Optimizing Water Resource Management Using GIS: A Case Study of Telivarai Kulam Tank, Kilinochchi

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ABSTRACT

The agricultural sector is one of the most critical components of Sri Lanka's economy and development (ADB, 2007; Ranathunga, 2018, Thibbotuwana, 2021). Among the country's seven provinces, the Northern Province contains significant agricultural land (Sivakumar, 2021; Deepakrishna Somasundaram, 2020). However, many of these lands remain underutilized or abandoned due to water scarcity and inadequate resource management (Tharani Gopalakrishnan, 2021, United Nations, 2011). This study focuses on the Telivaraikulam tank in the Kilinochchi District as a case study to explore the potential for optimizing agricultural land usage. The area surrounding the tank includes over 100 hectares of agricultural land, yet only 25 hectares are currently being cultivated, leaving most of the land abandoned. This research aims to investigate the underlying reasons for the underutilization of these lands and propose strategies to enhance their cultivation potential. Using Geographic Information Systems (GIS) and satellite image analysis, the study identified the tank bund of Telivaraikulam, which is situated upstream of the catchment area. Although the estimated capacity of the tank is 35 hectares, the current agricultural activities are confined to only 25 hectares. To address this issue, the study proposes reconstructing the tank bund at a downstream location to optimize its design and maximize the benefits to the local community. Comprehensive field surveys, ground measurements, and satellite imagery were employed to generate an area-capacity curve and delineate the catchment area. The findings indicate that by redesigning the tank infrastructure, the cultivated area can be significantly expanded. The study concludes with recommendations for improving water resource management and enhancing agricultural productivity in the region, emphasizing the importance of innovative design and resource optimization in addressing challenges in the agricultural sector.

Keywords: Water management, Abandon, GIS, Surveying, Agriculture, capacity

BACKGROUND

Sri Lanka has embarked on a long-term process of rebuilding its economy following the 30 years of conflict era (Weligodapola, 2022). The country’s basic revenue-generating sectors like Tourism and Agriculture both rely on clean, reliable water (Zerihun, 2018, Menuka Udugama, 2024). However, the water sector has to face the consequences of climate variability all around the world (Charles Nhemachena, 2020). Due to the climate changes, most of the water tanks used for traditional irrigation were not functioning and most of the cultivated lands were abandoned. Some of the areas are fully dry throughout a particular season and the other part of the area is over-flooded in the other season (Maha) of the year.

There are two major cultivation seasons Maha and Yala. The beginning of the Yala season (flooding and transplanting) can alter from May to the end of August. Similarly, the Maha season can vary from September to March in the following year (W.M.W. Weerakoon, 2023). But it can vary from season to season because there is no exact time location for this, paddy cultivation. A majority is cultivated during the Maha season. In the Yala season, the amount of cultivation is lower than in the Maha season due to a lack of water (Jayatissa, 2020, Suppiah, 1985). Therefore, improvement of water tanks needs to increase water in Yala season and farmers able to do necessary agriculture.

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Research questions and motivation

Research questions	Motivation
What are the primary reasons for the abandonment of agricultural lands surrounding Telivaraikulam?	To identify the factors limiting agricultural productivity and understand why potential cultivable lands are underutilized, guiding targeted interventions
How can GIS and satellite image analysis be utilized to assess the catchment and bund conditions of Telivaraikulam?	To leverage advanced technological tools for precise analysis of water resource availability and infrastructure conditions.
What modifications in the design of the Telivaraikulam tank can optimize water resource management for agriculture?	To develop a practical and sustainable solution for improving irrigation, addressing water scarcity issues, and supporting agricultural expansion.
How much cultivable land can be added by improving the tank design and management strategies?	To quantify the potential benefits of tank reconstruction and validate the feasibility of increasing cultivable land through improved water management.

METHODOLOGY

The methodology outlines the approach adopted to achieve the main objective and specific objectives of this research. The methods employed for data collection, analysis, and interpretation are presented, along with the materials utilized to progress the study. This includes details regarding the sources of materials, the periods considered, and the availability of relevant data.

A structured methodology flowchart is provided to illustrate the sequential steps undertaken during the research process. Each step was carefully followed under the flowchart to ensure systematic progression and consistency throughout the study. This approach facilitated the effective collection and analysis of data to derive meaningful insights and achieve the intended outcome.

Methodology flow chart

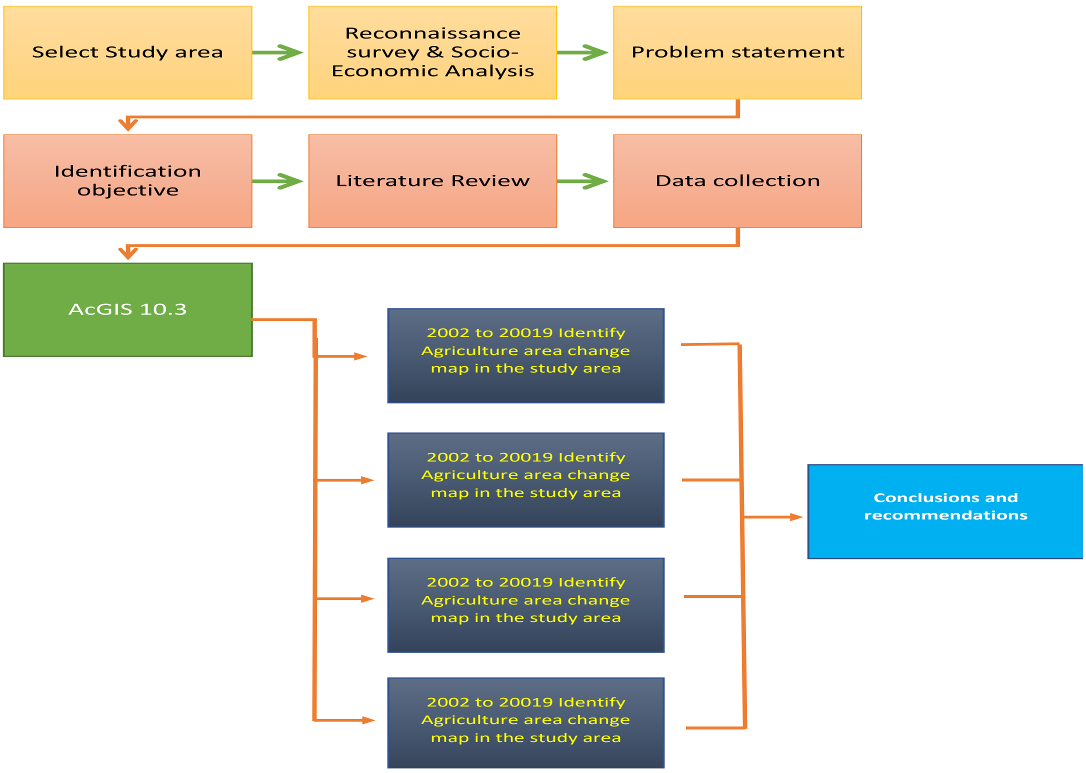

Figure 3-1 Methodology Flow Chart

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Study Area

The research was conducted in Thelikaraikulam, located within the Poonakary division of the Kilinochchi District in Sri Lanka. Geographically, Thelikaraikulam is positioned at coordinates N 9.447269 and E 80.195254. The tank's existing command area encompasses approximately 35 hectares, making it a significant asset for agricultural activities and water resource management in the region. The tank infrastructure features a bund with a total length of 1,000 meters and a maximum height of 2 meters. Other notable components include a single spillway, three wells, and a feeder canal that connects Enochchikulam to Thelikaraikulam. The tank bed spans a total area of 58.5 hectares, indicating substantial potential for enhancing water storage and agricultural productivity.

A Google Earth image of the study area is presented in Figure 3-2 to provide a visual representation of the tank and its surrounding features, emphasizing the importance of its geographic and infrastructural characteristics for the stud

Figure 3-2 Google Earth image of the study area

The Kilinochchi District is characterized by flat to gently undulating topography, with elevations ranging from 0 to 250 meters above mean sea level (MSL), although the majority of the region lies below 10 meters MSL. The dominant soil type in the district is red-yellow latosols, which cover approximately 36.36% of the land area (Jayatissa, 2020). These soils are fertile and rich in minerals, supporting a diverse range of crop cultivation, including in areas such as Tellivukarai Kulam (Mapa, 2019; Hansamali, 2018). The district experiences an annual temperature range of 20 to 30 degrees Celsius, with the highest temperatures typically recorded between June and August. The agroecological conditions of the region, shaped by the interplay of its climatic and soil properties, make it highly suitable for agricultural activities (Department, 2016, Geretharan, 2021)). The average annual rainfall in the district is approximately 1325 mm, with about 75% of the precipitation occurring during the northeast monsoon season from September to December (Jayawardena, 2016, Amarasingam Aginthini, 2023). Rainfall data from key gauge stations, such as Iranamadu, Akkarayan, and Kariyalainagapadduvan, indicate significant annual variability. For example, Iranamadu recorded 1822.4 mm of rainfall in 2011 compared to 1321.0 mm in 2000 (Manag, 2021). These physical and climatic conditions are pivotal in determining the agricultural potential and land use practices of the district. A reconnaissance survey conducted in the region provided critical preliminary insights into the area, laying the groundwork for the study by identifying key challenges and informing subsequent data collection efforts. This foundational step enabled a thorough understanding of the regional dynamics influencing agricultural development

Create a catchment area of the study area (Watershed Delineation

Watersheds, also known as basins or catchments, are geographic areas defined by the upstream region that drains to a specific outlet point (Khal & Agouti, 2020). The delineation of watersheds can be carried out manually using paper maps or digitally through Geographic Information System (GIS) platforms, which offer enhanced precision and efficiency.The watershed delineation process typically begins with acquiring a Digital Elevation Model (DEM) of the study area. The DEM, which provides detailed elevation data, is often sourced from the USGS Earth Explorer—a user-friendly platform that offers free access to Landsat imagery and other remote sensing data. Once the DEM is obtained, it is imported into GIS software such as ArcGIS 10.3. Using the Spatial Analyst extension toolbox within ArcGIS, hydrologic modeling tools are applied to automate the watershed delineation process. These tools analyze the elevation data to identify flow directions, flow accumulations, and the boundaries of the watershed. This streamlined, systematic approach ensures the accurate delineation of the watershed, providing a robust foundation for subsequent hydrological and environmental analyses.

Identify Agriculture area change map in the study area (2002 to 2021)

Digitizing study area in Google Earth

Google Earth is a computer program that provides a 3D representation of the Earth using satellite imagery (Lei Luo, 2018, Zhao, et al., 2021). It allows for a clear visualization of the Earth's surface, including temporal series of imagery. In this study, agricultural areas within the study region were identified by analyzing surface textures and temporal satellite imagery. These areas were then digitized and saved in the Keyhole Markup Language (KML) format for further analysis.

Extract Agriculture area

All 'kml' files are changed to layer files. And then all layer files are changed to shapefiles. Finally, the shapefile of all digitized agriculture areas was created by using ArcGIS 10.3 software. Then all agriculture is extracted by using this shapefile in ArcGIS 10.3 software.

Create LULC data map

Landsat satellite imagery was selected for this study based on a comprehensive literature review and prior research experience for several reasons. First, Landsat provides high-resolution imagery that is well-suited for analysing land use and land cover changes over time. Second, its long-term data archive, spanning several decades, allows for consistent temporal analysis, which is crucial for studying trends and impacts, such as changes in cultivated land. Additionally, Landsat imagery is freely available and easily accessible, making it a cost-effective choice for research purposes. The imagery's compatibility with Geographic Information Systems (GIS) further enables efficient processing and analysis, supporting detailed investigations into the spatial and temporal dynamics of the study area. Long-term change

detection: Landsat data has been available since 1972, providing a robust and continuous archive of satellite imagery covering the entire globe. This extensive dataset makes it ideal for detecting long-term Land Use and Land Cover (LULC) changes. For this study, which focused on detecting LULC changes in 2021, Landsat 8 data emerged as the most suitable option (Mohammad Ali Hemati, 2021).

Revisit frequency: The Landsat satellite has a 16-day revisit interval, which enhances data selection flexibility. This feature is particularly useful in overcoming challenges such as cloud cover, a common limitation in satellite imagery acquisition (James T. Iron, 2012, Michel E. D. Chaves, 2020,).

Accessibility: Landsat data is openly available, making it a popular choice for numerous research projects. This accessibility further supports its selection for this investigation. After selecting the appropriate satellite sensor, the next step involved acquiring the required Landsat imagery. Key considerations during this process

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included: Image quality: The primary challenge was obtaining cloud-free and analysable imagery (Yingjie Wu, 2020). Taking these factors into account, a single Landsat image was chosen for the study and obtained from the USGS Earth Resources Observation and Science (EROS) data repository:2021.04.05 Landsat 8 OLI/TIRS C2 L1 TM imagery: This image represents the current state of the study area's catchment in 2021.

Image classification using the ArcGIS 10.3 Spatial Analyst extension

The Multivariate toolbox includes capabilities for both supervised and unsupervised classification, thanks to the ArcGIS Spatial Analyst extension. Only supervised Image Classification was employed in this study. The Image Classification toolbar provides a user-friendly environment for preparing supervised classification training samples and signature files. The basic classification method is the Maximum Likelihood Classification tool (Robert A, 2007, Arti Kumari, 2022). This utility requires a signature file, which identifies the classes and associated statistics. The signature file for supervised classification is prepared using training samples and the Image Classification toolbar. The Spatial Analyst additionally includes filters and boundary-cleaning tools for post-classification processing.

Study area Bathymetric map and Area capacity curve

All bathymetric data was transformed to a 3D vector point shapefile with horizontal coordinates (x and y) and elevation in a GIS environment (or depth, z). A 2D vector shapefile of the reservoir's contour (without the island) was also created. A gridded Digital Elevation Model (DEM) was interpolated from bathymetric vector-points data inside the contour of the reservoir using the Toppo to raster function from 3D Analyst tools in ArcGIS 10.3, based on the "elevation" attribute (type Point Elevation). We can generate an Area capacity curve using the DEM of the research area.

ANALYSIS AND DISCUSSION

Study area

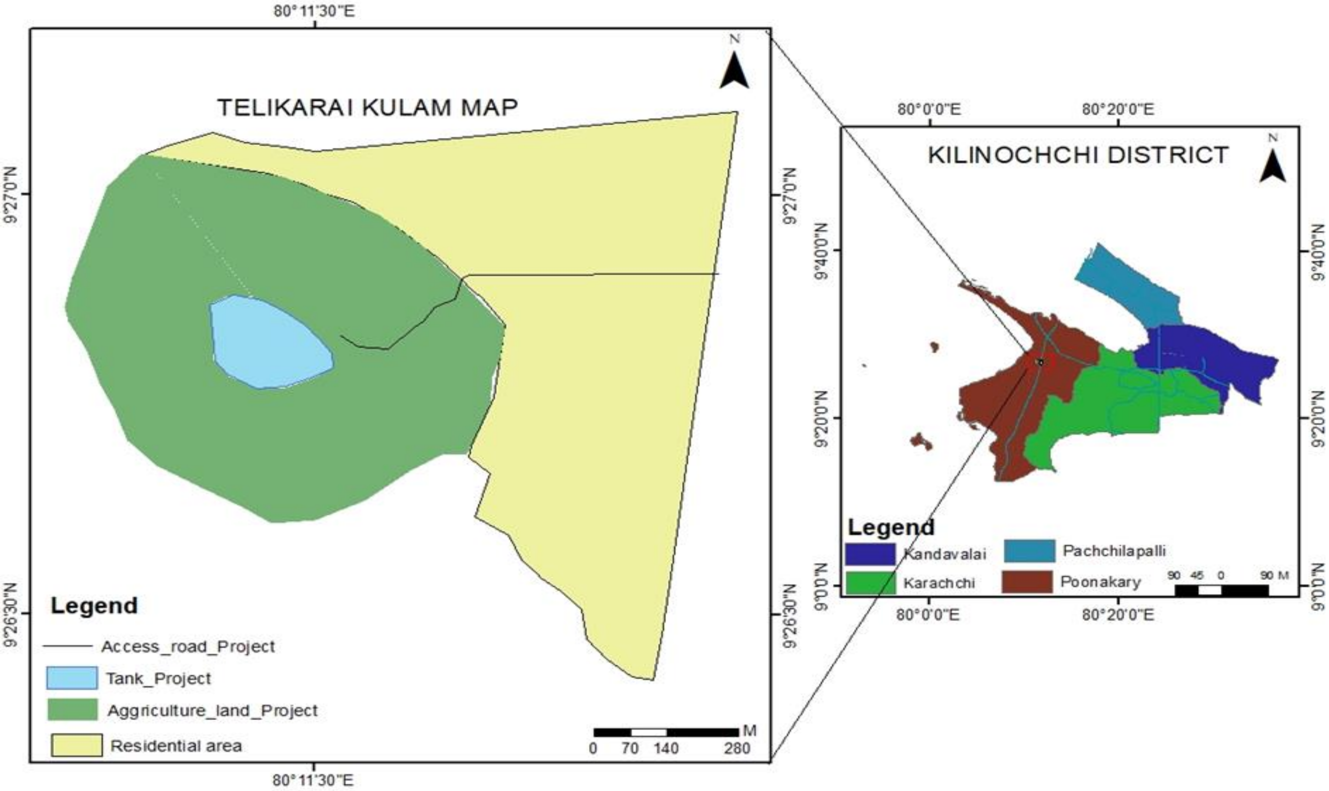

Figure 4-1 Study Area

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Telivukarai kulam cultivated area changing map (2002-2020)

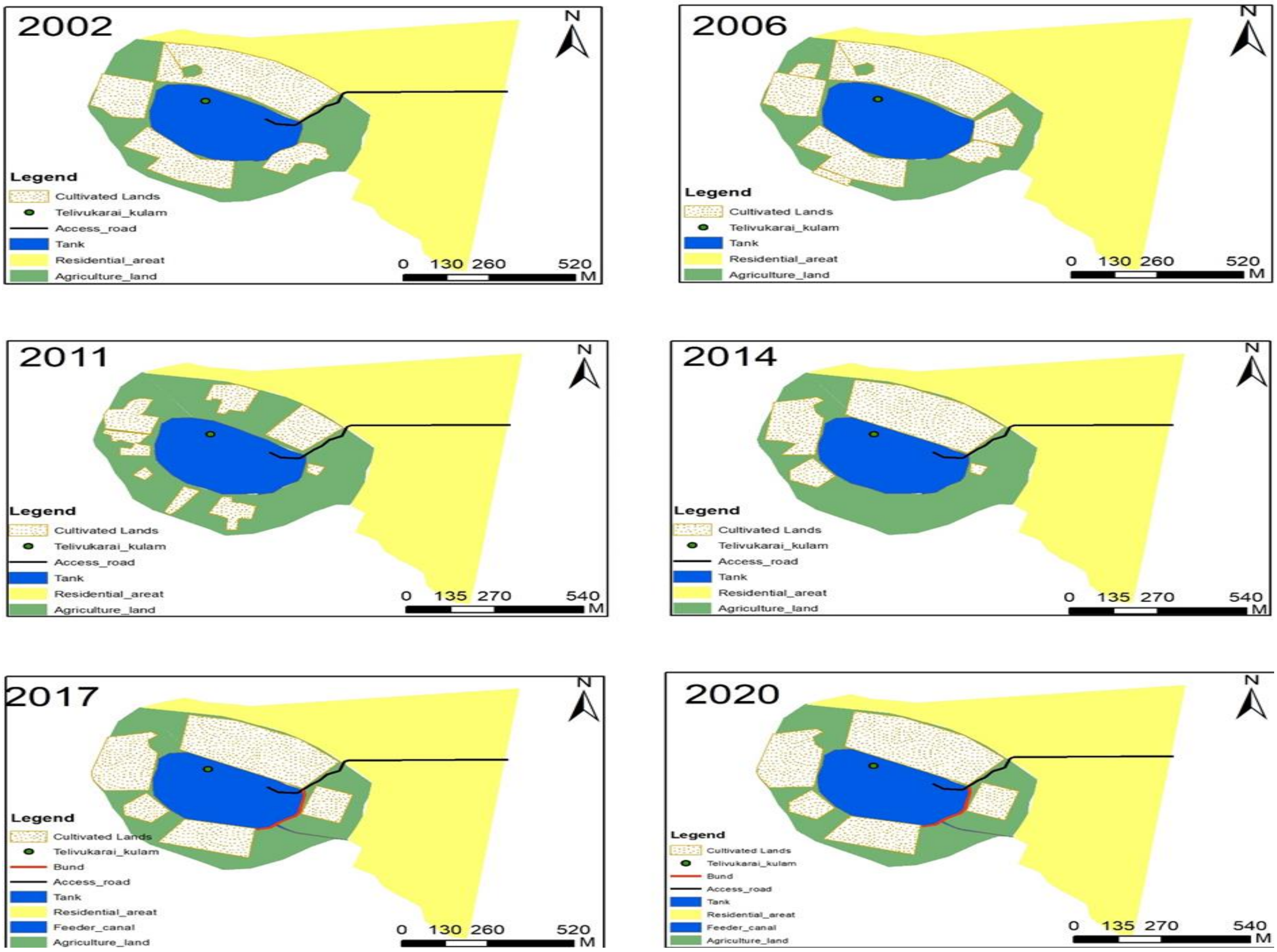

Figure 4-2 Telivukarai kulam cultivated area changing maps

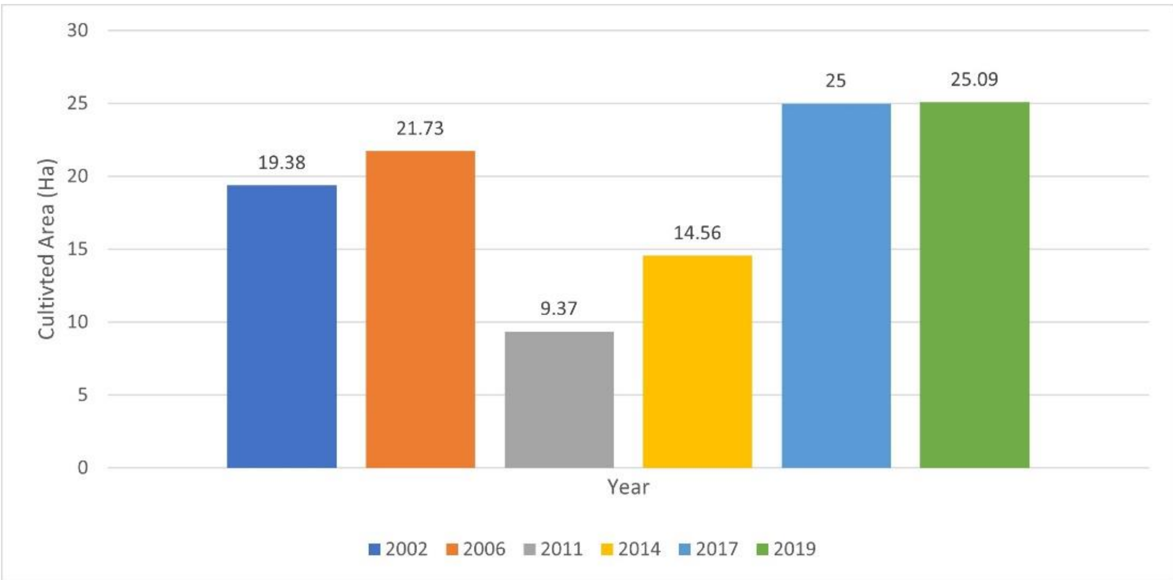

Figure 4-3 Telivukarai kulam cultivated area

According to Figures 4.2 and 4.3, the cultivated lands in the Telivukarai Kulam area have shown an overall increase during the period from 2002 to 2020. However, a significant decline was observed in 2011, which can be attributed to the impacts of the civil war in the region. In 2017, the tank underwent reconstruction with the construction of a new bund. Despite this development, the growth in cultivated land during the period from

2017 to 2020 appears minimal, indicating that the reconstruction did not result in substantial benefits for agricultural expansion during this time.

Catchment area of study area

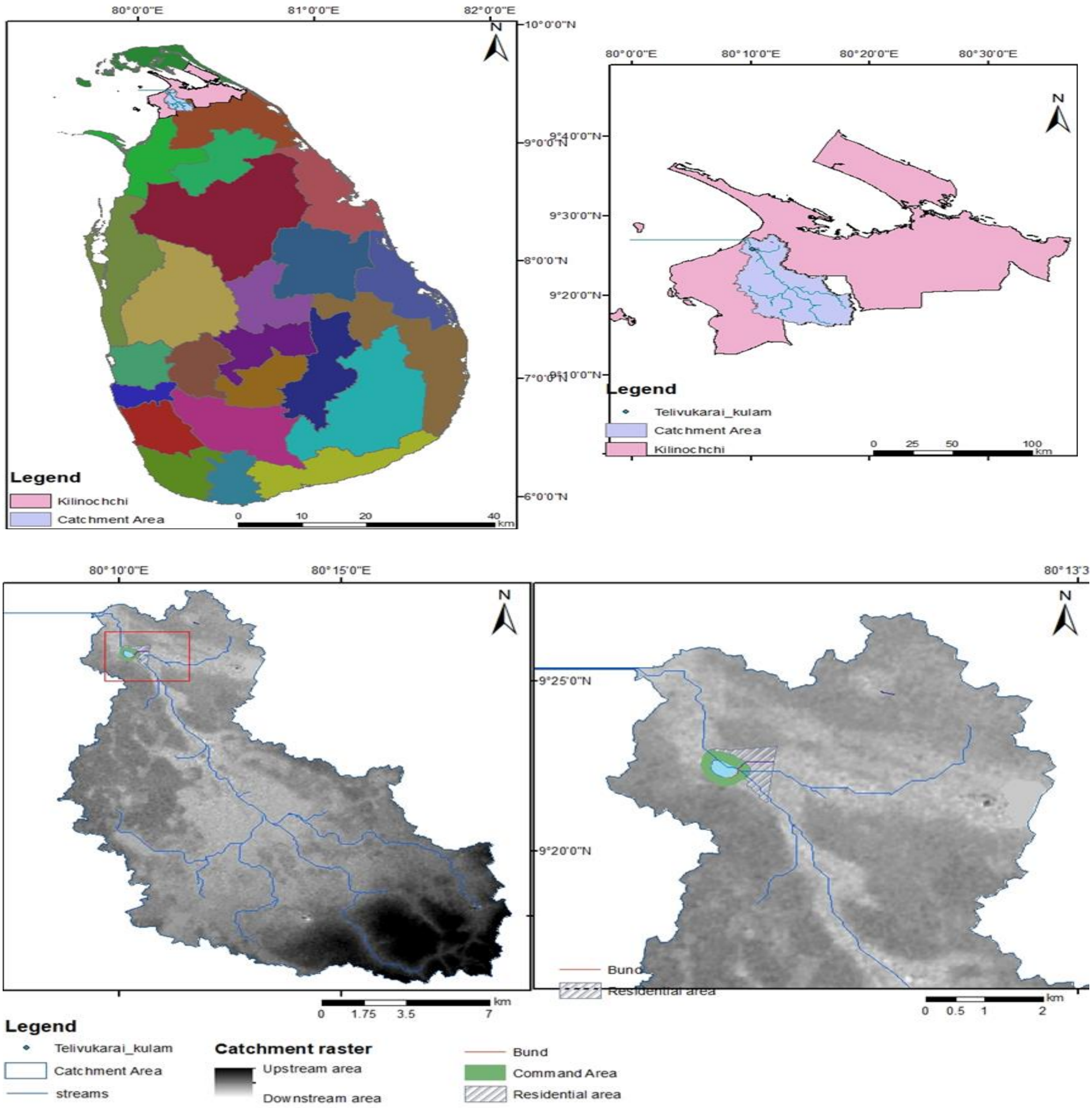

Figure 4-4 Catchment area of study area

Figure 4-4 shows the catchment area of Telivarai kulam. In this picture we can see the newly built dam has been built on upstream of the Telivukaikulam catchment.

Land Used Land Cover (LULC) map of catchment area

Select the satellite images of study area

The USGS is providing the Landsat series images. In this research case, the land use pattern of the catchment wanted to be identified. The maximum supervised classification is the best way to classify the image. But here, there is no field data for the study area. We can identify the features of land surfaces by using Google Earth. But we cannot say whether the paddy area is cultivated or not by using Google Earth images only. Mostly, the Landsat images have a cloud issue. If we use that cloudy image, then we cannot classify the image correctly. So, we need to download cloudless images for lULC analysis.

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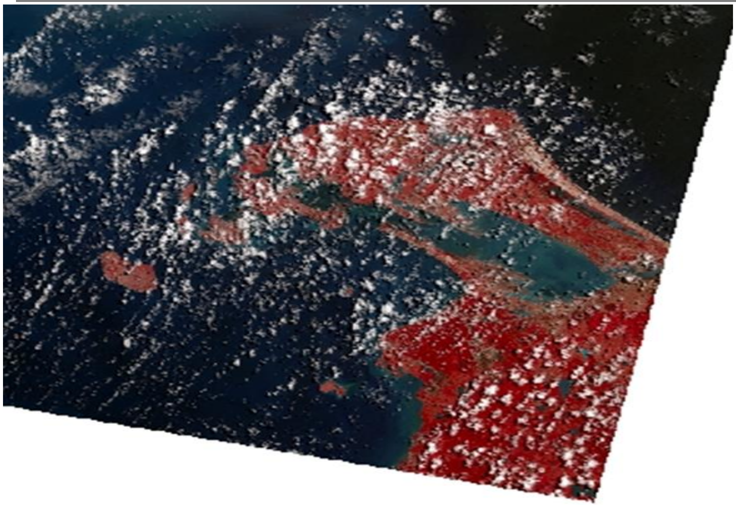

Figure 0-5 The Landsat 8 OLI/TIRS image on 2021-06-15

Figure 4-5 describes the composite band (1-7) of Landsat 8 OLI/TIRS on 2021-06-15. The study area is covered by clouds. So, there is no data in cloud areas. These images are of no use to do any processing in this research.

Figure 0-6 The Landsat 8 OLI/TIRS image on 2021-04-05

Figure 4-6 describes composite band (1-7) of Landsat 8 OLI/TIRS on 2021-04-05. The study area is covered Low-Level Clouds. These images can use to processing in this research.

Land use maps for study area

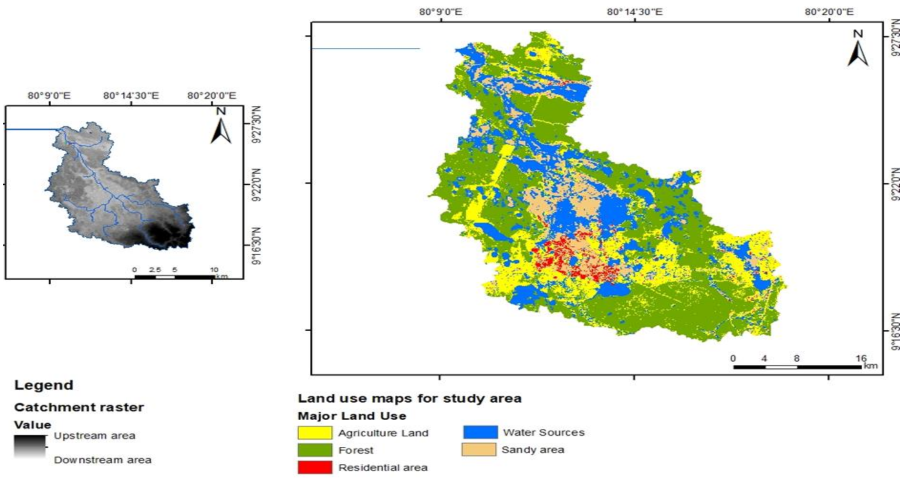

Figure 0-7 Land use map – Study area catchment (2021)

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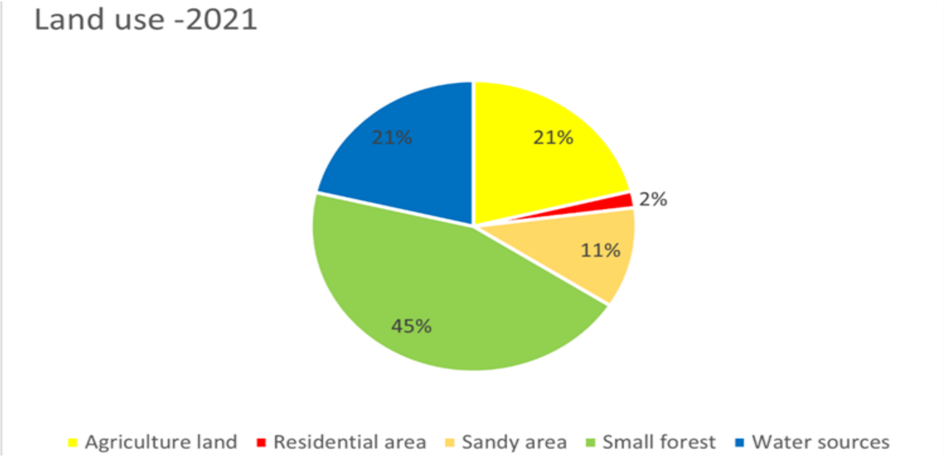

Figure 0-8 Land use -study area catchment

Figure 4.7 and Figure 4.8 shows the land use pattern in the study area of catchment. In this research we need to find out the Telivukarai kulam catchment to improve tank capacity. In the catchment area forest is being there for 45%.

Develop Elevation-Area-Capacity Curves of Telivukarai kulam

Bathymetric map

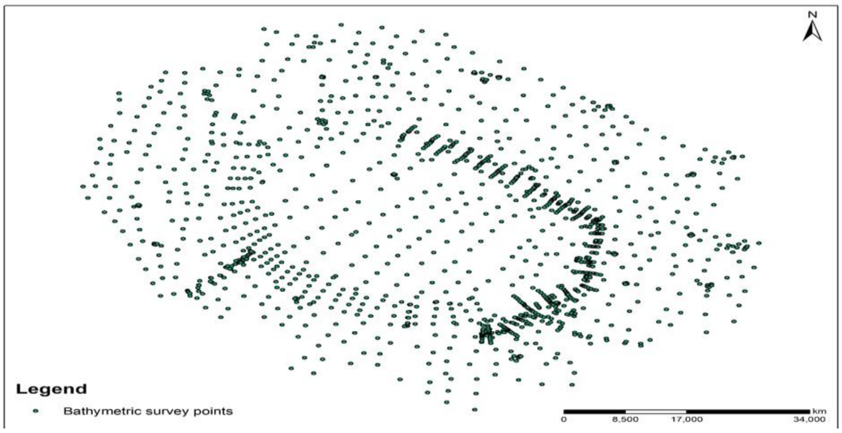

Figure 0-9 Bathymetric Survey points

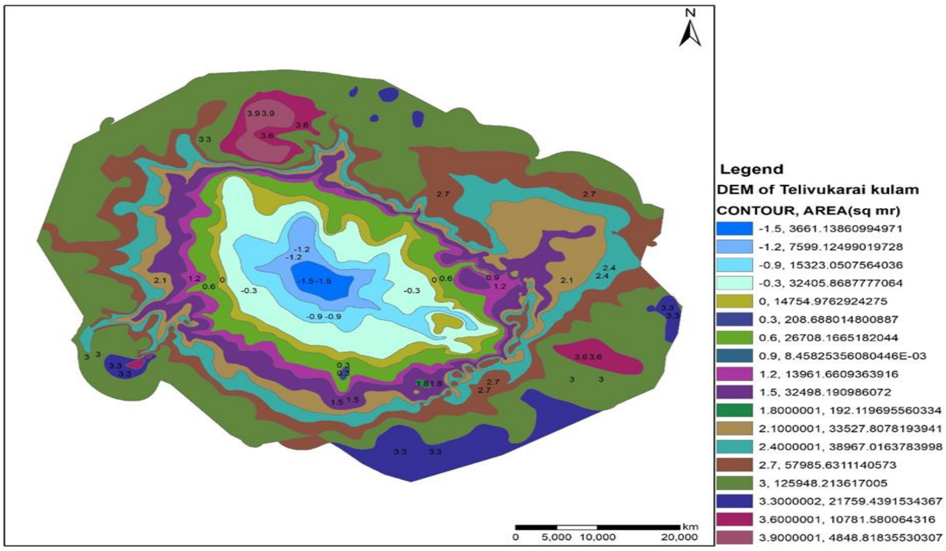

Figure 0-10 Bathymetric chart of Telivukarai kulam with contour lines (DEM)

Area-Capacity Curves of Telivukarai kulam

Table 4- 1 Tabulation sheet for Teluvukarai kulam

TABULATION SHEET FOR THELIKKARAI KULAM			
Contour intervals(m)	Mean Area(Acr)	Volume (Acr.ft)	Capacity(Acr.ft)
-1.50	0.09	0.09	0.09
-1.20	0.95	0.95	1.04
-0.90	2.48	2.48	3.52
-0.60	5.64	5.64	9.15
-0.30	9.97	9.97	19.12
0.00	13.76	13.76	32.89
0.30	17.96	17.96	50.84
0.60	21.69	21.69	72.53
0.90	24.58	24.58	97.11
1.20	27.68	27.68	124.79
1.50	30.85	30.85	155.64
1.80	35.02	35.02	190.66
2.10	43.70	43.70	234.36
2.40	52.29	52.29	286.66
2.70	65.03	65.03	351.68
3.00	86.46	86.46	438.14
3.30	103.55	103.55	541.69
3.60	106.94	106.94	648.63
3.90	107.83	107.83	756.45

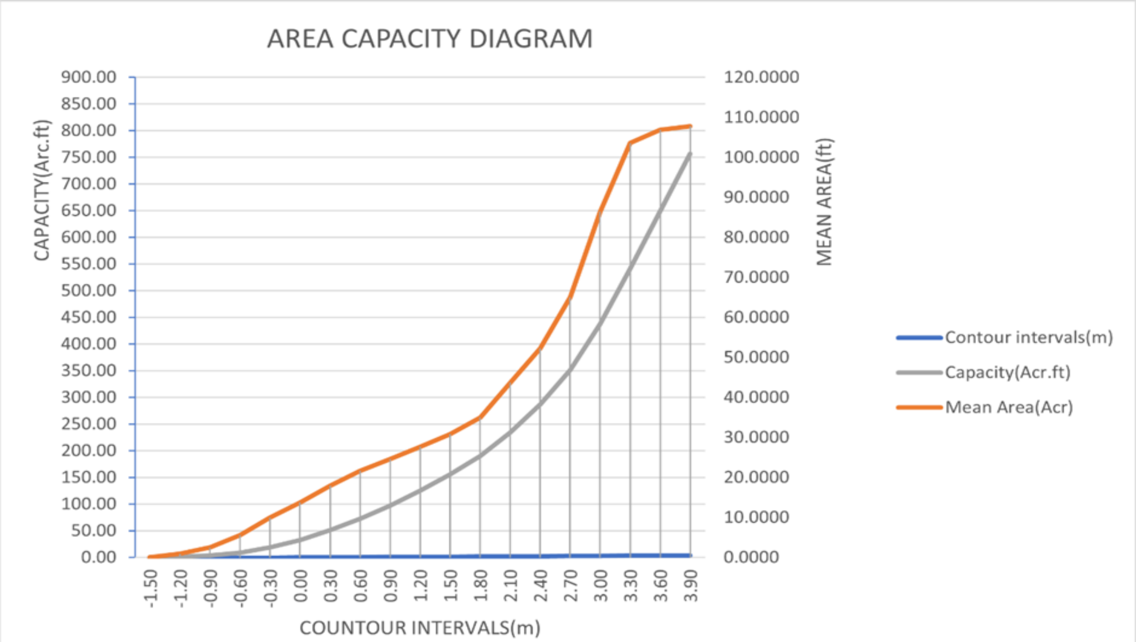

Figure 0-11 Area capacity diagram of Telivukarai kulam

Figure 4-11 depicts the Area-Capacity Curve of Telivukarai Kulam, a crucial tool for effective reservoir management and planning. This curve is instrumental in reservoir flood routing, aiding in the prediction and control of water flow during flood events. It supports reservoir operation by informing decisions on water release and storage management. Additionally, it facilitates the determination of water surface area and capacity at various elevation levels, essential for precise resource allocation. The curve also aids in reservoir classification, helping categorize reservoirs based on their storage and operational characteristics, and assists in analyzing sediment distribution, which is critical for maintaining long-term reservoir sustainability.

CONCLUSION AND RECOMMENDATION

This research highlights that the soil and climatic conditions of Telivukarai Kulam are highly favorable for agricultural activities. Despite the area comprising 35 hectares of cultivable land, only 25 hectares are currently under cultivation, primarily due to water scarcity. The study identified that the upstream positioning of the Telivukarai Kulam bund is a significant contributing factor to this issue. The upstream location obstructs the natural water inflow, limiting the tank's capacity to store sufficient water for agricultural needs. The study recommends relocating the bund to a downstream position to mitigate this challenge. This adjustment would enhance the tank's water storage capacity, ensuring adequate availability of water and alleviating the scarcity that restricts agricultural activities. Moreover, employing an area-capacity curve alongside detailed survey data can facilitate the redesign of the tank infrastructure. This redesign would optimize water management, support the expansion of cultivated areas, and contribute to the sustainable development of agriculture in the region.

REFERENCES

1. A.A.D. HANSAMALI, ,. L. (2018). Characterization of Calcic-Red Yellow Latosol of Northern Province for. Proceedings of 17th Agricultural Research Symposium , (pp. 247-251).
2. ADB. (2007). Agriculture and Natural Resources Sector Assistance Evaluation, Sri Lanka Country Assistance Program Evaluation.
3. Amarasingam Aginthini, E. U. (2023). Land Evaluation and Crop Suitability Analysis – A Case Study on Karachchi Divisional Secretariat, Kilinochchi District, Sri Lanka. Vavuniya Journal of Science, 02(01).
4. Arti Kumari, A. U. (2022). Decadal Land Use Land Cover Change Analysis using Remote Sensing and GrkarIS in Nagpur city of Maharashtra, India. Journal of AgriSearch,, 9 (03), 265-269.
5. Charles Nhemachena, L. N. (2020). Climate Change Impacts on Water and Agriculture Sectors in Southern Africa: Threats and Opportunities for Sustainable Development. Water, 12, , 2673. doi:; doi:10.3390/w12102673
6. Deepakrishna Somasundaram, F. Z. (2020). Spatial and Temporal Changes in Surface Water Area of Sri Lanka over 30 years. Remote Sensing, MDPI, 12.
7. Department, L. U. (2016). Land Use Plan Kilinochchi District .
8. Geretharan, T. (2021). Smallholder farmers' agricultural support services system in northern Sri Lanka. Massey University.
9. James T Iron, J. L. (2012). The next Landsat satellite: The Landsat Data Continuity Mission,. Remote sensing of Environment,. doi:10.1016/j.rse.2011.08.026
10. Jayatissa, R. (2020). OFC Cultivation in the Northern Province: Issues and Possible Solutions. Colombo: Hector Kobbekaduwa Agrarian Research and Training Institute.
11. Jayawardena, K. A. (2016). Investigation of combine effects of El Nino , Positive IOD and MJOon Second InterMonsoon Rainfall 2015 in Sri Lanka. Sri Lanka Journal of Meteorology.
12. L. N. Ranathunga, W. W. (2018). Agriculture in Sri Lanka: The Current Snapshot. International Journal of Environment, Agriculture and Biotechnology (IJEAB), 03(01).
13. Lei Luo, X. W. (2018). Google Earth as a Powerful Tool for Archaeological and Cultural Heritage Applications: A Review. Remote Sensing MDPI..
14. Manag., Y. &. (2021). Human Response to Flood Disaster in Kandawalai: Kilinochchi District in Sri Lanka. International Journal of Disaster Management, 51-60.
15. Maryam Khal and Abdallah Agouti. (2020). Evaluation of Open Digital Elevation Models: estimation of topographic indices relevant to erosion risk in the Wadi M'Goun watershed, Morocc,V . AIMSGeosience. doi:DOI: 10.3934/geosci.2020014.
16. Menuka Udugama, B. A. (2024). Willingness-to-Pay for Blue Ecosystem Services of Natural Pools in Sri Lanka: A Discrete Choice Experiment. Water, 16(17), 2437; https://doi.org/10.3390/w16172437. doi:doi.org/10.3390/w16172437
17. Michel E. D. Chaves, M. C. (2020,). Recent Applications of Landsat 8/OLI and Mapping: A Systematic Review. Remote Sens., 12 (18), 3062. doi:doi.org/10.3390/rs12183062
18. MohammadAli Hemati, M. H. (2021). A Systematic Review of Landsat Data for Change Detection Applications: 50 Years of Monitoring the Earth,. Remote Sensing MDPI.
19. Nations, F. a. (2011). 2. Food and Agriculture Organization of the United Nations , (2011) the state of the world's land and water resources for food and agriculture , Managing risk . The Food and Agriculture Organization of the United Nations and Earthscan.

20. Pushpa Malkanthi, U. G. (2009). Banning of Glyphosate and its Impact on Paddy Cultivation: A study in Ratnapura District in Sri Lanka. Journal of Agriculture Science.
21. Ranjith Mapa, P. G. (2019). Characterization of Soil Physical Properties of Calcic Red Latasols and Calcic Yellow Latasols in Jaffna Peninsula of Sri Lanka and their Applicability to Agriculture.
22. Richard M. Adams and Dannele E. Peck. (2008). Effects of Climate Change on Water Resources. Choice (Magazine. Choice (Magazine.
23. Robert A. (2007). Remote sensing models and methods, image processing third edition.
24. Sivakumar, S. S. (2021). Water Resources and Agriculture Potential in Northern Sri Lanka North and East Province,.
25. Suppiah, R. (1985). Four Types of Relationships between Rainfall and Paddy Production in Sri Lanka . South Asian Affairs II, 10(01).
26. Tharani Gopalakrishnan, L. K. (2021,). Linking Long-Term Changes in Soil Salinity to Paddy Land Peninsula, Sri Lanka. Agriculture, 11(03). doi:doi.org/10.3390/agriculture11030211
27. Thibbotuwana, N. D. (2021). Sri Lanka's Agri Food Trade Structure , Oppotunities , Challengeers & Impact of Covid 19. Feed Furure .
28. W.M.W. Weerakoon, B. K. (2023). Ensuring food and nutritional security while facing the looming crisis of drought. Tropical Agriculturist,, 171 (03).
29. Weligodapola, M. (2022). Resilience and growth of small enterprises in post-conflict economy. A Sheffield Hallam University thesis.
30. Yingjie Wu, S. F. (2020). Analyzing the Probability of Acquiring Cloud-Free Imagery in China with AVHRR Cloud Mask Data. Atmosphere , MDPI.
31. Zerihun, W. a. (2018). challenges and opportunities in the case of Bale Mountains National Park, Southeastern Ethiopia” Tourism–Agriculture Nexuses: practices, https://doi.org/10.1186/s40066-018-0156-6. Tourism–Agriculture Nexuses: practices. doi:https://doi.org/10.1186/s40066-018-0156-6
32. Zhao, Q., Yu, L., Li, X., Peng, D., Zhang, Y., & Gong, P. (2021). Progress and Trends in the Application of Google Earth and Google Earth Engine. Remote Sens., 13,, 3778. doi:doi.org/10.3390/rs13183778