ponds or Minor Tanks | 4 | 0 | 1 | 1 | 6 |
| | Small Dams | 3 | 1 | 1 | 1 | 6 |
| **Groundwater Based Irrigation Systems** | Qanats | 2 | 1 | 2 | 2 | 7 |
| | Karez | 3 | 1 | 2 | 0 | 6 |
| | Aflaj/ Falaj | 1 | 0 | 1 | 1 | 3 |
| **Floodwater Based Irrigation Systems** | Flood Plain | 2 | 0 | 1 | 1 | 4 |
| | Flood Inundation | 2 | 0 | 0 | 0 | 2 |
| | Spate | 1 | 0 | 0 | 1 | 2 |
| | Depression | 2 | 1 | 1 | 1 | 5 |
| | Total (AISs) | 46 | 19 | 18 | 18 | 101 |

Source: Authors' calculations

[1]The total row count and the column count exceed the number of journal papers reviewed since some articles cover multiple ecosystem services and multiple AISs.

Annex 3 of supplementary material provides details of the ecosystem services provided by TCSs of Sri Lanka. Dharmasena & Kadupitiya (2021) provided a comprehensive list of ecosystem services arising from TCSs based on the perception of the community and other stakeholders. Ratnayake et al. (2021) also provided ecologically important micro-land uses of the tank system and their provisioning, regulatory and supporting services. Likewise, Vidanage et al. (2022) reported that the TCSs provide storage water for irrigation with associated benefits of provisioning water for drinking, washing and bathing for human, water for fisheries and livestock, control of soil erosion, flood prevention and water quality control, reducing vulnerability to drought, retaining the health of the soil, and maintaining ground water and micro-environment. Benefit transfer method is used to estimate economic worth of ecosystem goods or services at a research site based on the valuation study conducted in other sites

(Kumar, 2010). Using this method, Vidanage et al. (2005), Vidanage (2019) and Dayananda et al. (2021) estimated the monetary value of components of a TCS in Sri Lanka. Vidanage (2019) used the Choice Experiment Method to assess nonmarket values of small TCSs. Interestingly, results showed local farmers' willingness to pay to restore the degraded small tanks.

When analysed by typology, most studies focussed on rainwater-based systems, with more comprehensive information for TCSs (Table 5). All irrigation schemes extensively provided provisional service of water for agricultural purposes. Among the groundwater-based systems, studies reporting ecosystems services provided by karezes were greatest followed by qanats with higher number of studies on provisioning followed by regulatory services. Among the flood-based types, studies on floodplains were highest followed by depressions and spate. Most studies on flood-based systems reported their role in providing the provisioning services.

### *4.1 Provisioning Services*

**TCSs:** The cascades, tanks and their associated components are resilient providing multiple uses with direct and indirect options for irrigation water management (Geekiyanage & Pushpakumara, 2013; Bandara, 1985; Renwick 2001; Thennakoon, 2017; Dharmasena & Kadupitiya, 2021; Vidanage et al., 2022). The diversity of the ecological system with the catchment forests, aquatic habitats, common areas, land use zoning system, and various crop combinations emerged as a response to ensure sustainable agriculture given the challenges of recurrent water storage and drought in seasonally dry environments prevailed in the TCSs (Bandara, 2009; Marambe et al., 2012). The crops suitable for lowland areas are cultivated in paddy (lowland) fields in wet (*Maha)* season which provide a staple food, although during the dry season (*Yala)* such area is also cultivated with other crops such as chilli (*Capsicum frutescens*), maize and kurakkan (*Eleusine coracana*). In general, TCSs provide around 25% of paddy production in Sri Lanka (Wijekoon et al., 2016). The rainfed upland fields are used for cultivation of other field crops such as maize and vegetables such as kurakkan, manioc *(Manihot esculenta*), sweet potato (*Ipomoea batatas*), pumpkin (*Cucurbita moschata*), luffa (*Luffa aegyptiaca*), pole beans (*Phaseolus vulgaris*) and other kinds of beans, gingelly oil (*Sesamum indicum* L.), etc. The tank also serves as the habitat for inland fisheries and aquatic plants which provide fish as a main protein source, lotus (*Nymphaea nouchali*) roots and seeds, kekatiya (*Aponogeton crispus*), and other edible aquatic plants. The home gardens around houses of the local communities residing near the tanks are usually cultivated with perennial crops such as coconut (*Cocos nucifera* L.), jackfruit (*Artocarpus heterophyllus Lam*.), breadfruit (*Artocarpus altilis*), mango (*Mangifera indica*), timber trees, medicinal plants, and vegetables. Interceptor (*kattakaduwa*), a land area with trees and shrubs dominated by native and endemic trees and plant species with medicinal values, with dual function of acting as wind barrier and water hardness up-taker, is located in between the sluice gate and paddy fields. Species associated with waterlogging environment in interceptor and reed bed (*perehana*) such as sedges (*pan*) provide material for industries for weaving. The forest in the catchment area protects the tank and provides non-timber forest products and habitat for wildlife. The catchment area, upper inundation area *(Wew-thaulla)*, home garden, and rice fallow provide grazing lands for livestock such as cattle, buffalo, and goat. The entire system components provide food and nutrient requirements and farming and livelihood opportunities to the settlers depending on the TCSs. The TCSs harvest rainwater and mitigate floods and drought (Vidanage et al., 2022). TCSs in India provide provisioning services in the form of drinking water, irrigation, fisheries, livestock, agriculture, shell, fodder, medicinal plant, vegetable, fuel, wood, flower, grass, fruits, aquaculture, domestic, washing, and bathing.

**Qanat and Ma'aayeen system**: Qanat irrigation systems in Iran provide provisioning services such as water to irrigate the community garden (bustan) to grow food crops, drinking, domestic, and livestock water, along with small-scale agriculture (Jayasena & Gangadhara, 2014). Ma'aayeen irrigation system in Yemen, a traditional water harvesting system, provides water for irrigation and mosques for ablution, washing, bathing and watering animals, to school and mosque gardens for irrigation, drinking, domestic, and livestock water, along with small-scale agriculture (Baquhaizel et al., 2011).

**Dams**: Dams in Yemen provide provisioning services such as irrigation and cultivation of vines and summer crops such as sorghum, water for domestic use, and irrigation (Maraqten, 2017).

### *4.2 Regulatory Services*

Flood control as a regulatory service is provided by TCSs (Abeysingha et al., 2021; Van Meter et al., 2016) and flood-based irrigation systems (Haile, 2015; Tadesse & Dinka, 2018). Also, both systems are important to overcome water scarcity problems under drought conditions and play a significant role in recharging ground water. Groundwater table in TCSs is raised through percolation and then gradually the percolated water is released to the tank through subsurface flow. Recharged groundwater table allows the villagers to extract water for drinking purposes from their home-built wells. The special component upstream tree belt (*gasgommana*) in TCSs acts as a wind barrier reducing the evaporation losses. Further, phyto-remediation is a unique feature in TCSs helping in water purification. Likewise, qanats offer regulatory services by acting as a buffer and becoming resilient against drought. The regulatory services are manifested by minimising the evaporation losses because the water passes through the underground canals. Further, its underground coverage protects against sediment deposition from windstorms and thus maintains water quality.

### 4.3 *Cultural Services*

The review showed that there are many socio-cultural or socio-economic services provided by TCSs in Sri Lanka. The *kem* methods, which are natural and inexpensive ritualistic crop protection measures in paddy fields while minimising environmental pollution and the destruction of other organisms, are among such cultural services. There are also some folk poems that come from an oral tradition. Ancient people sing folk songs to alleviate their feelings of isolation, sadness, and tiredness when engaged in agricultural tasks like planting, harvesting, and protecting the field from wild animals at night. Furthermore, there are recreational, spiritual, and aesthetic values of TCSs. Tank dependent people use their traditional knowledge and practices such as cosmic and astrology in performing agricultural practices. Furthermore, there are norms, rituals, religious beliefs (e.g., Buddhist values and practices) and customary laws within TCSs. MoA and FAO (2016) discussed about specific folklore, folksong, folk poems, folk music, folk drama, beliefs and rituals, traditional festivals and practices, and traditional arts and crafts as related to the village tank farming cultures in Sri Lanka. Some examples of such services include: (i) *Pal kavi* (poems recited by men at night to watch hut to protect fields from wild animals), (ii) *Nelun Kavi* (poems recited by women during weeding and gap filling in paddy fields), (iii) *Andahera* (verses recites during ploughing and threshing), (iv) folk dances such as *Goyam natuma* (reaping dance), *Kalagedi natuma* (traditional dance with a pot) and *Kulu natuma* (winnowing dance), and (v) *Sokeri* dance (a dramatic dance performed after harvesting paddy) (MoA and FAO, 2016).

MoA and FAO (2016) also provided some examples of prominent rituals such as: *Mutti nameeme mangallaya* (ceremony of pot, a ritual performed after harvesting to show gratitude to the god), *Kiri ithirim mangallaya* (after reaping of each crop, this ritual is performed to thank gods and deities for protecting their crops and cattle against evils and natural disasters) and *Kohombakankariya* (most venerated and elaborated traditional dance of healing rituals held to invoke the blessings of the twelve deities). Other rituals and related practices include: (i) *Aluth sahal mangallaya* - performed to offer milk rice cooked with the first portion of the paddy harvest to the Buddha collectively at the village temple, (ii) praying gods for crop protection - performed when there are disastrous situations such as drought, floods, epidemics, and (iii) ritualistic plant protection method such as use of *Kem*. Dharmasena and Kadupitiya (2021) reported that the recreational and aesthetic values and culture, traditions, and customs and practices provided by TCSs were the top ranked cultural services in Sri Lanka.

Likewise, in Iran, though many qanats have now been degraded, some (e.g., Kish qanat in Kish Island in South and Fin Garden Qanat) are being rehabilitated and converted to museums attracting many tourists each year thus providing cultural services indirectly (Alemohammad & Gharari, 2017).

### *4.4 Supporting Services*

Meeting household food security is the most valued support service provided by all AISs (Hadera, 2001; Geekiyanage & Pushpakumara, 2013; Jayasena & Gangadhara, 2014; Haile, 2015; Chowdhury & Behera, 2021). Rice is the main crop in India and Sri Lanka where AISs provide food security for large number of populations. In Yemen, vines, sorghums, and many other crops are irrigated using water from dams and hence become crucial for meeting food security (Baquhaize et al., 2011). In qanats too, water is used to grow crops such as cereals, pulses, vegetables, fruits, vines, olives, fruit trees, fodder, cotton, and tobacco. Furthermore, qanats provide water for community gardens which help meet food security. Likewise, spate irrigation in Africa is used to cultivate sorghum (Hadera, 2001) and sugarcane (Haile, 2015). Other most valuable supporting service provided by TCSs is conserving and maintaining the biodiversity by providing habitat for various flora and fauna (Dharmasena & Kadupitiya, 2021; Ratnayake et al., 2021).

## 5. Conclusions and Research Needs

This review identified and developed the typologies of AISs, documented their status and causes of degradation, and their ecosystem services and functions in Asia and Africa. Many AISs are in threat of degradation due to both natural and human induced causes. Climate change and associated factors and decreasing participation of local farmers and communities in their management were identified as main causes of degradation. Government and private sector support for their maintenance and rehabilitation has generally been declining though a renewed interest has been shown for TCSs in Sri Lanka due to their recent recognition by the FAO.

The review showed that although the provisioning services of TCSs have been adequately researched and documented long-term changes of such services have not been addressed. Further, the regulating, cultural and supporting services of TCSs have not been properly estimated and documented. Moreover, very little has been researched with the use of novel methods to assess the values of various ecosystem services. Further, much attention has been paid on individual tanks and there is paucity of knowledge on the evolution of the TCS as a whole and their changes with time. Hence, establishment of long-term permanent research program to study the productivity and sustainability of TCSs with multi-disciplinary teams is an urgent requirement.

Further, the failures in community management systems have led to degradation of many AISs and declining ecosystems services. The evidence provided suggests that it is critical to properly manage the AISs to remain resilient and sustainable and provide ecosystems functions and services, particularly for delivering irrigation water to crops and livestock and drinking water to local populations in the future. The review also revealed that the traditional community management systems such as *Rajakariya* in TCSs of Sri Lanka, and water users' associations in spate irrigation or local communities' associations in karez or qanat systems in Afghanistan, Pakistan, and middle east countries had played a major role in the sustainability of these systems in the past. Hence, the review suggests that the proper management of the AISs jointly by the local communities and government organizations with systems thinking would be required to preserve the ecosystems and provide various types of ecosystem services.

The provisioning services provided by AISs to the communities residing in and around those AISs are sizable. The review implied that even though the various types of ecosystems services provided by some AISs were not elaborated by previous researchers, most AISs have the potential to provide such services once they are restored and maintained. Therefore, it is important to treat AISs as global public goods and encourage global donors and national governments to invest in their restorations while supporting the local communities to engage them in maintenance of such important systems.

It is evident that AISs are diverse. Thus, the factors that led to their success in the past and the status and causes of their degradation are also highly context specific. This review shows that research investigations have been conducted only for certain AISs in some limited locations of some countries. New research is required to ascertain factors that led to successes vis-a-vi-s failures of AISs for sustainable rural development, to assess net returns on investments, and to ascertain investment needs through environmental cost-benefit analysis in Asia and Africa.

## Acknowledgement

This work was financially supported by the World Bank funded project (AHEAD/RA3/DOR/STEM/PDN/No 52) administered by the Ministry of Higher Education, Sri Lanka.

## References

Abdelgalil, E., Bushara, A.I., 2018. Participation of water users associations in Gash spate system management, Sudan. Water Science 32(1), 171-177. https://doi.org/10.1016/j.wsj.2016.12.002.

Abeysingha, N.S., Dissanayake, S.P., Sumanaweera, S.,De Silva, S.S.K., 2021. Cascade tank water quality management: A case study in Thirappane tank cascade system, Sri Lanka. Journal of Environmental and Earth Sciences 3(1), 59-70. https://doi.org/10.30564/jees.v3i1.3277.

Abeywardana, N., Schütt, B., Wagalawatta, T., Bebermeier, W., 2019. Indigenous agricultural systems in the dry zone of Sri Lanka: management transformation assessment and sustainability. Sustainability 11(3), 910. https://doi.org/10.3390/ su11030910.

Agus, F., Irawan, I., Suganda, H., Wahyunto, W., Setiyanto, A., Kundarto, M., 2006. Environmental multifunctionality of Indonesian agriculture. Paddy and Water Environment 4(4), 181-188. https://doi.org/10.1007/s10333-006-0047-5.

Albinson, B., Perry, C.J., 2002. Fundamentals of Smallholder Irrigation: The Structured System Concept Research Report 58, International Water Management Institute (IWMI), Colombo, Sri Lanka

Alemohammad, S.H., Gharari, S., 2017. Qanat: An ancient invention for water management in Iran. Proceedings of Water History Conference, Delft, The Netherlands. 24–26 June 2015. https://www.researchgate.net/publication/321914743_Qanat_An_Ancient_Invention_for_Water_Management_in_Iran. Downloaded (accessed 08 September 2022.).

Ambler, J., 1994. Small-scale surface irrigation in Asia: Technologies, institutions and emerging issues. Land Use Policy, 11(4), 262-274. https://doi.org/10.1016/0264-8377(94)90052-3.

Angelakıs, A.N., Zaccaria, D., Krasilnikoff, J., Salgot, M., Bazza, M., Roccaro, P., Jimenez, B., Kumar, A., Yinghua, W., Baba, A., Harrison, J.A., Garduno-Jimenez, A., Fereres, E., 2020. Irrigation of world agricultural lands: Evolution through the millennia. Water 12(5), 1285. https://doi.org/10.3390/w12051285.

Ashraf, M., ul Hasan, F., 2020. Groundwater Management in Balochistan, Pakistan: A Case Study of Karez Rehabilitation. Water Knowledge Note. World Bank, Washington, DC. World Bank. https://openknowledge.https://openknowledge.worldbank.org/handle/10986/33241 License: CC BY 3.0 IGO. (accessed 28 August 2022).

Azami, A., Sagin, J., Sadat, S.H., Hejran, H., 2020. Sustainable irrigation: Karez system in Afghanistan. Central Asian Journal of Water Research 6(2), 65-86. https://doi.org/10.29258/CAJWR/2020-R1.v6-2/1-18.eng.

Bandara, C.M.M., 1985. Catchment ecosystems and village tank in the dry zone of Sri Lanka. In: Lundquist et al., (eds.), Strategies for river basin development. D. Reidel Publishing Company, Germany, pp 265-277.

Bandara, C.M.M., 2009. Village Tank Cascade Systems of Sri Lanka. India Water Portal, 328–336. https://www.indiawaterportal.org/sites/default/files/iwp2/tankcascade_.pdf. (accessed 09 September 2022.).

Bastakoti, R.C., Prathapar, S.A., Okwany, R.O., 2016. Community pond rehabilitation to deal with climate variability: A case study in Nepal Terai. Water Resources and Rural Development 7, 20-35. https://doi.org/10.1016/j.wrr.2016.01.001.

Baquhaizel, S. A., Saeed, I. A., Bin Ghouth, M. S., 2011. Documentary study on models of traditional irrigation systems & methods of water harvesting in Hadramout & Shabwah governorates, MetaMeta, The Netherlands.

http://www.hydrology.nl/images/docs/dutch/yemen/Traditional_irrigation_systems_water_harvesting.pdf. (accessed 8 August 2022).

Bebermeier, W., Meister, J., Withanachchi, C. R., Middelhaufe, I., Schütt, B., 2017. Tank cascade systems as a sustainable measure of watershed management in South Asia. Water 9(3), 231. https://doi.org/10.3390/w9030231.

Biswas, B., Chakraborty, D., Timsina, J., Bhowmick, U.R., Dhara, P.K., Lkn, D.K.G., Sarkar, A., Mondal, M., Adhikary, S., Kanthal, S. and Patra, K., 2022. Agroforestry offers multiple ecosystem services in degraded lateritic soils. Journal of Cleaner Production, *365*, 132768. https://doi.org/10.1016/j.jclepro.2022.132768.

Bitterman, P., Tate, E., Van Meter, K. J., Basu, N. B., 2016. Water security and rainwater harvesting: A conceptual framework and candidate indicators. Applied Geography76, 75-84. https://doi.org/10.1016/j.apgeog.2016.09.013.

Chai, Y., Zeng, Y., 2018. Social capital, institutional change, and adaptive governance of the 50-year-old Wang hilltop pond irrigation system in Guangdong, China. International Journal of the Commons 12(2), 191-216. http://doi.org/10.18352/ijc.851.

Charbonnier, J., 2009. Dams in the western mountains of Yemen: a Ḥimyarite model of water management. In Proceedings of the Seminar for Arabian Studies, London. 24-26 July 2008. 39..81-93. http://www.jstor.org/stable/41223972. (accessed 05 August 2022).

Chinnasamy, P., Srivastava, A., 2021. Revival of traditional cascade tanks for achieving climate resilience in drylands of South India. Frontiers in Water 3, 639637. doi: 10.3389/frwa.2021.639637 (accessed 09 August 2022).

Chowdhury, K., Behera, B., 2018. Is declining groundwater levels linked with the discontinuity of traditional water harvesting systems (tank irrigation)? Empirical evidence from West Bengal, India. Groundwater for Sustainable Development 7, 185-194. https://doi.org/10.1016/j.gsd.2018.05.007.

Chowdhury, K., Behera, B., 2021. Economic significance of provisioning ecosystem services of traditional water bodies: Empirical evidences from West Bengal, India. Resources, Environment and Sustainability 5, 100033. https://doi.org/10.1016/j.resenv.2021.100033.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'neill, R.V., Paruelo, J. and Raskin, R.G., 1997. The value of the world's ecosystem services and natural capital. Nature 387(6630),253-260. https://doi.org/10.1038/387253a0.

Daily, G.C. (ed). 1997. Natures Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC.

https://www.researchgate.net/publication/305063590_Nature's_Services_Societal_Dependence_on_Natural_Ecosystems. Accessed on September 09, 2022.

Das, A., Datta, D., Samajdar, T., Idapuganti, R. G., Islam, M., Choudhury, B.U., Mohapatra, K.P., Layek, J., Babu, S., Yadav, G.S., 2021. Livelihood security of small holder farmers in eastern Himalayas, India: Pond based integrated farming system a sustainable approach. Current Research in Environmental Sustainability 3, 100076. https://doi.org/10.1016/j.crsust.2021.100076.

Dayananda, D., Weerahewa, J., Weerasooriya, S.A. 2021a. Water Availability, Crop Choices and Profitability of Farming: A Case Study of Mahakanumulla Tank Village System. Topical Agricultural Research 32(1), 81-94. http://doi.org/10.4038/tar.v32i1.8444.

Dayananda, D., Dilhari W.A.D.S., Weerahewa, J., 2021b. An assessment of economic and environmental benefits of desilting village tanks in Sri Lanka: An application of linear programming. 24th International Congress on Modelling and Simulation, Sydney, NSW, Australia, 5 to 10 December 2021. https://doi.org/10.36334/modsim.2021.J7.dayananda.

Debnath, S., Adamala, S., Palakuru, M., 2020. An overview of Indian traditional irrigation systems for sustainable agricultural practices. International Journal of Modern Agriculture 9(4), 12-22.

Deivalatha, A., Ambujam, N.K., 2011. Sustainable agriculture productivity through restoration of tank irrigation system with stakeholder decision: Case study in rural tank ecosystem. International Journal of Biodiversity and Conservation 3(11), 527-539. https://academicjournals.org/article/article1382000632_Deivalatha%20and%20Ambujam.pdf. (accessed 12 August 2022)

Darma, D., Yasin, S., Masunaga, T., 2011. Nutrients movement characteristic in terrace sawah occupied by cascade irrigation system in West Sumatra, Indonesia. Journal of Ecology and the Natural Environment 3(4), 139-148. https://doi.org/10.5897/JENE.9000076.

Department of Census and Statistics, 2022. Paddy Statistics. http://www.statistics.gov.lk/Agriculture/StaticalInformation/rubpaddy. Downloaded (accessed 09 September 2022.).

Dharmasena, P.B., Kadupitiya, H.K., 2021. UNEP-GEF Project: Managing Agricultural

Landscapes in Socio-Ecologically Sensitive Areas to Promote Food Security, Wellbeing and Ecosystem Health in Sri Lanka. South Asia Co-operative Environment Programme. http://www.sacep.org/pdf/Reports-Technical/2021.04.15-Baseline_Assessment_of_Biodiversity_Ecosystem_Services_Land_Degradation_Food_Security_and_Human_Health_in_Village_Tank_Cascade_Systems_of_Sri_Lanka.pdf (accessed 08 September 2022).

Dixon, J., Garrity, D., Boffa, J.M., Williams, T.O., Amede, T., Auricht, C., Mburathi, G., 2020. Farming Systems and Food Security in Africa, first ed. Routledge, 2 Park Square, Milton Park, Abingdon, Oxon. ISBN: 978-1-138-96335-1 pp. 599.

dos Anjos Luís, A., Cabral, P., 2021. Small dams/reservoirs site location analysis in a semi-arid region of Mozambique. International Soil and Water Conservation Research 9(3), 381-393. https://doi.org/10.1016/j.iswcr.2021.02.002.

Dubois, O., 2011. The state of the world's land and water resources for food and agriculture: managing systems at risk, Earthscan, London, UK. ISBN: 97818497132769781849713276.

Egloff, L., Bista, B.B., Shakya, S., 2013. Pond Irrigation System: Nepal. https://lib.icimod.org/record/34325/files/Flyer_6.pdf?type=primary. (accessed 12 August 2022)

Hoanh, C.T., Facon, T., Thuon, T. and Bastakoti, R.C., 2009. Irrigation in the Lower Mekong Basin countries: The beginning of a new era?, in: Molle, F., Foran, T., Kakonen, M. (Eds.), Contested Waterscapes in the Mekong Region: Hydropower, Livelihoods and Governance. Routledge., pp. 165-194. ISBN 9781849770866

Haque E., A.K., Mukhopadhyay, P., Nepal, M., Shammin, M.R., 2022. Climate Change and Community Resilience: Insights from South Asia. Singapore: Springer Nature. https://doi.org/10.1007/978-981-16-0680-9.

Huq, N, 2017. Small scale freshwater ponds in rural Bangladesh: Navigating roles and services. International Journal of Water. 11. 73-85. Doi:10.1504/IJW.2017.081112.

FAO, 2011. The state of the world’s land and water resources for food and agriculture (SOLAW) – Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London.

FAO, 2017. Agricultural Heritage around the World [WWW Document]. GIAS Glob. Important Agric. Herit. Syst. URL. http://www.fao.org/giahs/giahsaroundthew orld/en/ (accessed 8.1.21).

Fazle, M., Khan, K., Nawaz, M., 1995. Karez irrigation in Pakistan. GeoJournal 37 (1), 91-100.

Geekiyanage, N., Pushpakumara, D.K.N.G., 2013. Ecology of ancient tank cascade systems in island Sri Lanka. Journal of Marine and Island Cultures 2(2), 93-101. https://doi.org/10.1016/j.imic.2013.11.001.

Hadera, M.T., 2001. Soil and water management in spate irrigation systems in Eritrea. Wageningen University and Research, Wageningen, Netherlands. ISBN 90-5808-388-8

Haile, G.G., 2015. Irrigation in Ethiopia: A review. Journal of Environment and Earth Science

5(15), 141-147.

Haines-Young, R., Potschin, M., 2018. Common international classification of ecosystem services (CICES) V5.1 and guidance on the application of the revised structure [WWW Document]. https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf. (accessed 14 August 2022)

Hakeem, K.A., Raju, P.V., 2009. Use of high- resolution satellite data for the structural and agricultural inventory of tank irrigation systems. International Journal of Remote Sensing 30(14), 3613-3623. https://doi.org/10.1080/01431160802590488.

ul Hasan, F., Fatima, B., Heaney-Mustafa, S., 2021. A critique of successful elements of existing on-farm irrigation water management initiatives in Pakistan. Agricultural Water Management 244, 106598. https://doi.org/10.1016/j.agwat.2020.106598.

Himat, A., Dogan, S., 2019. Ancient Karez System in Afghanistan: The Perspective of Construction and Maintenance. Academic Platform Journal of Engineering and Science 7(3), 347-354. https://doi.org/10.21541/apjes.466757.

IUCN, 2015. Project Implementation Plan. IUCN programme on Restoring Traditional Cascading Tank Systems Technical Note # 1. Colombo: IUCN, International Union for Conservation of Nature, Colombo, Sri Lanka & Government of Sri Lanka. pp.34

Jayatilaka, C.J., Sakthivadivel, R., Shinogi, Y., Makin, I. W., Witharana, P., 2003. A simple water balance modelling approach for determining water availability in an irrigation tank cascade system. Journal of Hydrology 273(1-4), 81-102. https://doi.org/10.1016/S0022-1694(02)00360-8.

Jayasena, H.A.H., Gangadhara, K. R., 2014. A review on the qanats in Iran and the Tank Cascade System (TCS) in Sri Lanka–Parallel evolution based on total environment. Journal of the Geological Society of Sri Lanka 16, 75-91.

Johnson, S. H., Svendsen, M., Gonzalez, F., 2004. Institutional Reform Options in the Irrigation Sector. The International Bank for Reconstruction and Development /The World Bank. 1818 H Street, NW, Washington, DC.

Kahathuduwa, K.K.P.N., Prasada, D.V.P.., 2022. Variation of water productivity in paddy cultivation within a tank cascade: A case study in Ulagalla, Sri Lanka. Tropical Agricultural Research, 33(3), 247-259. http://doi.org/10.4038/tar.v33i3.8569.

Kahlown, M.A., Khalil, M., Munir, M., 1988. Karez Irrigation in Balochistan: Benchmark Study. Pakistan Water and Power Development Authority, Government of Pakistan and USAID, Pakistan. 233 pp.

Kekulandala, B., Jacobs, B., Cunningham, R., 2021. Management of small irrigation tank cascade systems (STCS) in Sri Lanka: past, present and future. Climate and Development 13(4), 337-347. https://doi.org/10.1080/17565529.2020.1772709.

Khan, M.F.K., Nawaz, M., 1995. Karez irrigation in Pakistan. GeoJournal 37(1), 91-100. https://doi.org/10.1007/BF00814888.

Kool, M., van Steenbergen, F., Mehari Haile, A., Abbas, Y.M., Hagos, E., 2018. The Promise of Flood-Based Farming Systems in Arid and Semi-arid Areas, In: Leal Filho, W., de Trincheria Gomez, J. (Eds), Rainwater-Smart Agriculture in Arid and Semi-Arid Areas. Springer., Cham, pp. 77–94. https://doi.org/10.1007/978-3-319-66239-8_5.

Kotagama, H., 2021. Aflaj Water Markets in Oman: An introduction and Prospective lessons for Sri Lanka VTCS Management, in:Weerasooriya, S.A. (Eds.), Proceedings of Cascade Ecology & Management Conference,. Faculy of Agriculture, Unversity of Peradeniya, Peradeniya, Sri Lanka, 17-18 September 2021, pp. 18-19.

Krishnaveni, M., Sankari, S., Rajeswari, A., 2011. Rehabilitation of Irrigation Tank Cascade System Using Remote Sensing GIS and GPS. International Journal of Engineering Science and Technology 3(2), 1624-1629.

Kulasinghe, T.N., Dharmakeerthi, R.S., 2022. Effects of land use type and tank components on soil properties and sustainability of tank cascade system in the Dry Zone of north central Sri Lanka. Agricultural Systems 201, 103474. (This issue) https://doi.org/10.1016/j.agsy.2022.103474.

Kumar, P., (Ed), 2010. The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Earthscan: London and Washington. http://www.teebweb.org/ (accessed on 8 September 2022)

Kumari, M.K.N., Sakai, K., Kimura, S., Yuge, K., Gunarathna, M.H.J.P., 2019. Classification of groundwater suitability for irrigation in the Ulagalla tank Cascade landscape by GIS and the analytic hierarchy process. Agronomy 9(7), 351. https://doi.org/10.3390/agronomy9070351.

Lightfoot, D. R., 1996. Syrian qanat Romani: history, ecology, abandonment. Journal of Arid Environments 33(3), 321-336.

Macpherson, G.L., Johnson, W.C. and Liu, H., 2017. Viability of karezes (ancient water supply systems in Afghanistan) in a changing world. Applied Water Science 7(4),1689-1710. https://doi.org/10.1007/s13201-015-0336-5.

Mady, B., Lehmann, P., Gorelick, S.M., Or, D., 2020. Distribution of small seasonal reservoirs in semi-arid regions and associated evaporative losses. Environmental Research Communications 2(6), 061002. https://doi.org/10.1088/2515-7620/ab92af.

Mahatantila, K., Chandrajith, R., Jayasena, H.A.H., Ranawana, K.B., 2008. Spatial and temporal changes of hydrogeochemistry in ancient tank cascade systems in Sri Lanka: evidence for a constructed wetland. Water and Environment Journal 22(1), 17-24. https://doi.org/10.1111/j.1747-6593.2007.00077.x.

Marambe, B., Pushpakumara, G., Silva, P., 2012. Biodiversity and Agrobiodiversity in Sri Lanka: Village Tank Systems, in: Nakano, Si., Yahara, T., Nakashizuka, T. (Eds.), The Biodiversity Observation Network in the Asia-Pacific Region. Ecological Research Monographs. Springer, Tokyo, pp 403–430. https://doi.org/10.1007/978-4-431-54032-8_28

Maraqten, M., 2017. Typology of irrigation systems in ancient Yemen in the light of the epigraphic evidence. Proceedings of water & life in Arabia Conference . Abu Dhabi Tourism and Culture Authority, pp. 115-135.

Maraqten, M., 2017. Typology of irrigation systems in ancient Yemen in the light of the epigraphic evidence, in: Al Tikriti, W., and Yule, P.A. (Eds.), Proceedings of water & life in Arabia conference, Abu Dhabi Tourism and Culture Authority, Abu Dhabi, pp. 115–135.

McCartney, M., 2021. Integrated Management of Small reserviors for Multiple Benefits: Lessons from Volta, in: Weerasooriya, S.A. (Eds.), Proceedings of the Cascade Ecology & Management Conference. Peradeniya, Sri Lanka, 17-18 September 2021, pp. 20–21..

Mehari A., Van Steenbergen, F. Schultz, B., 2011, Modernization of Spate Irrigated Agriculture: A New Approach. Irrig. and Drain. 60, 163–173. https://doi.org/10.1002/ird.565.

Mehretie, B., Bewket, W., 2013. Traditional irrigation and water management practices in highland Ethiopia: Case study in Dangila Woreda. Irrigation and Drainage 62, 435–448. https://doi.org/10.1002/ird.1748.

Mekdaschi, R., Liniger, H., 2013. Water harvesting: guidelines to good practice. Centre for Development and Environment. Centre for Development and Environment. ISBN 978-3-905835-35-9

Melles, G., Perera, E. D., 2020. Resilience thinking and strategies to reclaim sustainable rural livelihoods: Cascade Tank-Village System (CTVS) in Sri Lanka. Challenges 11(2), 27. https://doi.org/10.3390/challe11020027.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being: Synthesis. 581 Island Press, Washington, DC.

MOA. 2011. Small-scale irrigation situation analysis and capacity needs assessment. Ministry of Agriculture, Natural Resources Management Directorate. Addis Ababa, Ethiopia.

MoA and FAO, 2016. The Cascade Tank-Village Systems (CTVS) in the dry zone of Sri Lanka. Ministry of Agriculture & Food and Agriculture Organization of the United Nations, Sri Lanka.

Molden, D., Oweis, T.Y., Steduto, P., Kijne, J.W., Hanjra, M.A., Bindraban, P.S., Bouman, B.A.M., Cook, S., Erenstein, O., Farahani, H., Hachum, A., Hoogeveen, J., Mahoo, H., Nangia, V., Peden, D., Sikka, A., Silva, P., Turral, H., Upadhyaya, A., Zwart, S., 2007. Pathways for increasing agricultural water productivity, In: Molden, D. (Eds.), Comprehensive Assessment of Water Management in Agriculture, Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. International Water Management Institute, London: Earthscan, Colombo.

Nanthakumaran, A., Kadupitiya, H.K., Devaisy, S., Athukorale, W.E.P., 2021. Exploring the village tank cascade systems (VTCSs) in Vavuniya district, Sri Lanka. Journal of Water and Climate Change 13(2), 999-1006. https://doi.org/10.2166/wcc.2021.412.

Ojha, H., Poudel, N.S., Timsina, J., Chaudhary, S., Baral, H., 2022. Chapter 19, Ecosystems Services from Community Forestry: Prospects and Challenges for Improving Local Livelihoods in Nepal, page 337-356, In: Timsina et al. (eds.), Agriculture, Natural Resources and Food Security, Sustainable Development Goals Series, https://doi.org/10.1007/978-3-031-09555-9_1.

Oppen, M.V., 1987. Tank irrigation in southern India: adapting a traditional technology to modern socioeconomic conditions , in: Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, Patancheru, A.P. (India).

Palanisami, K., 1991. Conjunctive use of tank and well water in tank irrigation systems. Occasional Papers. Washington, DC: International Food Policy Research Institute (IFPRI),pp. 134-145.

Palanisami, K., Flinn, J.C., 1988. Evaluating the performance of tank irrigation systems. Agricultural systems 28(3), 161-177. https://doi.org/10.1016/0308-

521X(88)90049-2.

Panabokke, C.R.,1999. The small cascade systems in the Rajarata: Their Setting Distribution Patterns and Hydrography. Mahaweli authority of Sri lanka. ISBN 955-9185-06-3

Panabokke, C.R., Sakthivadivel, R., Weerasinghe, A.D., 2002. Evolution, present status and issues concerning small tank systems in Sri Lanka. Colombo, Sri Lanka: International Water Management Institute.

Panabokke, C.R., 2009. Small village tank systems of Sri Lanka. Hector Kobbekaduwa Agrarian Research and Training Institute.

Pandey, D.N., Gupta, A.K., Anderson, D. M., 2003. Rainwater harvesting as an adaptation to climate change. Current Science 85(1), 46-59. http://www.jstor.org/stable/24107712. (accessed 17 August 2022).

Paranage, K., 2018. Understanding the relationship between water infrastructure and socio-political configurations: A case study from Sri Lanka. Water 10(10), 1402. https://doi.org/10.3390/w10101402.

Perera, M.P., 2017. Evolution of tank cascade studies of Sri Lanka. Saudi Journal of Humanities and Social Sciences 2(7), 597-610. https://doi.org/10.21276/sjhss.

Ratnayake, S.S., Kumar, L., Dharmasena, P.B., Kadupitiya, H.K., Kariyawasam, C.S., Hunter, D., 2021. Sustainability of village tank cascade systems of Sri Lanka: exploring cascade anatomy and socio-ecological nexus for ecological restoration planning. Challenges 12(2), 24. https://doi.org/10.3390/challe12020024.

Reddy, V.R., Reddy, M.S., Palanisami, K., 2018. Tank rehabilitation in India: review of experiences and strategies. Agricultural Water Management 209, 32-43. https://doi.org/10.1016/j.agwat.2018.07.013.

Renwick, M.E.., 2001. Valuing water in irrigated agriculture and reservoir fisheries: a multiple use irrigation system in Sri Lanka. International Water Management Institute (IWMI). Research Report 51, pp 34. https://doi: 10.3910/2009.059.

Rout, B., 2008. Water management, livestock and the opium economy: how the water flows: a typology of irrigation systems, in:Lee, C., Ed),(Eds.),Applied Thematic Research into Water Management, Livestock and the Opium Economy, Afghanistan Research and Evaluation Unit.

Saatsaz, M., 2020. A historical investigation on water resources management in Iran. Environment, Development and Sustainability 22(3), 1749-1785. https://doi.org/10.1007/s10668-018-00307-y

Satishkumar, U., Balakrishnan, P., & Ramaswamy, K., 2010. Analysis of irrigation return flow under the cascade system of tanks in Raichur region-A case study. Karnataka Journal of Agricultural Sciences, 23(5).

Sirimanna, S., Prasada, D. V. P., 2021. Water productivity in tank cascade systems: A case study in Mahakanumulla tank cascade, Sri Lanka. Tropical Agricultural Research, 32(3), 298-306. http://doi.org/10.4038/tar.v32i3.8493

Sirimanna, S., Kahathuduwa, K.K.P.N., Prasada, D.V.P., 2022. Are Cascade Reservior Systems Resilient Agroecosystems? A Comparative Assessment of Efficiency, Effectiveness and Resource Footprint in a Sri Lankan Micro Cascade. Agricultural

Systems. In press.

Sirimewan, D.C., Mendis, A.P.K.D., Rajini, D., Samaraweera, A.,& Manjula, N.H.C., 2021. Analysis of issues in sustainable water management of irrigation systems: Case of a developing country. Built Environment Project and Asset Management 11(4), 529-543. https://doi.org/10.1108/BEPAM-02-2020-0038..

Srivastava, A., Chinnasamy, P., 2021. Water management using traditional tank cascade systems: a case study of semi-arid region of Southern India. SN Applied Sciences 3(3), 1-23. https://doi.org/10.1007/s42452-021-04232-0

Srivastava, A., Chinnasamy, P., 2022. Assessing groundwater depletion in Southern India as a function of urbanization and change in hydrology: a threat to tank irrigation in Madurai city. In: Kolathayar, M, A., Chian, S.C., (Eds) Climate change and water security. Springer, Singapore. 293–308. https://doi.org/10.1007/978-981-16-5501-2_24

Tadesse, K. B., Dinka, M. O., 2018. Improving traditional spate irrigation systems: A review. IntechOpen. https://doi.org/10.5772/intechopen.71840

Takeshima, H., Edeh, H., 2017. Constraints for small-scale private irrigation systems in the North Central zone of Nigeria: Insights from a typology analysis and a case study (No. 1879-2017-5717). AgEcon Search. https://doi.org/10.22004/ag.econ.265414

Tesfai, M., Stroosnijder, L., 2001. The Eritrean spate irrigation system. Agricultural Water Management 48(1), 51-60. https://doi.org/10.1016/S0378-3774(00)00115-3.

Thenkabail, P. S., Biradar, C. M., Noojipady, P., Dheeravath, V., Li, Y. J., Velpuri, M., Reddy, G.P.O., Cai, X.L., Gumma, M., Dutta, R., 2008. A Global Irrigated Area Map (GIAM) using remote sensing at the end of the last millennium, International Water Management Institute, Colombo, Sri Lanka. pp 63.

Thennakoon, T. M. S. P. K., Kandambige LS, T., Liyanage, C., 2017. Impact of human–elephant conflict on livelihood: A case study from a rural setting of Sri Lanka. International Journal of Applied Research 3(7), 1107-1111.

Thennakoon, S., 2004. Rural livelihood strategies and the five capitals: a comparative study in selected villages of Sri Lanka. In Proceedings of the 18th European Conference on Modern South Asian Studies. Lund, Sweden, July 2004. pp. 6-9.

Turner, B., 1994. Small-scale irrigation in developing countries. Land Use Policy 11(4), 251-261. https://doi.org/10.1016/0264-8377(94)90051-5

Unami, K., Mohawesh, O., Sharifi, E., Takeuchi, J., & Fujihara, M., 2015. Stochastic modelling and control of rainwater harvesting systems for irrigation during dry spells. Journal of Cleaner Production 88, 185-195. https://doi.org/10.1016/j.jclepro.2014.03.100

United Nations Educational, Scientific and Cultural Organization (UNESCO), 2021. Cultural Mapping of pilot sites for Karez system cultural landscape Quetta Ziarat, Pishin, Rogers Kolachi Khan & Associates, Lahore, Pakistan

Van Meter, K. J., Steiff, M., McLaughlin, D. L., Basu, N. B., 2016. The socioecohydrology of rainwater harvesting in India: understanding water storage and release dynamics across spatial scales. Hydrology and Earth System Sciences 20(7), 2629-2647. https://doi.org/10.5194/hess-20-2629-2016

Vermillion, D. L., Al-Shaybani, S., 2004. Small dams and social capital in Yemen: How assistance strategies affect local investment and institutionsResearch Report76. IWMI, Colombo, Sri Lanka.

Vidanage, S., Perera, S., Kallesoe, M. F., 2005. The value of traditional water schemes: small tanks in the Kala Oya Basin, Sri Lanka. IUCN water nature and economics technical paper No. 6. The World Conservation Union, Ecosystems and Livelihoods Group Asia; IUCN: Colombo, Sri Lanka; ISBN 9558177504

Vidanage, S. P., 2019. Economic value of an ancient small tank cascade system in Sri Lanka. Doctoral research series of the Department of Economics. University of Colombo, Colombo, Sri Lanka.

Vidanage, S.P., Kotagama, H.B., Dunusinghe, P.M., 2022. Sri Lanka's small tank cascade systems: Building agricultural resilience in the dry zone. In: Haque, A.K.E., Mukhopadhyay, P., Nepal, M., Shammin, M.R. (eds) Climate Change and Community Resilience. Springer, Singapore. https://doi.org/10.1007/978-981-16-0680-9_15

Wijekoon, W. M. S. M., Gunawardena, E. R. N., Aheeyar, M. M. M., 2016. Institutional reforms in minor (village tank) irrigation sector of Sri Lanka towards sustainable development. In Proceedings of the 7th International Conference on Sustainable Built Environment, Kandy, Sri Lanka, 16–18 December 2016; pp 9.

Xiaofei, M., Zhu, J., Zhang, H., Yan, W., Zhao, C., 2020. Trade-offs and synergies in ecosystem service values of inland lake wetlands in Central Asia under land use/cover change: A case study on Ebinur Lake, China. Global Ecology and Conservation 24, e01253. https://doi.org/10.1016/j.gecco.2020.e01253

Zenebe, M. G., Fleskens, L., Ritsema, C., Steenbergen, F., 2022. Basin-wide productivity and livelihood analysis of flood-based agricultural systems in African drylands: A case study in the Fogera floodplain. Agricultural Water Management 261, 107379. https://doi.org/10.1016/j.agwat.2021.107379.

Zingiro, A., Okello, J. J., Guthiga, P. M., 2014. Assessment of adoption and impact of rainwater harvesting technologies on rural farm household income: The case of rainwater harvesting ponds in Rwanda. Environment, Development and Sustainability 16(6), 1281-1298. https://doi.org/10.1007/s10668-014-9527-8.

**Declaration of 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.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Jeevika Weerahewa reports financial support was provided by University of Peradeniya.