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Exploring the village tank cascade systems (VTCSs) in Vavuniya district, Sri Lanka

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ABSTRACT

An attempt was made to identify, validate the village tank cascade systems (VTCSs) and study the water flow from one village tank to another in each VTCS in the eight Agrarian Service Centre (ASC) divisions in the Vavuniya district from October 2017 to December 2018. VTCS contribute a significant share of available water resources for the livelihoods of households in the Vavuniya district. The 1:10,000 topographic map of the Survey Department, satellite images and the digital elevation model were used to identify the cascades and flow direction map for the study area using ArcGIS 10.2.2. Among 756 village tanks in the district, 80 VTCSs comprising 514 village tanks were identified, and only 69 cascades were validated in the field. In addition, this study identified 111 isolated village tanks without connecting with other village tanks and 131 abandoned village tanks. Further investigation is recommended to explore the possibilities of increasing the cascade areas in the study area by connecting isolated tanks with VTCSs. Initiation taken towards rehabilitation of cascades would enhance the livelihood of farm households in the Vavuniya district and lead to sustainable water resource management.

Key words: cascades, DEM, GIS, livelihood, validation, village tanks

HIGHLIGHTS

- The VTCS play a crucial role in sustainable management and water conservation.
- The number of the identified VTCSs is more than that of validated in the field of the study area.
- Tank siltation and water scarcity altered the natural settings of the VTCS.
- The findings will benefit urban planners for developmental activities and farmers for their livelihood.

INTRODUCTION

The village tank cascade system (VTCS) is 'a connected series of village tanks organized within a micro-catchment of the dry zone landscape, storing, conveying and utilizing water from an ephemeral rivulet' (Madduma Bandara 1985). These systems are one of the oldest and the most advanced water conveyance/irrigation systems during the hydraulic civilization (Mahatantila *et al.* 2008; Nanthakumaran & Palanisami 2010; Ratnayake *et al.* 2021). In Sri Lanka, these systems were developed by the ancient kings during the Rajarata hydraulic civilization as a water conservation strategy by harvesting rainwater to optimize the water utilization for irrigation in the dry zone of Sri Lanka (Madduma Bandara 1985). Rainwater is the sole input to the VTCS; thus, these are considered rainwater harvesting structures. The excess water received by the upstream tank is allowed to spill out through sluices to flood the rice fields/other vegetation downstream, then the excess water from the rice fields/vegetation is captured by the adjacent downstream reservoir. Thus, the water resource is continuously recycled (Panabokke *et al.* 2002; Lakshman *et al.* 2019; Dharmasena 2020). Hence, the cascade lines are considered an adaptation strategy to overcome threats from the long-term changes due to climate change (Withanachchi *et al.* 2014; Galagedara *et al.* 2018).

VTCSs and the unconfined aquifer of groundwater are the available water resources for the livelihoods of households in the Vavuniya district. The Vavuniya district falls under the dry zone of Sri Lanka and receives less rainfall (annual average of <1,200 mm), high evaporation (mean annual of 1,700–1,900 mm) and high temperature (mean annual of 26 – 34 °C), resulting in hot weather and water shortage especially from May to August. Madduma Bandara (1985) reported that these VTCSs contributed to the shallow regolith aquifer recharge maintaining a high water table. Previous studies found substantial groundwater recharge in the proximity to VTCS operational in the Vavuniya district. Tharani *et al.* (2015) found a significant positive correlation between the water levels of the village tanks and the water levels of the wells situated in its command area. Shanmuganathan *et al.* (2010) identified that human alterations on the proximity to the cascades had reduced the sustainable production of groundwater resources in the localities.

Therefore, it is vital to keep the cascades operational to ensure the sustainable utilization of water resources. The VTCS must be considered in the planning stages of any development projects to ensure they are environmentally sound and economically viable in nature. In view of this, lack of proper documentation of the VTCS functioning in Vavuniya (Sudusinghe *et al.* 2016) is the major constraint for decision-makers to integrate ecological aspects in the environmental impact assessments.

Furthermore, it has been explored that the village tank performance had been declining with a reduction in tank capacity due to tank siltation and improper maintenance. This situation made the farmers request tank rehabilitation to store more water in the village tanks. In the recent past, the non-governmental organizations and the World Bank funded and rehabilitated some randomly selected village tanks in the Vavuniya district, as there is no documentation or knowledge of the cascade lines of the village tanks. This resulted in the inundation of adjacent tanks due to overflow of tanks during the rainy season (Personal Communication). It ultimately affected the livelihood of the farmers in the adjacent tanks. The objective of the study was to identify and validate the VTCS and to study the water flow from one village tank to another in each VTCS located in the eight ASC divisions in the Vavuniya district.

STUDY AREA

The whole Vavuniya district was considered for this study. The cascades were analyzed in the eight ASCs, namely *Cheddikulam*, *Pampaimadu*, *Kovilkulam*, *Madukandha*, *Nedunkerny*, *Omanthai*, *Ulukulam* and *Kanagarayankulam*, which are shown in Figure 1. The total extent of the study area is 1,995 km^2.

METHODS

The identification and mapping of VTCSs separately for each ASC in the Vavuniya district were performed through GIS approaches with available digital maps, remote sensing images, field investigation and validation in consultation with local experienced senior people in the respective village tanks.

Digital topographic map layers (scale: 1:10,000) of the study area were obtained from the Survey Department, and all GIS (shape) files were corrected with on-screen editing facilities available with Quantum GIS 2.8.8 free software with online base maps (Google Earth Global Viewer). Draft-corrected VTCS maps were finalized after comprehensive field verification with

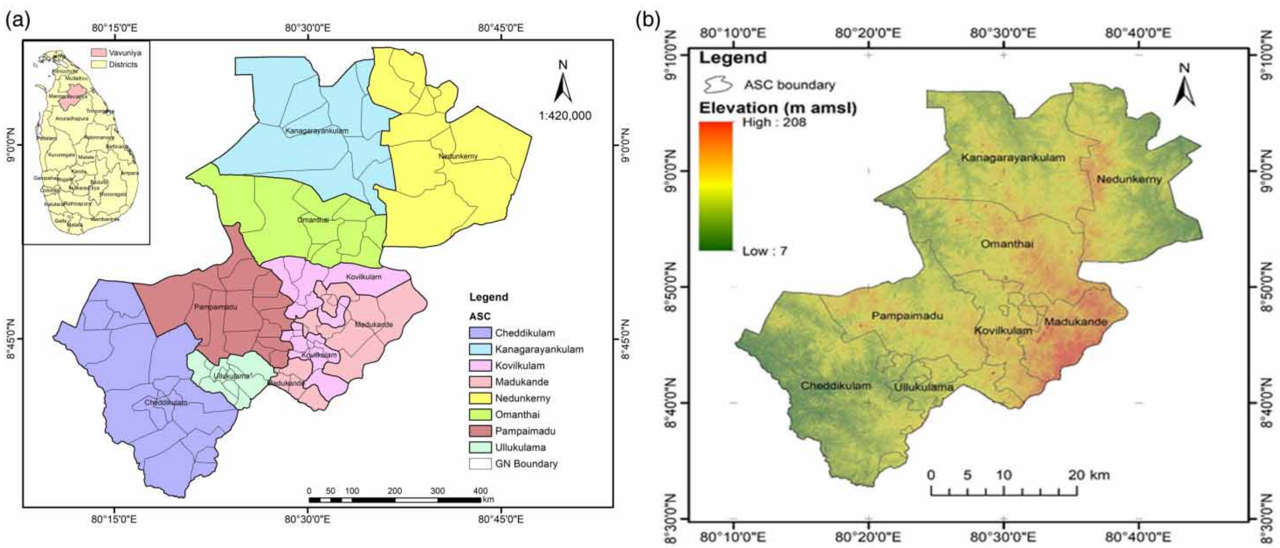

Figure 1 | Study area: (a) Eight ASCs of Vavuniya district and (b) Topographic map.

hand-held global positioning system (GPS) device (eTrex 10). The VTCS map was used as a guide map during all field-level investigations.

The digital elevation model (DEM) with a 100 m resolution was developed using shape file format elevation contour data with interpolation tool available with ArcGIS 10.2.2 software and used for the hydrological analysis using the same software.

The DEM of the Vavuniya district was clipped to create the study area's flow direction map. The DEM was created using contour maps in the format of contour lines and points. A triangulated irregular network (TIN) was created using elevation information and used to create the DEM. The TIN file was developed using the TIN tool in Arc GIS 10.2.2. The DEM file for the study area was created as a square that could cover the total study area. Hence, it would not collapse the stream flow.

Fill-sink, flow accumulation and flow direction maps were prepared using hydrological tools in Arc GIS 10.2.2 to understand the pattern of natural water flow or cascade system. A fill-sink map was created to get depression-free DEM surface for the error-free running of hydrological feature extraction algorithms in hydrological feature development using hydrologic tools of ArcGIS. A flow direction map was created to determine the direction in which water would flow out of each cell. A flow accumulation map was created to calculate the number of upslope cells flowing to a location and hence create a stream network. Flow lines were extracted using threshold values of 100, 200, 500 and 1,000 m. The most suitable threshold value for the study area was selected based on the field investigations, records and Google map. Finally, the created flow accumulation map was overlaid with the digitized tank shape file, and then the VTCS map was developed. Mapping accuracy was assessed using field verifications. The exact threshold value was selected as 100 m for the flow accumulation map. Village tank cascades were verified and validated at the field level using local people's knowledge in the respective village tank cascades.

RESULTS AND DISCUSSION

Based on the secondary data available at the Office of the Asst. Commissioner of Agrarian Services from 2017, there were 756 village tanks in the eight ASCs of the Vavuniya district. However, this study identified a total of 80 cascades comprising 514 village tanks using the GIS approach. Out of the identified number of cascades, 69 cascades were validated in the field using the knowledge of local people. In addition, this study identified 111 isolated village tanks (15%) without connecting with other village tanks and 131 abandoned village tanks (17%) in the district. The summary results of the above are illustrated in Table 1.

As shown in Table 1, the *Pampaimadu* ASC is comprised of a more significant number of village tanks in the Vavuniya district than that of the rest of the ASCs, while the *Kanagarayankulam* ASC has the lowest number. However, in terms of interconnected tanks, i.e., cascades, more cascades were identified in *Omanthai* ASC than that of other ASCs, and the lowest number was recorded in *Madukanda* ASC in the desk study.

Among the ASC divisions, the *Omanthai* ASC is found to have the highest variation in a number of cascades identified and validated (six). In contrast, in *Pampaimadu*, *Ulukulam* and *Kanagarayankulam* ASC divisions, the variation is only two cascades in each, and in *Madukanda* only one cascade. This may be due to the fact that there was a temporal variation in

Table 1 | Summary results of the study on the village tank cascades in Vavuniya district

ASC division						
Name	**Area (m^2)**	**Number of cascades identified in the desk study**	**Number of cascades validated in the field**	**Total number of tanks in the cascades**	**Number of isolated tanks**	**Number of abandoned tanks**
Cheddikulam	428	16	13	90	22	43
Pampaimadhu	235	16	14	124	14	28
Kovilkulam	111	05	07	82	03	05
Madukanda	137	04	03	49	08	03
Nedunkerny	336	07	10	47	07	30
Omanthai	289	17	11	68	24	10
Ulukulam	86	07	05	35	02	02
Kanagarayankulam	372	08	06	19	31	10
Total		**80**	**69**	**514**	**111**	**131**

the identification and the field validation of cascades, as the degree of stream/water flow in the cascades is highly dependent on seasons.

Based on the field validation, the highest number of cascades (14) were observed in *Pampaimadu* ASC, and the lowest number (three) of cascades were notified in *Madukanda* ASC. Therefore, in order to show the operative cascades, the authors take *Pampaimadu* ASC and *Madukanda* ASC as two examples, as these ASCs are validated with the highest and lowest number of cascades, respectively. The field study explores the *Kovilkulam* ASC with the highest number of village tanks per cascade, and *Kanagarayankulam* ASC with the least number of village tanks per cascade (Table 2).

Figure 2 shows three distinct cascades (along with tanks and water flows) in the *Madukanda* ASC which are notified as A, B and C. Field validation confirmed that 46 village tanks connected to the three cascades in the said ASC, while eight village

Table 2 | Minimum and maximum number of village tanks connected in cascades of each ASC in the Vavuniya district

Name of the ASC division	Minimum number of village tanks in a cascade	Maximum number of village tanks in a cascade
Cheddikulam	02	23
Pampaimadhu	02	23
Kovilkulam	03	47
Madukanda	05	23
Nedunkerny	02	23
Omanthai	03	11
Ulukulam	02	12
Kanagarayankulam	02	05

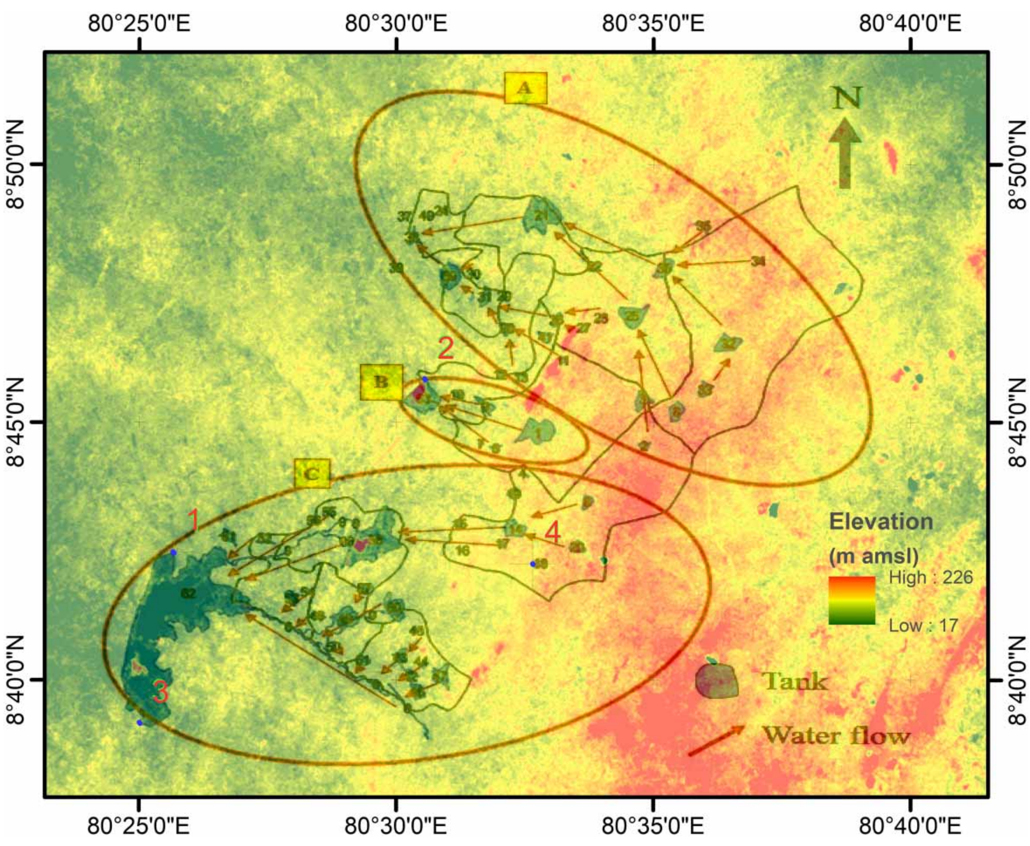

Figure 2 | Cascade validated in the Madukanda ASC division (three cascades: A–C).

tanks are isolated and three are abandoned. The isolated tank is not connected to any other tank, and there is no water flow from or into the tank.

However, in *Pampaimadu* ASC (as shown in Figure 3), the highest number of cascades, i.e., 14 distinct cascades, are observed in the field study, and 124 village tanks are connected to the existing cascades. These 14 distinct cascades are marked A–N, as shown in Figure 3. The cascades of *Pampaimadu* ASC are highly fragmented compared to *Madukanda* ASC, as a greater number of distinctive cascades are observed. The *Madukanda* ASC does not seem highly fragmented as fewer cascades are validated in the field. *Madukanda* ASC consists of cascades connecting from five to 23 village tanks per cascade, while Pampaimadu ASC ranges from two to 23 village tanks per cascade (Table 2). In total, 14 village tanks have been isolated, and 28 village tanks abandoned in the Pampaimadu ASC, which accounted for 25% of the total tanks in the said ASC. The cascade connected to a maximum number of village tanks is expected to have more water conserved (Panabokke *et al.* 2002; Matsuno *et al.* 2003).

On the contrary, the ASC divisions, namely *Kovilkulam* and *Nedunkerny*, were found, respectively, with two and three more cascade lines to be operational during the field validation, but not identified in the desk study. This shows that the connectivity of the tanks was fragmented, leaving a more significant number of small cascades in the field as operational. This could be due to tank siltation (Bebermeier *et al.* 2017), human interventions, such as encroachments, and improperly planned developmental activities (Somaratne *et al.* 2005). In addition, the improper developmental activities undertaken in the particular area would have let the water flow lines find alternative paths in line with the terrain. Somaratne *et al.* (2005) added that water shortage and the breach of tank bund due to heavy rain and lack of financial support from government/other organizations to renovate the tanks also could be the possible reasons for the village tanks to be abandoned/isolated.

It was further noticed that there are some village tanks that remained either isolated or abandoned in each ASC. The migration of farmers toward urban areas due to inadequate income from farming and the situation of unrest that existed for nearly three decades may be the reasons for a substantial number of village tanks being abandoned. The prolonged ignorance of relevant authorities on VTCS for maintenance and rehabilitation led to 17% of tanks being abandoned and 15% of tanks being isolated.

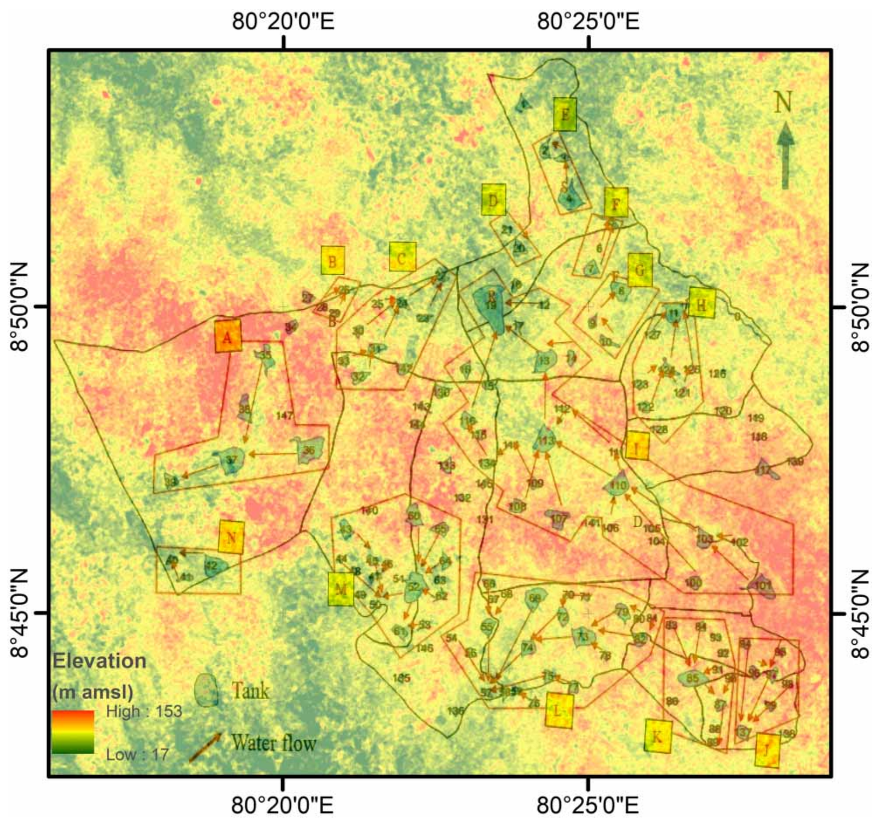

Figure 3 | Cascades validated in the Pampaimadu ASC division (14 cascades: A–N).

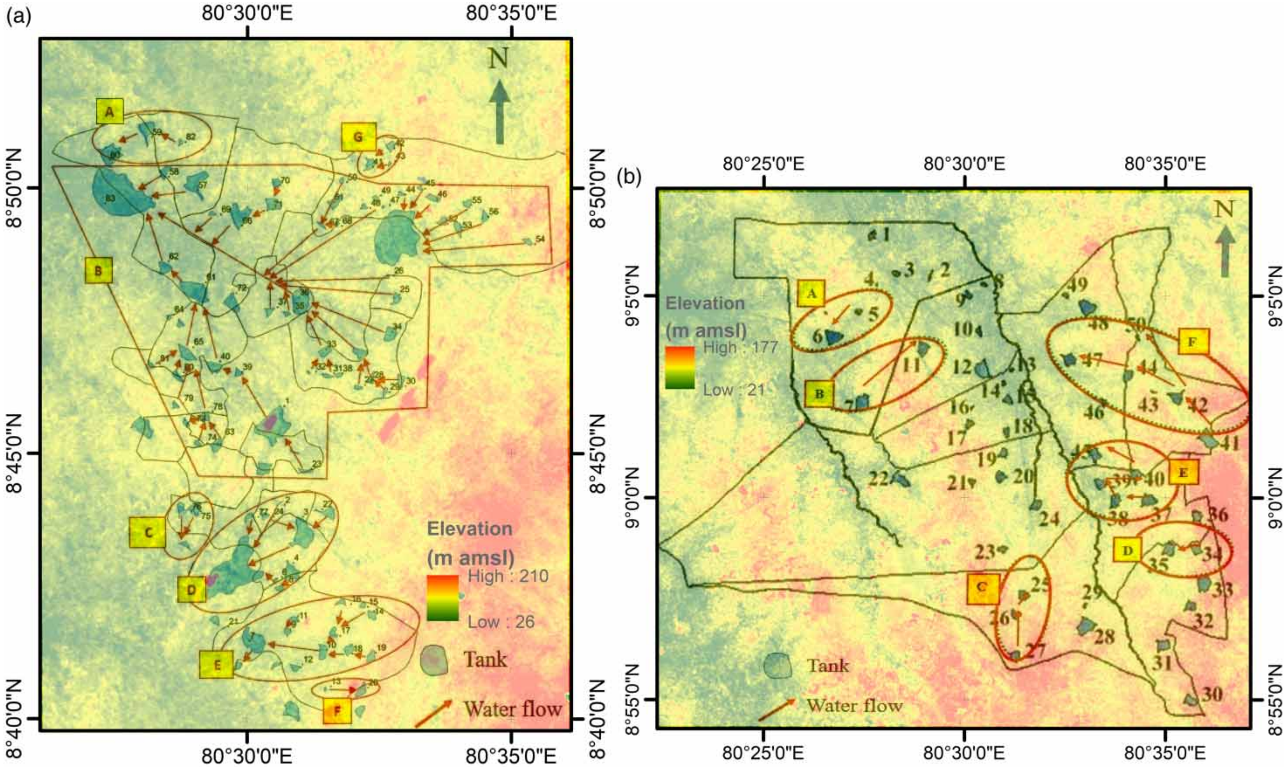

Figure 4 | Cascades validated in the field study: (a) Kovilkulam ASC and (b) Kanagarayankulam ASC.

Moreover, as shown in Table 2, the authors highlight the minimum and the maximum number of village tanks in different cascades in each ASC division in the Vavuniya district, in which the *Kovilkulam* ASC identified with a maximum of 47 village tanks in one cascade. In contrast, *Kanagarayankulam* ASC is shown with a minimum of five village tanks in a cascade (Figure 4). As the *Kovilkulam* ASC is located close to the Vavuniya town region, households continued their farming activities under these village tanks, and the desilting activities were undertaken by the farming community. Furthermore, the ASC might have obtained a source of funding for village tank rehabilitation from time to time, as the *Kovilkulam* ASC was not much affected during the civil unrest. As such, the fragmentation of cascade lines might not have happened in the same way as other ASCs in the Vavuniya district. However, this is contrary to Somaratne *et al.* (2005) and Shanmuganathan *et al.* (2010), as the disruption of cascades due to human settlements are more prone to the town area.

In *Kanagarayankulam* ASC, the number of tanks validated in cascades is 19, while the number of isolated tanks identified is 31 which is the highest number among the ASCs studied. *Kanagarayankulam* ASC is located in the north of Vavuniya and was affected severely during the civil unrest (1990–2009); during that period no farming activities were undertaken due to the mass displacement of the households. No rehabilitation or desilting was carried out for a long time which meant a higher number of village tanks were left isolated due to natural siltation on the water flow lines.

Therefore, pinpointing the primary cause for the fragmentation of cascades is still challenging, and the research should be done in-depth incorporating the historical records and interviews with key stakeholders in the relevant villages regarding water flow lines. Further investigation is recommended to study the possibilities of increasing the cascade areas in the study area by connecting isolated tanks with cascades (connecting the village tanks for water flow from one village tank to another). Initiation taken toward rehabilitation of cascades would enhance the livelihoods of farming households in the Vavuniya district and lead to sustainable water resource management.

As shown in Table 1, nearly 17% of abandoned tanks need to be restored to harvest the seasonal rainwater which could be achieved by the rehabilitation of the abandoned village tanks. As per the previous literature (Dharmasena 2009; Aheeyar 2013; Melles & Perera 2020), social and economic conditions in these regions should also be considered in addition to the engineering aspects of rehabilitation.

CONCLUSIONS

The identification and mapping of VTCS separately for each ASC in the Vavuniya district were performed through GIS approaches with available digital maps, remote sensing images, field investigation and validation in consultation with local older people in the respective village tanks.

In total, 69 VTCSs comprise 514 village tanks validated in this study that would be used for a rapidly developing region like Vavuniya district for sustainable water resources management integrating ecological aspects in an environmentally friendly manner. There have also been 111 isolated village tanks and 131 abandoned village tanks identified in the Vavuniya district. Furthermore, the initiation must be taken to connect those isolated tanks into cascade lines, thereby increasing the water availability for agriculture. Moreover, rainwater harvested in abandoned village tanks would contribute to groundwater recharge in this region. Hence, taking initiatives to rehabilitate and conserve those abandoned village tanks would be essential for sustainable water resource management and livelihood enhancement. These documented VTCSs along with water flow could be used by planners, engineers, environmentalists, hydrologists, researchers, etc., in the planning and implementation of water resources management projects in the Vavuniya district.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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