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**EDITORIAL ARTICLE**

# An Emerging Threat: Time to Act on Dam Safety, Adopting a Collaborative Interdisciplinary Approach

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**Abstract:** At present, dam failures gain significant attention due to their devastating impacts on economies, environments, and local communities in the global context. In Sri Lanka, most of the dams are earthen embankment dams that were built in ancient times. Therefore, apprehensions for dam safety need to be based on the recognition that our dams are ageing and deteriorating and therefore, highly vulnerable to climate extremes; at the same time, these dams and the associated irrigation infrastructure have sustained for more than two millennia, apparently owing to the engineering ingenuity of ancient times. This communication delves into the timely need of addressing dam safety aspects with consideration for the entire disaster management cycle that consists of prevention, preparedness, response, and recovery phases. It is highlighted that drawing inferences from the ancient irrigation heritage is beneficial when a holistic approach extending mere safe operation of dams is sought. Particularly, the sustainable planning interventions of the tank cascade systems that consist of tank village eco-systems are appreciated for their role in nourishing the ecosystem and the concern for disaster prevention via small dam networks as opposed to haphazard developments of large-scale dams that increase both the hazard potential and the vulnerability of the downstream communities. Present-day interventions for dam safety apparently require an interdisciplinary collaborative approach in which professionals from engineering, management, environmental sciences, and sociology, etc., work together with dam owners, governing/regulatory authorities, and the communities as a whole.

***Keywords***: *Ancient Irrigation Heritage, Collaborative, Dam Safety, Disaster Management Cycle, Interdisciplinary Approach*

## Introduction

**A crucial reminder:** The Hard hit of Storm Daniel in Derna, Libya, resulting in the collapse of two flood protection dams near Derna on September 11, 2023, led to devastating floods that killed thousands of people. Witnessing the devastation a dam breach can cause was a crucial reminder of the emerging threats faced by dams worldwide due to unprecedented weather patterns and climate scenarios. According to the media reports, the Libyan court has convicted 12 officials of mismanagement, negligence, and mistakes that contributed to the dam breach disaster, reminding us of all our responsibilities to act on the emerging threat to dam safety.

### Modes of dam failure

Particularly, when earthen embankment dams are concerned, the highest number of dam breaches occur due to overtopping caused by hydrological failures (Kamaladasa, 2017; ASDSO, 2025) associated with inadequate spillway designs and debris blockage of spillways (ASDSO, 2025). With the changes in climatic conditions and land use over the recent decades, risk of overtopping has heightened; rainfall

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intensities are observed to be increasing while, land use trends in catchments suggest reduction in forest cover; collectively, these factors result in rapid reservoir level rises upon receiving rain, inhibit controlled release of water through the spills, and thus heighten the risk of overtopping. Only secondary to overtopping, piping (i.e., internal erosion caused by seepage) is recognized as one of the major reasons for dam failures (Foster *et al.*, 2000; CDA, 2007; ASDSO, 2025). Seepage that is poorly monitored for signs of erosion (such as seepage flow which is muddy and carrying soil material and eroded material depositions around seepage outlets) may continue to degrade the dam body, leading to sinkholes that may develop on the surface of the embankment, followed by rapid and complete failure of the dam.

**Hazard identification for managing consequences**

Although there is no easy answer to the question of whether a dam breach disaster is large or small, it is well known that the impacted community diverges substantially from its normal social structure. Also, given the rapidity of a dam breach, like a tsunami wave approaching the inland, the downstream community may not receive advanced warnings with sufficient lead time, making the consequences of uncontrolled release of water more catastrophic. It is also known that, despite the recent advancements in geotechnical and hydrotechnical modelling efforts, dam breach prediction is far from satisfactory, especially due to the complex nature of site-specific conditions and the difficulties that exist in the verification of prediction models for the unique nature of a given dam and its surroundings. However, learning lessons from dam breach incidents cannot be overlooked to provide some valuable insights on actions that can be taken to reduce the hazard level of the dams (referring to its probability of failure) as well as to reduce the vulnerability of the downstream communities allowing us to better prepare for such incidents elsewhere in the future. In this regard, to instigate a proactive and sustainable approach to disaster management, it is required to align our actions with the well-known disaster management cycle (Figure 1), which includes four phases, namely: prevention, preparedness, response, and recovery.

## Dam Safety in Sri Lanka

### Sri Lankan dam network

Sri Lanka's dam network consists of nearly 350 medium to large dams and over 12,000 small dams; according to classification by the International Commission on Large Dams (ICOLD), 80 are large structures. Many of these dams are earthen embankment dams that were built in ancient times, forming the so-called Rajarata irrigation landscape. These dams played a vital role in the techniques that established a sustained scheme for water resources management that included "collection, storage, and distribution of rainfall and runoff" for irrigation, domestic use, and flood protection (Bebermeier *et al.*, 2023).


Figure 1. Disaster management cycle

These dams, therefore, formed a part of a system that allowed the "domestication of water" (Gebel, 2004). Accounts of the island's history suggest that "South Indian Chola invasions and the unstable political conditions that followed" led to the recession of the Rajarata irrigation tradition in the middle of the 13$^{th}$ century CE (Abeywardana *et al.*, 2018). Later, in the 19th century CE, during the colonial period, many dams/reservoirs underwent restoration and were brought to operation under new governance structures (Gebel, 2004; Brohier, 2006). With the further changes that have been occurring in the irrigation landscape over the present post-colonial era, nearly 10,000 dams with their origin rooted in the ancient water-harvesting system form an extensive dam network which contributes to the country's water needs.

In this context, apprehensions for dam safety need to have based on two key aspects: (1) the recognition that our dams are aging, possibly deteriorating, and becoming highly vulnerable to climate extremes of the present day, and (2) the engineering ingenuity of the ancient times created an irrigation heritage that sustained for more than two millennia. Attention shall be directed to dam health, not only for their contribution to the national economies but also for the need to safeguard vulnerable communities. In this regard, this communication particularly intends to direct attention towards the need for addressing dam safety with a focus on all four phases of the disaster management cycle, while any efforts on revitalization of our dam network consider decoding the conceptualization of the ancient irrigation heritage. Such an approach would provide useful insights when seeking inferences on the effectiveness of modern-day irrigation systems and ensure the continued application and preservation of treasured characteristics of the irrigation heritage of Sri Lanka.

A dive into Sri Lankan irrigation heritage, particularly relevant to tank cascade systems (Figure 2) of the dry zone, which is a cluster of earthen dam reservoirs, indicate that the existence and the operation of the dams/reservoirs were never considered to occur in isolation in the ancient conceptualization of water resource management. Instead, a systems approach characterized by various traditional, yet rationalized procedures has been used to secure the water needs of human civilization and to safeguard the dam and the reservoir from risks associated with flood loading while maintaining ecological balance. This resulted in systems where principles of sustainability were at the very core of the development. The ancient practices institutionalized sustainability using technology for the creation of irrigation systems having their individuality to suit and preserve the local ecology, community ownership, and ethical governance principles that remain globally relevant (Sandell (Sandell, 1993; Abeywardana *et al.*, 2018; Bebermeier *et al.*, 2023)

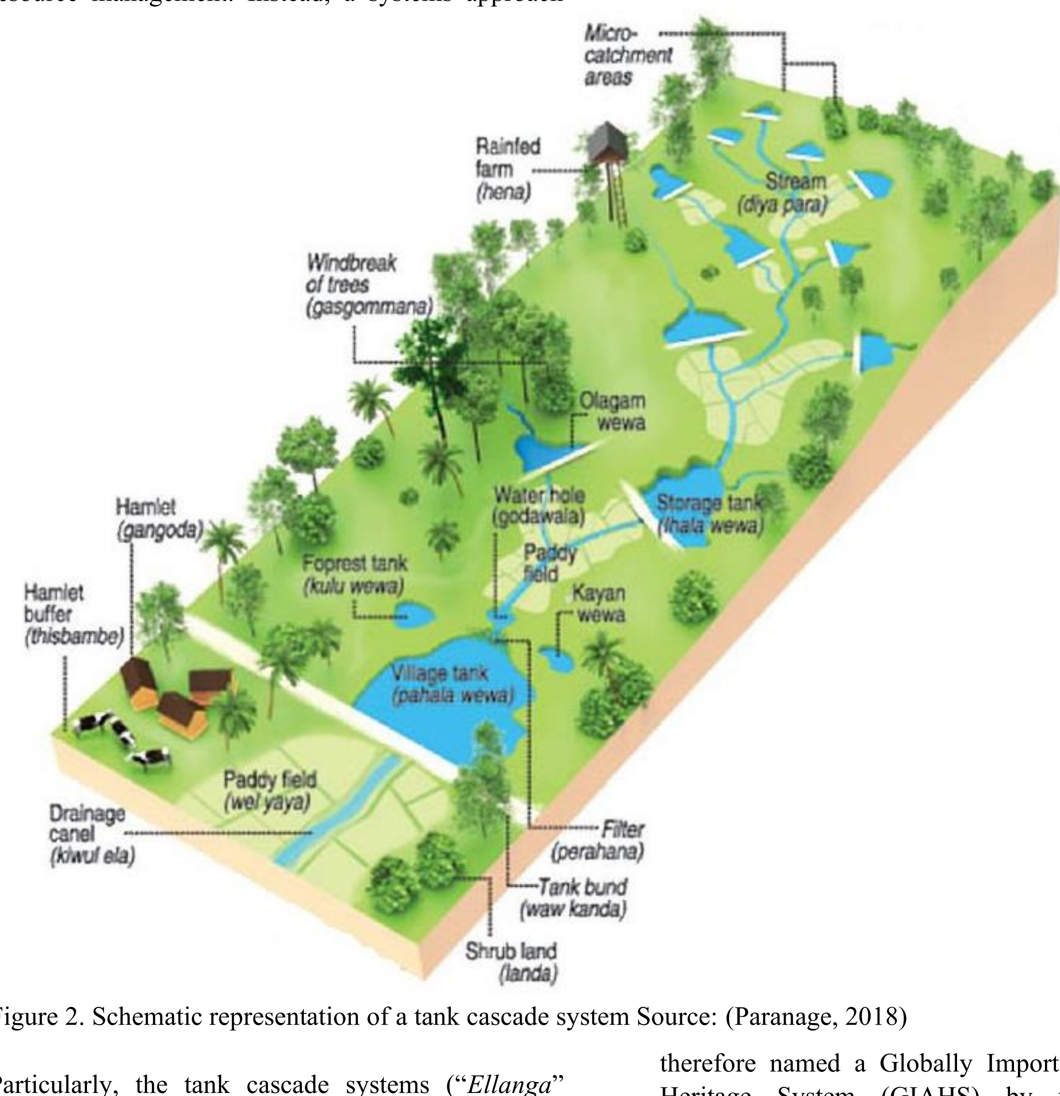


Figure 2. Schematic representation of a tank cascade system Source: (Paranage, 2018)

Particularly, the tank cascade systems (“*Ellanga*” systems) of the dry zone of Sri Lanka are globally recognized as one of the most sustainable and are therefore named a Globally Important Agricultural Heritage System (GIAHS) by the Food and Agriculture Organization (FAO). The layout follows the natural slope of the land to create a network of tanks that allows storage of water at multiple locations along the linear riverine ecosystem, and the size and capacity of tanks increase towards downstream (Madduma Bandara, 1985). This layout enabled overflow of water from one tank to feed the next, helped recharge the groundwater system, ensuring year-round irrigation in the dry zone while building resilience against environmental shocks (Wimalawansha, 2025). Also, these systems, which consisted of tank-village eco-systems (Figure 3), established ecological balance by means of demarcating different land use segments for various purposes.

In these tank-village eco-systems, certain elements are incorporated to manage sediment infilling of the tanks, intending maintenance of the tank capacity for reducing the threats of floods and droughts; these include features such as '*Perahana*' – a meadow located in the upstream of the tank and '*Iswetiya*' or '*Potawetiya*' – an upstream bund constructed to prevent eroded soil from upper reaches of the slopes entering the tank (Dharmasena, 2010a) . Certain other elements work to desalinate the water released for irrigation – for instance, '*Kattakaduwa*' is a reserved area of land below the tank bund (Dharmasena, 2010a) . The '*Gasgommana*' is a naturally grown vegetation in the upstream land strip that acts as a wind barrier to minimize water loss by evaporation (Dharmasena, 2010a). These features together form a system that greatly preserves the ecological balance. Community ownership and ethical governance principles that helped sustain the ancient irrigation practice included shared responsibility in the event of a dam failure, where the people living in downstream settlements showed serious concern in the safety of upstream tanks and pooled their resources to repair a breached bund along the chain of tanks of a given cascade. In the times of low rains, the farmers resorted to '*Bethma*' - a practice that temporarily redistributed smaller plots of land among the farmers based on a common proportional ownership basis.

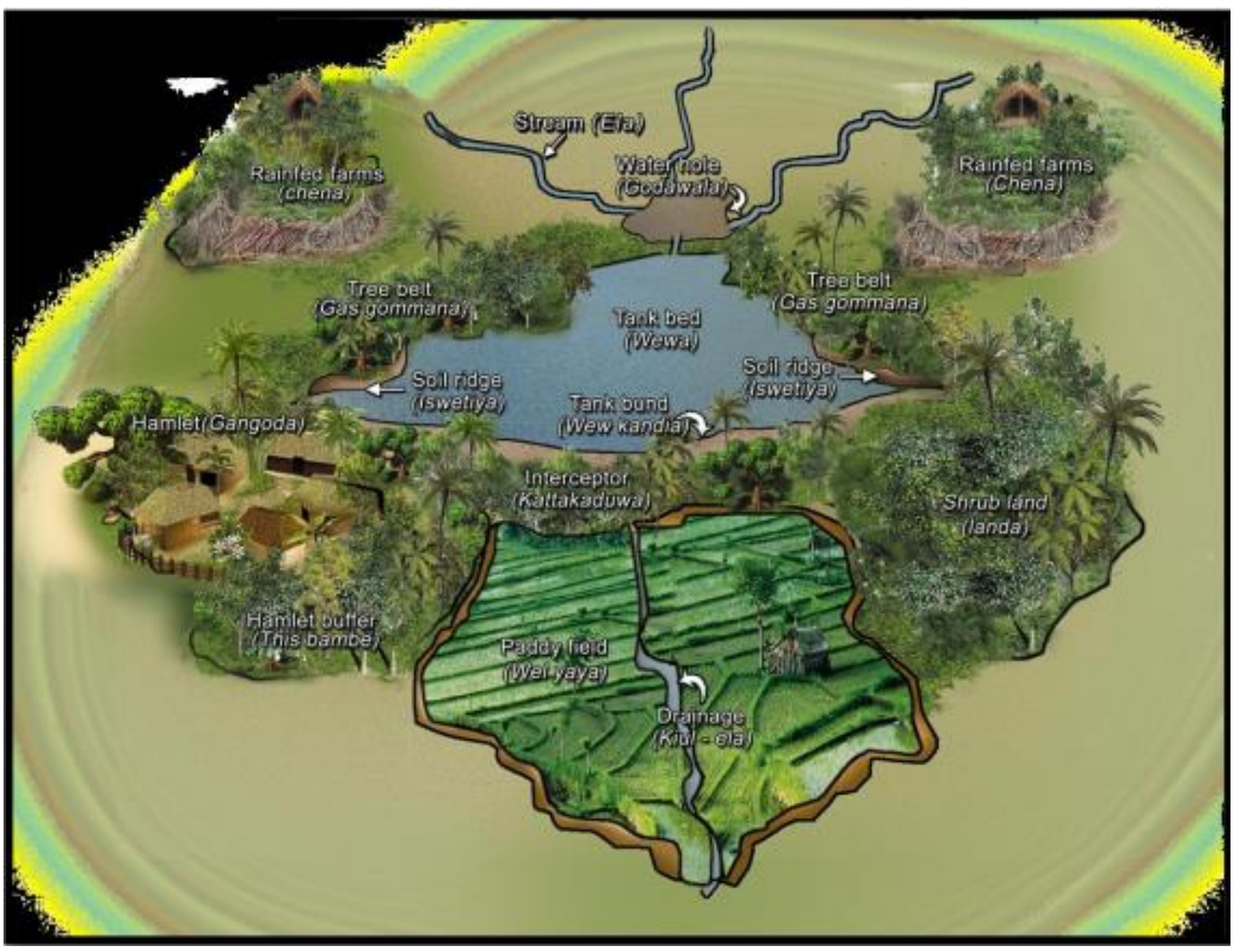


Figure 3. Tank-village ecosystem Source:(Dharmasena, 2010a)

These features and practices are characteristics of the drive for sustainable water management in ancient days.

**The present-day efforts for restoration and considerations for dam safety**

It is noteworthy that this communication is made amid certain ongoing efforts to restore Sri Lanka's dam/reservoir systems with a concern for dam safety. As an important first step, the Irrigation Department of Sri Lanka, as one of the major dam owners and a responsible authority for the operation of irrigation works, is presently engaged in drafting dam safety guidelines. Further, the Dam Safety and Water Resources Planning Project (DSWRPP) for Sri Lanka is taking initiatives to reduce dam-related hazards and improve water resources planning. The ongoing rehabilitation of small tanks since 2019 under the Climate Smart Irrigation Agriculture Project (CSIAP), which is implemented under the Ministry of Agriculture, Land, Livestock, Irrigation, Fisheries, and Aquatic Resources, shall also be mentioned. The project focuses on 12 climate hotspots across six provinces to assess the climate resilience of the smallholder agriculture sector. More recently, the government has made cabinet decisions on regulation and monitoring of land use in the vicinity of selected major reservoirs under the governance of the Irrigation Department to mitigate undesirable impacts on water management; the actions are to include clear demarcation of peripheral boundaries of water reach etc., together with recognition for features such as tree belts. These efforts indicate hope for positive developments towards instigating a holistic approach for dam safety in the years to come.

Given that the present context is as described above, the following sections of this communication focus on a compilation of thoughts for better management of dam-related disasters.

## Disaster Management Cycle for Dam Breach Disasters

**Prevention**

Pre-disaster mitigation efforts related to the "prevention" phase of dam-related disaster management aim at strengthening the dam to maintain operation at design level performance through technical measures to safety monitoring, and control (Viseu and de Almeida, 2009).

Knowing that a dam itself is a hazard, proper safety monitoring and control are a must to ensure early detection and monitoring of hazards. For large dam structures with high hazard levels, it is imperative to have modern interventions such as piezometers and inclinometers embedded to understand pore pressure and seepage conditions and detect movements, leaving room for corrective actions taken long before the dam's condition develops into a catastrophic failure. Regular site reconnaissance surveys (i.e., visual inspections) also play a major role in pre-disaster mitigation efforts for early identification of adverse conditions and provision of input to dam and dam site maintenance.

The early day integration of the key elements, such as spillways (*Pitawana*), sluices (*Sorowwa*), and regulation chambers (*Bisokotuwa*) to effectively release water reflects the deep understanding of the use of technical measures for safe operation of the dams. Particularly, the operational mechanism of the *bisokotuwa* as an intermediate chamber for flow regulation and surge action has earned great respect as a remarkable innovation in ancient irrigation heritage. The existence of many ancient earthen embankment dams that have been well sustaining for more than two millennia provides evidence of ancient wisdom that certainly ensured longevity by considering prevention, a matter of utmost importance.

**Preparedness**

In addition to establishing prevention measures, there are proactive measures that should be taken into consideration at the pre-disaster stage to ensure an effective response to the identified threat of a dam failure. Present interventions to enhance preparedness may mean skill development of personnel involved with hazard detection to help with prevention measures, hazard zoning, establishment of early warning and communication systems, and conduct of regular dam safety drills. Skilled professionals' involvement is imperative in interpreting hazard detection and monitoring information to generate disaster alerts and warnings, irrespective of the availability of sophisticated technologies for early detection of hazards. As a part of establishing preparedness measures, it is also vital to develop better official structures for detection, warning, and communication in which the vulnerable communities can also engage in participatory decision making during a dam failure event (DELWP, 2015), Preparedness at this intensity can significantly reduce the number of fatalities and other losses during a dam failure event.

It is admirable how the ancient irrigation heritage had integrated social and cultural values into participatory decision making for empowering the downstream community to collectively manage the agricultural activities and safeguard the dam and the community. The famous quote '*Wewai-Dagebai, Gamai-Pansalai*' explains the fundamental structure of the society that is formed around the notions of ownership and interconnectivity among the elements of the dam-based social cultural system. However, there is evidence that modern interventions have disregarded this rich legacy. For example, the lack of understanding of the cascade principle has often led the land development authorities to seek expansion of irrigable areas and increase the storage capacity by replacing village tanks with large reservoirs in a haphazard manner in response to popular demands (Madduma Bandara, 1985). This short-sighted approach has significantly disturbed the connection with the dam/reservoir and degraded the cohesion within the farmer communities, leading to many issues related to water rights and social unrest at times.

The present-day communication technology is indeed advanced, and warnings can be received once an imminent threat of dam breach is identified. However, the disconnection between the dam and the community can lead to missing the detection of early signs of failure, and flood waves can reach the community without leaving any time for warning, communication or evacuation. Therefore, it is imperative that present interventions should address developing a sense of ownership of the dam and the reservoir among the downstream community for receiving support in the detection of early signs of failure and consequent issuance of credible warnings by the respective authorities.

**Response**

Emergency response phase includes the actions to be taken by the dam owner, dam safety professionals, emergency management professionals, as well as the community in responding to a possible dam-related emergency. The actions that serve to protect the dam at this phase will also protect downstream communities and properties by reducing the severity of the flooding. The inherent characteristics of the ancient tank cascade systems could reduce the severity of flooding in terms of intercepting the destructive power of flood waves at each of the downstream storage tanks, leaving enough time for the communities to respond to the emergency. Also, the relative arrangement of the tank, community settlement (Gangoda), tree belts, the paddy fields, shrub land, etc. (Dharmasena, 2010b). facilitated the spread of water over the paddy lands and reduced the speed and height of flood water, minimizing the impact of disaster on the community settlement.

At present, in parallel to the emergency response measures to prevent a complete failure of the dam, the emergency management professionals need to activate and communicate evacuation procedures to the communities at risk before a disaster strike. Measures implemented at the emergency response phase also include site-specific emergency response plans that maintain a record of material sources to quickly address dam maintenance issues, a list of local contractors with suitable plant and equipment to contact in case of emergency, and contact details of downstream residents, etc. (DELWP, 2015).

**Recovery**

Catastrophic failures of dams resulting in many fatalities, injuries, as well as property damage, environmental damage, significantly impact the well-being of the community at the post-disaster stage. Specifically, the downstream community loses the benefits provided by the dam, and revitalizing the dam-based community can be a huge challenge. Past cases of dam disasters provide evidence on how downstream communities struggled to recover. For an agricultural community, a significant impact of a dam breach can result in the complete loss of their homes, livelihood, and their loved ones. In the present context, encroachment of riparian zones as well as non-agricultural reclamation of paddy fields for residential use has highly increased the vulnerability of the downstream community in the event of a dam failure, thereby complicating the recovery process. An examination into the ancient agricultural communities highlights careful downstream land use where agricultural lands, mainly the paddy fields, were set at the immediate downstream risk zones of the dams, while the human settlements were located off the track of flood waters, minimizing the exposure of the human settlements to disastrous impacts. In these ancient systems, the layout for water management (which relied on the spread of small to medium-scale tanks) allowed the communities to collectively rebuild the failed dams within the communities' capacity and thus allowed a prompt restoration of the system functionality and recovery of their livelihoods. It appears that planning for recovery can use insight from ancient systems, at least to some extent, as relevant to modern-day communities.

The overall cycle of disaster management thus requires concern for many different aspects when a holistic approach to national-level intervention is expected.

## A Way Forward – A Collaborative Interdisciplinary Approach to Dam Safety

Resolving that dams are essential elements of modern-day infrastructure and considering that dams are hazards themselves, it is clear that safe operation certainly needs to include consideration for all aspects of the disaster management cycle – prevention, preparedness, response, and recovery. When sustained environments, economies, and societies are intended, a holistic approach extending mere safe operation of dams is necessary, where interdisciplinary collaboration of professionals from engineering, management, environmental sciences, and sociology etc., work together with dam owners, governing/regulatory authorities, and the communities. The technical aspects of the process, such as those involved with engineering for dam safety, which investigates structural and stability considerations, are comprehensively addressed by Dam Safety Guidelines (such as ASDSO, CDA, and ICOLD). However, environmental concerns seeking ecological balance may draw inferences from the rich legacy of ancient irrigation heritage to a great extent. The ancient systems were formulated around the idea of retention of water on the surface and in the subsurface, allowing groundwater recharge and thus nourishing the ecosystem for optimum usage of fresh water as opposed to the notion of rapid distribution/diversion of modern-day irrigation practices. The ancient approach of combined water conservation and utilization appears to lead us towards the sought-after environmental sustainability of the present-day attempts, an approach that was practiced and promoted long before the term 'sustainability' existed, as reflected in the words of King Parakramabahu the Great: 'Let not a single drop of water flow into the sea without being used for the benefit of mankind'. Environmental sustainability is hardly addressed without the implementation of good governance practices, which can also take great insight from ancient irrigation heritage that included a sense of community ownership and mechanisms for cooperation among farmer groups along and across riverine systems. All in all, adopting an interdisciplinary collaborative approach is needed to implement sustained measures for dam safety.

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