The Journal of Archaeology and Heritage Studies (JAHS) 2023: 10 (II) 74-86 pp

The Journal of
ARCHAEOLOGY & HERITAGE STUDIES

Journal Home page https://fssh.rjt.ac.lk/index.php/jahs/

Research Paper

Reimagining Key Technical Elements in 'Yodha Eḷa': A Contemporary Perspective

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ABSTRACT

The evolution of ancient civilisations has been significantly influenced by their ability to harness and manage water resources for agricultural and societal development. One remarkable example of this is the sophisticated irrigation systems that emerged in various regions around the world. Among these, the Yodha Eḷa (YE) Canal stands as an exemplary feat of engineering and hydrological management. In Sri Lanka, there are several canals known as YE in several parts of the country. Out of those, the most intrinsic canal is the one which connects Kalāväva Tank to Tisāväva Tank in Anuradhapura, built by King Dhātusēna. The use of gravity-driven flow, intricate single-side embankment systems, a very low gradient at some places and some components known as diyakali and amuṇu gilma are the features that demonstrate the profound understanding of hydrodynamics possessed by ancient Sri Lankan engineers. Some researchers have explained the functions of certain components of the YE based on certain principles. This article is an attempt to explain those functions from a different perspective based on the concepts known as amuṇu gilma and diyakali with new definitions. The new theory is mainly based on the understanding of the function of the amuṇu gilma, mentioned in later chronicles such as Pūjāvaliya and Alakēśvara Yuddhaya. This is supplemented by the folklore which confirms the existence of amuṇu gilma. With the present research it is expected to confirm that the main objective of the construction of the YE was to ensure the water security of the capital Anuradhapura and the amuṇu gilma was the main component used by the ancient engineers to find the levels, control water flow and ensure water security.

ARTICLE INFO

Article history:
Received 04 September 2023
Accepted 28 June 2024
Available online 16 July 2024

Keywords: **Anuradhapura, Amuṇu Gilma, Canal, Diyakali, Irrigation, Yodha Eḷa**

1. Introduction

The YE has captured the attention of researchers due to its unique characteristics, particularly the low incline observed from its initial section up to Mahailuppallama. Additionally, technical aspects like the positioning of gates approximately 2 ½ feet above the bottom, the feature known as diyakali, and the methods employed by ancient engineers to determine optimal river basin crossings have attracted scholarly interest. However, the explanations provided by researchers regarding various phenomena of the YE, require further scrutiny since no proper conclusions are available on certain issues. This paper aims to evaluate the adequacy of these explanations and explore alternative interpretations.

For instance, the scientific rationale offered for positioning gates above the canal's bottom is intriguing. It suggests that the presence of dissolved salts makes the water at the bottom heavier, thereby ensuring better water quality downstream. It is doubtful whether the ancient people had such knowledge about the salts.

How the ancient engineers achieved a minimal gradient in certain sections of the YE remains a mystery. Some researchers speculate that they utilised highly precise equipment, a theory not universally accepted within the academic community.

This paper endeavours to address these unresolved questions and propose a novel concept termed 'amuṇu gilma' to elucidate the technical features of the YE. Through this innovative framework, it seeks to offer fresh insights into the engineering marvels of antiquity, challenging conventional explanations and paving the way for further scholarly discourse.

1.1 Yodha Eḷa in brief

Numerous research studies have been conducted on the ancient Sri Lankan canal known as Yodha Eḷa built by King Dhātusēna (461-479).[1] This canal served as a sustainable water management and conveyance system for about 1500 years. Its purpose was to transport water from Kalāväva [tank] in Kekirava to Tisāväva [tank][2] in Anuradhapura, spanning a distance of about 39 km, as the crow flies. The length of the canal is 87 km (54 miles). One of the intrinsic features of the canal is its low average gradient of 10 cm per km in the first 27 km (17 miles). The slope in certain sections of the canal has been reported by researchers as of about 2 cm per km a precision difficult to achieve even with modern equipment. How the ancient builders achieved such precision is something still not properly understood. The technical intricacies of the YE have intrigued researchers, leading to investigations into water flow dynamics, hydrology, technical features, scientific research on water quality, and many other aspects of the canal. The YE passes through three river basins; Kala Oya, Modaragam Aru, and Malvatu Oya. Present research is focuses on certain specific technical aspects and functions related to them.

[1] The YE discussed in this paper is the manmade inter-basin canal to convey water from Kalāväva Tank to Tisāväva Tank. In addition, there are several similar trans-basin canals elsewhere in Sri Lanka are also called YE with a prefix indicating the area. E.g. Minipe YE, Elahera YE.

[2] Sri Lankan manmade reservoirs are called Tanks.

1.2 The Research Gaps

Previous researchers have extensively discussed the technical features of the ancient YE: however, certain points benefit from further exploration, particularly in light of the principle of the amuṇu gilma. Identified research gaps include:

1. The primary purpose of constructing YE specifically regarding its role in irrigation.[3]
2. The absence of connections between YE and any of the tanks despite supplying water to over 300 tanks in ancient times.
3. The positioning of gates to sub-canals approximately 2 ½ - 3 feet from the bottom rather than at the bottom.
4. The existence and functions of the purported 48 Amuṇu Gilmas and 48 diyakalis in folklore.
5. Defining Amuṇu Gilma and exploring its uses.
6. Addressing the conveyance of water to Anuradhapura when water levels near the gates of sub-canals were less than 2 ½ feet.
7. Understanding the decision of British engineers install gates at points where ancient amuṇu gilmas existed.
8. Identifying the technical methods employed by ancient Sri Lankan engineers to achieve a low gradient in specific sections.
9. Assessing the feasibility of understanding and applying ancient technology in modern engineering projects tailored to local conditions.

1.3 Definitions

Amuṇu Gilma (AG): An installation across a stream, river, or canal to impede the water flow until a predetermined water level is reached, somewhat similar to a weir. Some variations feature gates that, when closed allow only overflow resulting in an upstream water level rise. An amuṇu gilma and a weir have many differences.

Diyakali: A small to medium size reservoir formed as a result of an AG, typically long and narrow depending upon the terrain.

Further elaboration on these matters will follow.

2. Research Methodology

After analysing the chronicles and legends, it was found that there should be a component called AG associated with the ancient irrigation systems. Upon scrutinizing Google Earth

[3] Many researchers have suggested that the YE was built to ensure water security of Anuradhapura.

images, specifically the street view, it was possible to identify some of the places that could be considered potential sites to search for these remains. A field survey was conducted in January 2021 to identify a few AGs. Several sections covering approximately 8 km of the canal were selected and examined. During this visit, the physical remains of several ancient AGs were found, and photographs were taken. Additionally, some elderly residents knowledgeable about the area were interviewed.

3. Results and Discussion

The residents confirmed the presence of 'bridge-like structures' which they assumed to be bridges and had used for crossing the canal. They affirmed that more remains of the AGs were physically present in the 1960s when they were young. Another observed feature was the presence of sluice gates built during the British Period near the AGs. These gates likely served the same purpose as the AGs: raising the upstream water level. This indicates that British engineers were aware of the ancient technique and may have opted to install new gates rather than repairing the old AGs. Although the remaining physical evidence is limited, it provides insight into this important ancient component of irrigation systems. Water level changes in the main canal and sub-canals were estimated based on visual clues, as exact measurements were neither feasible nor necessary for the current research. However, precise measurements will be necessary for future in-depth studies of the system.

3.1 Functions and Definition of Amunu Gilma (AG)

AG is one of the crucial components of the ancient YE system. While AGs may have been used in other systems as well no research has been conducted on this matter. In the absence of direct information, it is essential to search for clues in the chronicles about ancient water management systems. Such a clue is available in two later chronicles, namely Alakēśvara Yuddhaya (20) and Rājāvaliya (216) which refer to the construction of an 'amunu gilma' to fill water. This reference pertains to the defence of the ancient capital of Sri Lanka, Kōṭṭe (c. 1375-1551).

The word "amuṇa" can be translated into English as a weir or anicut which are commonly used in modern irrigation systems.

The term "gilma" is used by farmers and irrigation officers and is described in various ways: some interpret it as a drop in elevation or sinking while others interpret it as being filled with water. The combined term ‘amuṇu gilma’ is not commonly used. Since this term has not been defined by experts in the field, an inquiry was made to a writer on the subject who opined that water overflows at an AG. This function is similar to an amuṇa however, there are differences in usage. An amuṇa supplies water to a field or nearby canal by opening its gate while AGs do not supply water to fields but only to canals supplying water to tanks. achieved by closing the gate of the AG. This results in an increase in the upstream water level, reaching the level of the sub-canal gate (Figure 2). The AG is a component of a system that supplies water to distant places.

Another difference between an amuṇa and an AG is that an AG always results in a diyakali due to raising of water level, whereas an amuṇa does not.

Based on the above information and clues in the chronicles, the security arrangement in Kōṭṭe could be understood. It was found that the AG at Kōṭṭe was also built not to supply water for agriculture but to secure the defences of the city maintaining a constant water level in the Diyavannā Tank. This was essential to keep the mud layer in proper condition.

Kōṭṭe is akin to a peninsula, surrounded by marshland on three sides and connected to the mainland to the south. There are two river branches bordered the eastern and western sides of the marshy area. In the southern part of the peninsula, the primary access road ran through the centre, while the rest was fortified with two moats on either side. This access road was further fortified with two bastions. To fortify the remaining sides, an AG was constructed approximately 90 meters[4] ahead of the northern tip of the peninsula, spanning the river after its branches converged into one. This action raised the water level around the peninsula, flooding the marshy area. Subsequently, elephants were used to trample and level the area, forming a layer of mud. The AG was designed and built to fill the reservoir in a manner that maintained around 10 cm of water above the mud layer preventing passage by swimming or boat. Crocodiles were also reared to deter any attempts to cross the mud layer on foot. This defensive system proved highly effective, holding off invaders for 150 years, until the kingdom's end.[5] Therefore, the AG's function in this instance was to maintain a consistent water level. Couto (p.227-8) referenced breaking the dam (AG) as the sole means to breach the defences and enter the fortress.

[4] This was within the rage of an arrow which was about 300 m at that time.

[5] Kotte: the Fortress, Fonseka, Prasad., 34 ff.

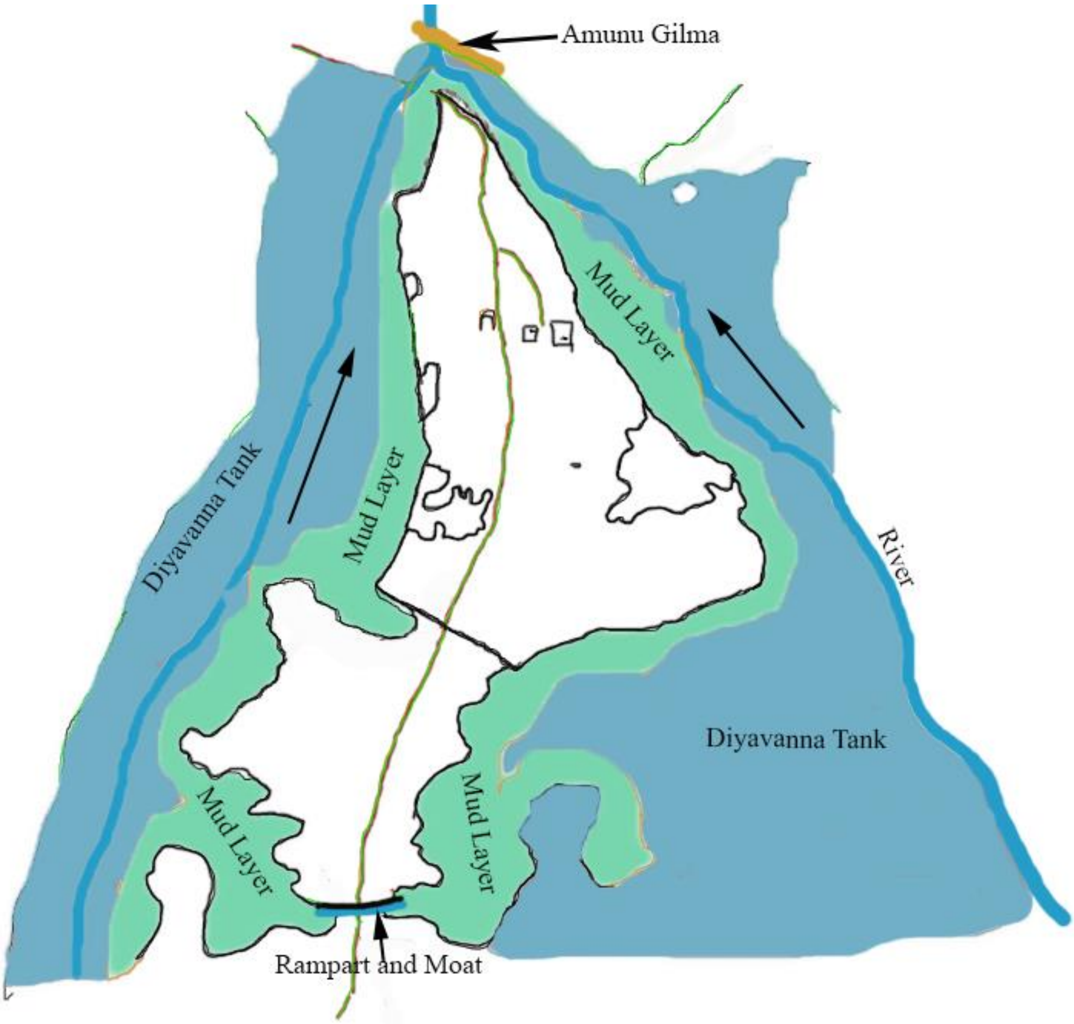

Figure 1: Map of Ancient Kōṭṭe

Figure 1 depicts the ancient Kōṭṭe Fortress after the AG's construction. Part of the marshland had transformed into a tank, with the fortress's surroundings covered in a layer of mud. Removing the AG would cause the water level to drop, completely drying the mud layer and providing enemy forces an opportunity to cross. Thus, maintaining the water level as described was vital for defending the city.

This confirms that the Kōṭṭe AG was used to elevate the upstream water level to a desired height. Another function of an AG across a canal is to discharge water over at a higher level enabling it to convey water over long distances.

AGs seem to have been constructed using granite blocks and mortar. Consequently, the functions of YE's AGs can be summarized as follows:

1. Constructing an AG several meters downstream from the main canal to raise the upstream water level when water is to be supplied to a tank or sub-canal. Closing the gate causes the upstream water level to rise above the sluice gate level (Figure 2).

2. To convey water across a low-lying area, building a bund to connect high ground and constructing an AG across an extended canal to control water levels, creating a tank that inundates low-lying areas (Figure 3).

3. Constructing AGs to elevate upstream water levels when conveying water with minimal elevation drop, facilitating controlled water flow at higher levels by building additional AGs at suitable points (Figure 4).

4. Utilizing AGs to measure elevation differences during new canal construction (Figure 14).

3.2 Diyakali[6]

As mentioned earlier, another significant outcome of an AG is the formation of narrow, elongated reservoirs known as diyakali or kali.[7] This system offers several advantages.

[6] There are other definitions for diyakali such as the definition by Karunaratna and Bandaranayeke, 2021. The present definition is based on the concept of amuṇu gilma.

[7] Ratha B Ekanayake says there had been 48 diyakalis along YE (https://www.divaina.com/ 2015/06/28/feature10.html; Bhairavas who destroyed the Yodha Ela by Contracting New Jayaganga [21/10/2021]).

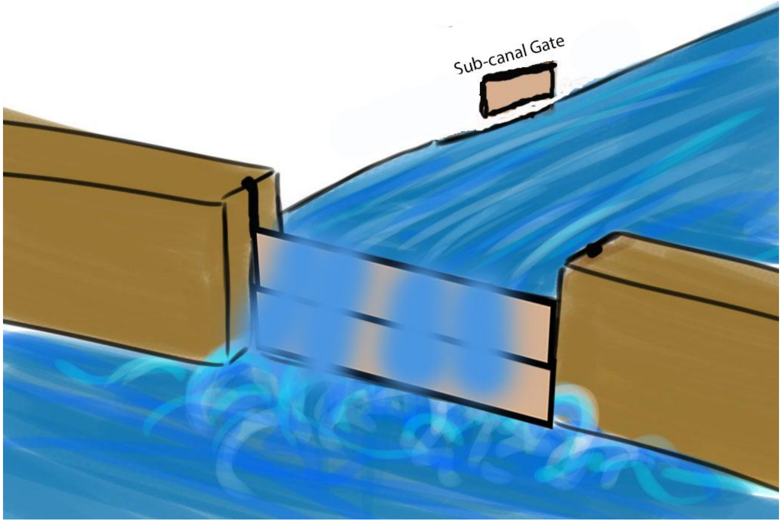

Figure 2: Raising of the water level to supply water to a sub-canal. When another plank is placed the sub-canal would get water.

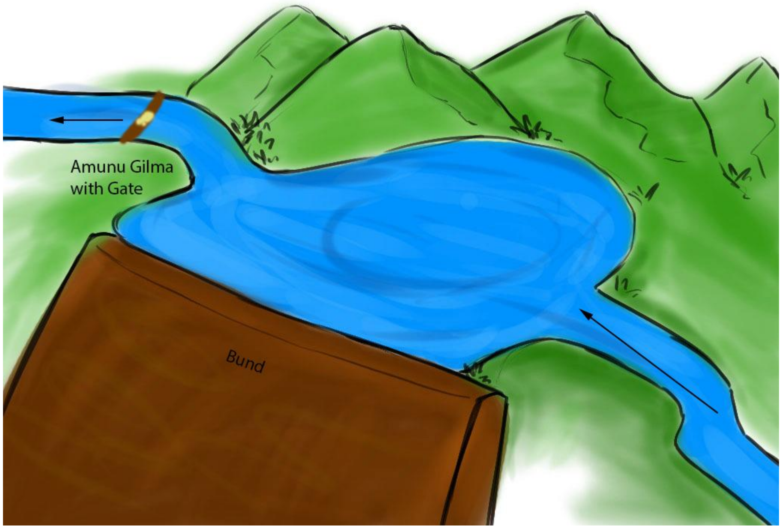

Figure 3: Passing a low-lying area by building a bund to form a tank

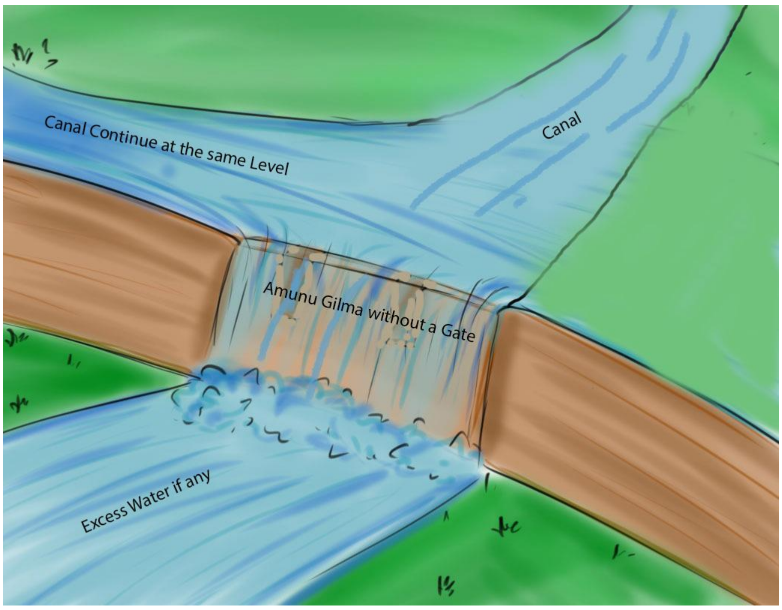

Figure 1: Canal Continuing at a Higher Level

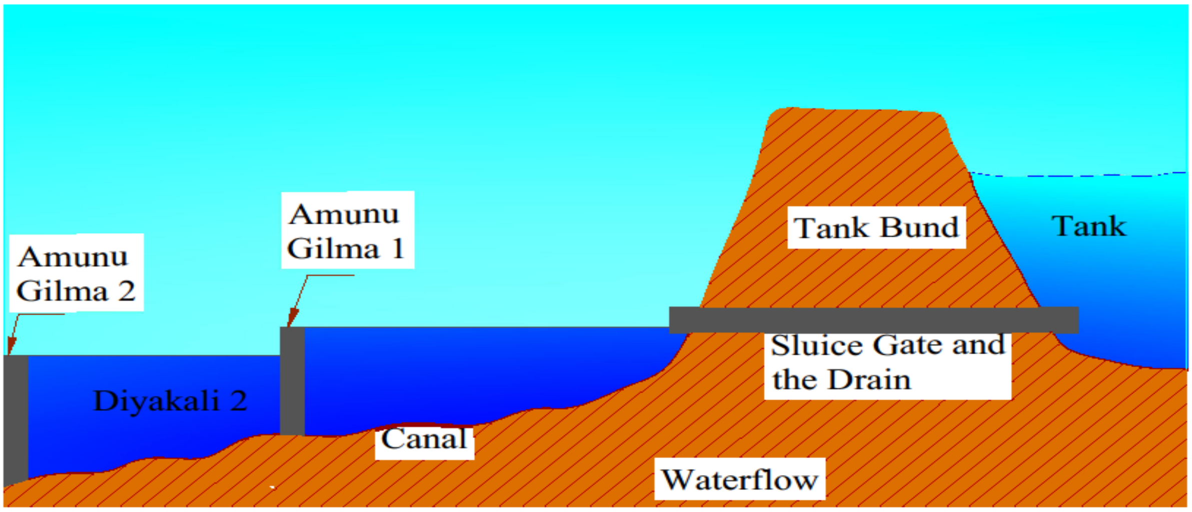

Figure 2: Schematic Diagram of a System consisting of a Tank, Amunu Gilma and Diyakali *(top figure)*

Figure 6: The First kaliya of Yodha Eḷa

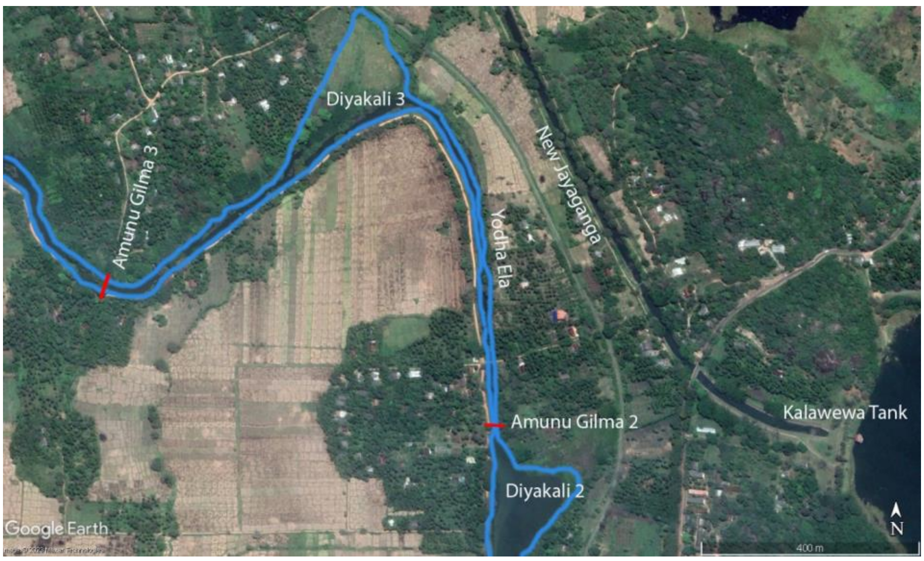

Figure 7: Diyakali Nos. 2 and 3, and Amunu Gilma Nos. 2 and 3 of the Yodha Eḷa

1. Conveying water at higher levels, facilitating delivery to distant locations even with minimal elevation differences.

2. Slower water flow within diyakalis reduces embankment erosion and promotes sedimentation, easing de-silting due to their shallow depth.

3. The slow water flow also facilitates increased sedimentation of mud. making de-silting much easier since diyakalis are shallow.

4. Furthermore, the water flow primarily occurs at the surface, resulting in less energy loss due to viscosity.

5. 5. Surface-level water typically has lower salinity, improving water quality, and any seepage could remove some amount of heavy saline water from the bottom layers.

6. The supply of water to sub-canals could be controlled by lowering the water level;

Figure 7 depicts the area after diyakali 2. In this area, AG 2, and AG 3 form diyakalis 2 and 3. Some remains of both AG 2 and 3 are still available. Among the two locations, AG 2 is the most significant, with remains visible on both sides of the canal (Figure 8). Local residents[8] recall their fathers bringing stone pillars from the ancient bridge at AG 3 to improve the bridge at that location. Perhaps, there was no bridge there initially, only the AG. As people settled in the area, they likely developed it into a bridge. Ancient bridges in Sri Lanka were typically constructed on erected stone pillars.

AG 3 is situated in an area with boulders providing ample evidence of both an AG and a bridge. As mentioned earlier, some pillars from AG 2 were used to construct this bridge.

An enlarged map of the area around AG 2 highlights an important construction possibly dating back to the British Period. It is a gate across the canal designed to raise the water level. It seems that the engineers attempted to mimic ancient practices by constructing a similar structure near AG 2 to elevate the water level. Although now abandoned this structure indicates that British engineers understood the necessity of reconstructing the gate to operate the system. They may have also repurposed some materials from the damaged AG 2 for this purpose.

[8] Mr Tennakoon of Amunakkattuwa on 03/01/2022.

3.3 Intersection with Natural Streams

Since the YE follows contour lines, it intersects with several natural streams. All these streams have been connected to the YE, augmenting its water volume. At certain points, the canal occupies part of the stream for some distance possibly

Figure 3: Remains of Amunu Gilma 2. Note the remains on the other side. Note: The type of granite blocks on the other side indicates they are not from a bridge. Bridges always have stone pillars

Figure 4: A new Bridge is being constructed at Amunu Gilma 3

Figure 10: A British Period Sluice Gate near Amuṇu Gilma

Figure 11: One of the British Period Gates closer to an Amunu Gilma

Figure 5: The Ditch and the Natural Stream

Figure 13: Dam at the entrance to Koonväva

after embankment Improvements. In one section the canal utilizes about 400m of a natural stream[9] in the opposite direction.[10] Following a past flood, the embankment breached where the stream was blocked, but it was later repaired.[11]

Generally, the YE is a single-embankment canal with the man-made bank positioned on the lower side. On the upper side, there is typically no artificial bank, as the natural slope of the terrain acts as the bank. However, there are certain sections of the canal without an artificial bank. Brohier (Part II, 8) has identified this area as a ditch, indicating the absence of artificial banks on both sides. This is the first ditch he mentioned located 5 miles from Kalāväva Tank.[12] Ancient engineers not only utilized approximately 400 metres of the natural stream to convey water in the opposite direction, but also found that the canal could continue after cutting a ditch at this point. Perhaps they observed another small stream a few hundred metres ahead and decided to cut a ditch. Some remnants of a stream are visible, but confirmation would require a detailed ground study. Further research is needed to understand the methodology they used to assess elevation differences. However, it is likely that they followed water streams, especially during rainy seasons to determine their connections to rivers and find points for crossing from one basin to another.

3.4 Sending Water to Anuradhapura

The primary purpose of the YE was to supply water to Anuradhapura as generally accepted. During droughts, when water levels were low, they likely achieved this by opening all AG gates. This would have resulted in water levels at all sub-canal gates being below 2 ½ -3 feet, preventing water supply along the way and directing the water directly to Anuradhapura.

3.4.1 Possible Paradigm of Amuṇu Gilma near Koonwewa

Figure 13 Indicates that water was supplied from YE to Koonväva during ancient times circumventing it. Presently, it is directly connected to the tank. During drought periods, a dam can be seen across the short ancient supply canal, now part of the present YE. The path of the ancient YE, connected to the present YE, is visible left of the dam. This indicates that during ancient times, water supply could have been controlled with the dam, which seems to be constructed of granite blocks. Accordingly, this dam appears to be the remains of an ancient AG with a gate to control the water supply to Koonväva.

Additionally, a new sluice gate may have been constructed to raise the water level to the previous YE level. Furthermore, when water levels are low, it appears that a section of the YE has been deepened, perhaps involving a portion of the tank. However, physical verification is necessary.

3.5 How the Ancient Engineers Constructed Canals (A Hypothesis)

It seems that ancient engineers employed the AG technique in determining levels when constructing canals rather than equipment. To decide the path of a new canal, they may have first cleared the area and visually checked levels. Then, they could have built embankments and closed the end with a dam to resembling an AG, forming a long and narrow pond. After filling the water to a certain level, they could have determined the levels. The spill level would be at the same level as E (Figure 14), which corresponds to the level

[9] This place and the stream were shown to us by Mr H D D Sirisena of Asvedduma, Kalakarmbewa on 02/01/2022, who is living nearby. Without his assistance this matter would not have been noticed.

[10] This had virtually made the water flow upward of the stream as the legends say.

[11] The natural stream has several small tanks connected upstream. Perhaps, some of them existed before the construction of YE.

[12] This is the point where the YE crosses to a basin from one tributary to another tributary of Kala Oya basin, the second ditch is 40 miles away from Kalāväva Tank where it crosses to the Malvatu Oya basin from Modaragam Aru basin.

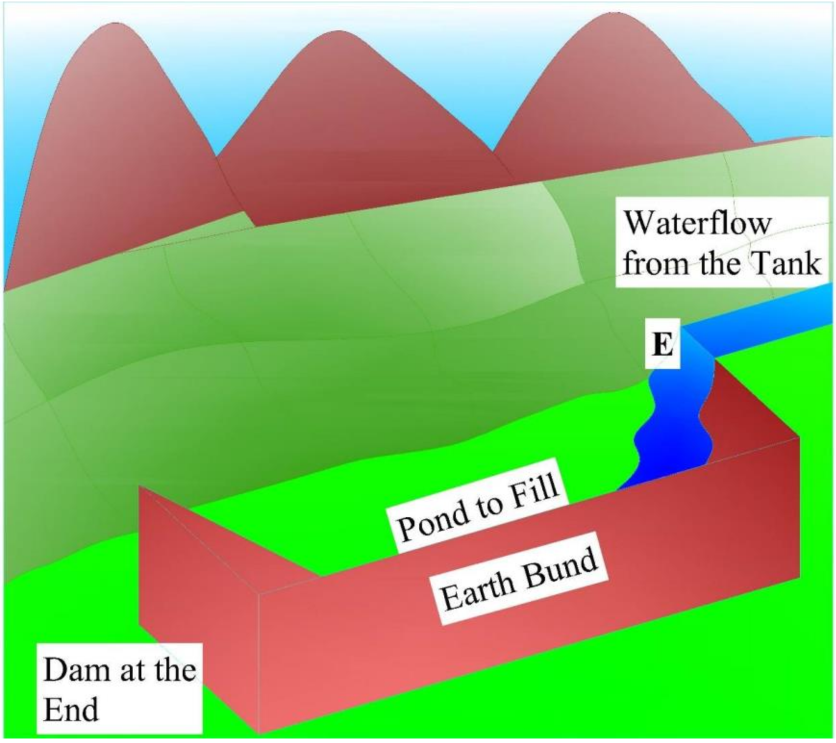

Figure 6: Building of a long pond to determine the path of the canal.

of the sluice gate of the tank. They may have determined levels in increments of about 400-500 metres at a time, or even more if the terrain was visible. After determining the path, they would have made the embankment permanent and proceeded further ensuring contour following.

3.6 Purpose of Constructing the Yodha Eḷa

Understanding the factors that led to the construction of the YE is crucial for this study. Some scholars argue that its primary objective was the development of agriculture due to population growth. Whether it was built to develop agriculture in the canal's surrounding area or to ensure water security in the capital, Anuradhapura, are the arguments to be considered. As the population of the Kingdom of Anuradhapura increased, there would have been a need to develop agriculture and ensure water security. Sri Lanka's climate is characterized by two monsoon seasons and dry intervals in between. The dry regions including Anuradhapura receive rain mainly from the northeast monsoon. This means that failure of monsoon rains could lead to prolonged dry spells. Failing of two monsoons could ultimately result a famine. During such times, the priority shifted from agriculture to securing water for people's daily needs, especially in urban areas.

Historically, water for the capital's population was primarily supplied from the Tisāväva Tank a practice that continues today, providing water to both the ancient city area of Anuradhapura and the new town area. Connecting the YE to this tank undoubtedly enhanced water supply to the ancient capital. The connection to Tisäväva Tank suggests that there were water-related challenges at that time as mentioned in the chronicles. Sri Lanka had experienced famines on multiple occasions,[13] with one particularly severe famine occurring during the reign of King Upatissa (368-410), aggravated by a plague. It's plausible that the need to ensure water security in the capital arose from such severe droughts.

Observations from Google Earth images indicate that certain tanks existed before the construction of the YE, receiving water from tributaries of the mentioned rivers. After the YE's construction, some of these tributaries were connected to the canal, augmenting water flow. Additionally, tanks below the YE likely received water from it, and new tanks may have been constructed and filled with YE water. Thus, the main purpose of the YE appears to have been irrigation water supply.

Two other factors should be considered in determining the purpose of building the canal, why no tanks were directly connected to the YE, and why all sub-canals and other gates are at least 2 ½ feet above the tank bottom. These questions lead to further research. The lack of direct connections to tanks (Figure 15) strongly suggests that the main purpose of the YE's construction was to cut off all supplies on the way, ensuring water reached Anuradhapura. How the YE flows without connecting to the tanks[14] is depicted in (Figure 16)

In summary, the YE's construction likely aimed to ensure water security for Anuradhapura during times of drought, with irrigation water supply being a secondary but significant objective.

[13] Famines have been reported during the reigns of kings; Duṭṭhagāmaṇī (B. C. 161-137), Vaṭṭagāmaṇī (B. C. 89-77) Cōranāga (B.C. 63-51) , Kuňcanāga (193-194), Saṅghabōdhi (250-252), and Upatissa I (368-410) prior to construction of Yodha-ela. During the reign of King Kitsirimegha (551-569) there was famine but not severe as during King Upatissa, (perhaps due to the construction of Yodha Ela). (Floods, Droughts and Famines in Pre-Colonial Sri Lanka, W. I. Siriweera; http://dlib.pdn.ac.lk › bitstream PDF [10/01/2022]),

[14] Under Mahaweli Project implemented in 1970s and 1980s several tanks were connected to the YE causing adverse effects like silting.

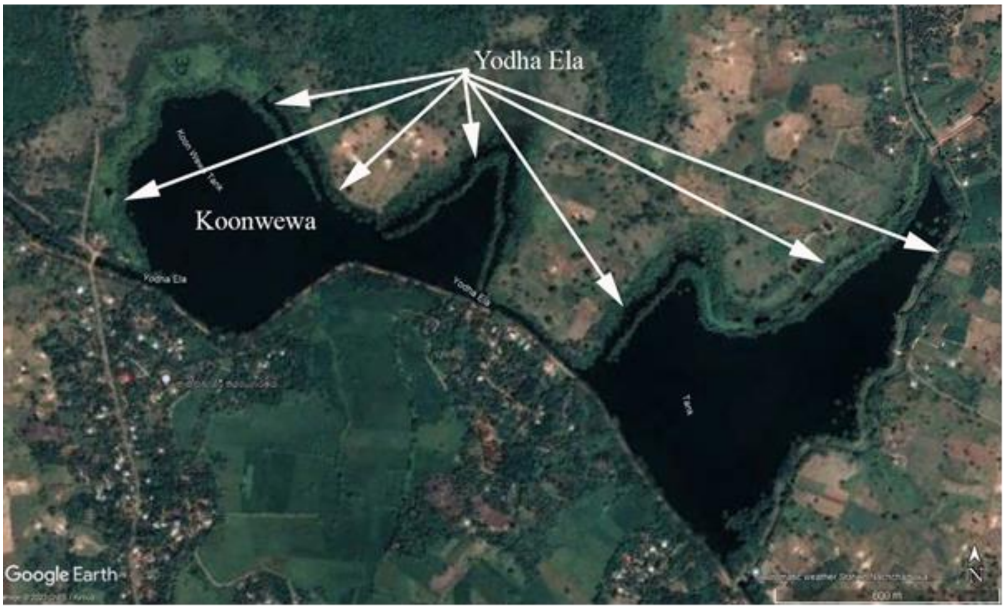

Figure 7: The Google Image depicts how the YE had gone around Koonväva and another tank. At present those are connected to the YE and due to that the water level of the tanks has been increased to the level of the YE.]

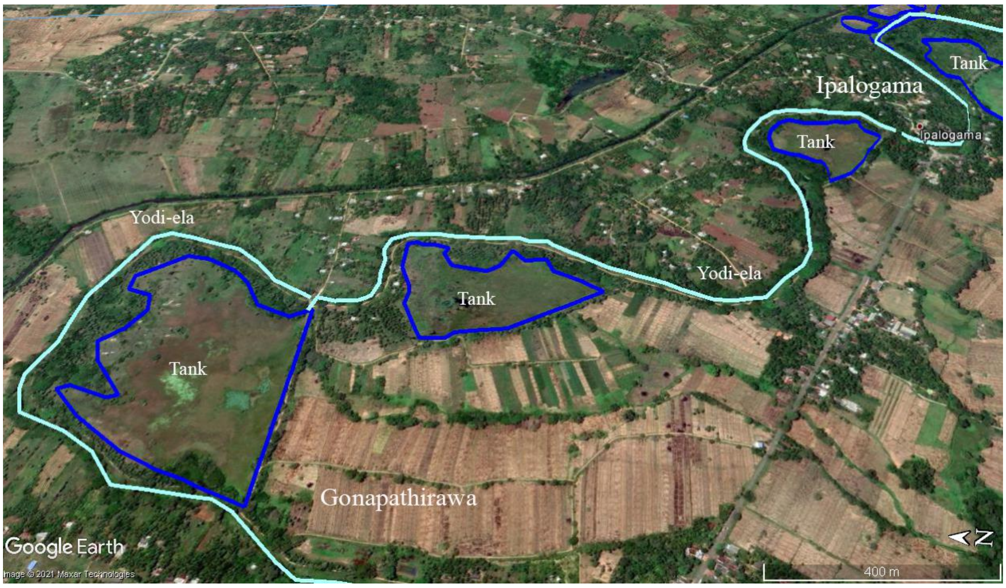

Figure 8: four tanks in a raw, not directly Connected to Yodi-ela from Ipalogama to Gonapathirawa

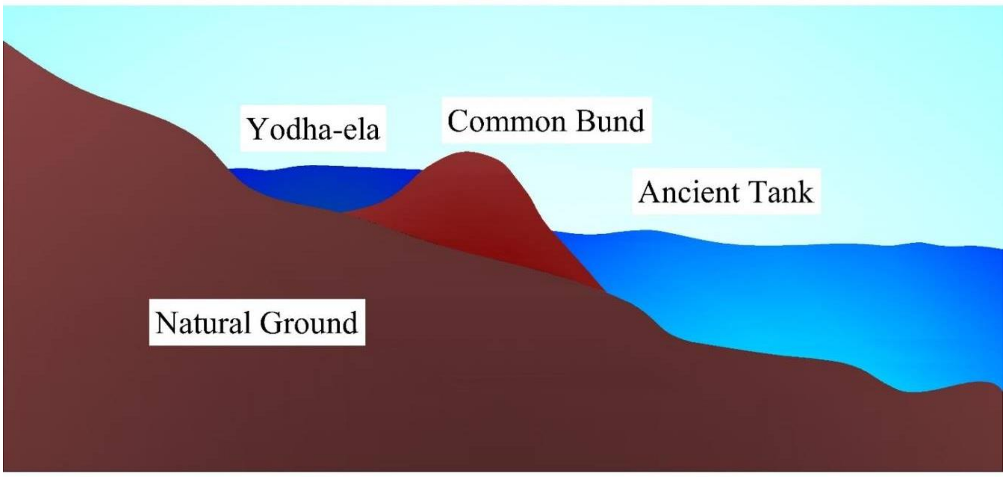

Figure 9: Graphical representation of the cross-section of Yodi-ela, common bund, and a Tank

Figure 18: Ganthiriyagama Tank - Ancient Sluice Gate Repaired and Used until the 1980s

Elevation of the YE being higher than the tanks necessitated deepening the section connecting to modern Jaya Gangaa, or using gates to raise the water level of tanks to match that of the YE. Both methods appear to have been employed under the Mahaveli Project.

During the visit, it was observed the remains of an ancient sluice gate that supplied water to the Ganthiriyagama Tank This sluice gate possibly repaired by British engineers, was in use until the 1980s, when this section of the YE was abandoned with the Mahaweli Development Project. The gate's mechanism, utilizing wood planks to control water flow, reflects ancient Sri Lankan irrigation practices, likely employed in other gates along the canal and elsewhere.

It would be intriguing to investigate what happened to YE water when there were no amuṇu gilmas. British engineers likely encountered this scenario during initial repairs. In such cases, water would have flowed slowly to Anuradhapura, without supplying water to any tanks en route. To address this, British engineers may have installed gates, as mentioned earlier to redirect water to canals supplying tanks.

4. Conclusions

Ensuring sub-canal gates were positioned above 2 ½ feet from the bottom cut off water supply to all sub-canals during YE low-water periods, ensuring continuous water supply to Anuradhapura, reliant on water availability in Kalaväva Tank. Thus, the main objective of constructing the ancient YE appears to have been fulfilled. During the rainy season, the YE supplied water from Kekirawa to Anuradhapura area and stored enough water for the dry season in tanks.

The canal was designed to cease water supply during dry periods prioritising its primary objective. The Amunu Gilma was device played a crucial role in this regard, used for multiple functions such as measuring elevation differences, and raising water levels in canals and tanks, to required levels.

Legend suggests there were 48 AGs along the Yodha Eḷa a plausible count given about 6 such sites were identified within about 8 km.

Each AG created a diyakali, reservoir serving multiple functions including supplying water to tanks en route to Anuradhapura.

During repairs in the 19th century, British engineers likely observed the ancient system and built several sluice gates near some AGs, although these are now abandoned.

The ancient Yodha Eḷa suffered irreversible damage during the Mahaveli Project due to a lack of research on ancient techniques. However, reactivating the abandoned section up to Mahailluppallama, is feasible by reactivating old AGs or British gates enabling water supply to neglected and abandoned tanks and settlements.

5. Acknowledgements

We extend our gratitude to late Mr. Ratna B. Ekanayake of Eppawala, whose insights into Amunu Gilma, formed the basis of this study. Special thanks to Mr. H T B Sirisena, Kalakarambewa, Aswedduma, and Mr. I Thennakone, Amunakkattuwe, for valuable information shared during interviews. We appreciate Mr. Yasitha Rohana Withanachchi's photography contributions and commend Ms Nashali Bharti and Ms Drani Ranga Lankapriya of Rajarata University, for their artistic contributions. Mr. R. D. Premachandra's support made our fieldwork successful.

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