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Rediscovering Negombo Fort, Sri Lanka: Integrating LiDAR and Historical Dutch Maps to Reconstruct a Colonial Landscape Altered by Time

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Abstract: *This study investigates the surviving spatial configuration of the Negombo Fort, a major colonial fortification on the western coast of Sri Lanka, through the integration of airborne LiDAR data and a georeferenced eighteenth-century Dutch plan. A Digital Elevation Model (DEM) (0.5 m) generated from classified ".las" LiDAR data reveals subtle yet distinct topographic signatures corresponding to the fort's eastern defensive structures, including the northern and southern bastions and the connecting rampart, all of which retain their original geometric forms despite extensive modern development. Georeferencing the 18th-century plan against the LiDAR-derived DEM confirms the spatial correspondence of these features and further identifies a previously unrecognised mound representing the southern bastion on the fort's western side, an element not documented in earlier studies. The analysis also demonstrates the partial survival of the moat system, now integrated into the contemporary lagoon. These results highlight the value of combining LiDAR with historical cartography to reconstruct heavily altered colonial landscapes. The study demonstrates that LiDAR, traditionally used in non-urban archaeological contexts, is equally effective in dense urban environments, offering a powerful methodological framework for identifying concealed or altered archaeological features. The findings refine existing interpretations of the Negombo Fort and emphasise the utility of integrative spatial approaches in urban archaeological research.*

Keywords*: DEM, Dutch, Georeferencing, Hillshade, LiDAR, Negombo*

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1. Introduction

In recent years, Geographic Information System (GIS) and Remote Sensing (RS) technologies have been increasingly integrated into archaeological research, enhancing the analysis, interpretation, and visualisation of spatial and environmental data related to past human activities. The integration of

Remote Sensing and Geographic Information Systems (GIS) has profoundly transformed archaeological research by providing non-intrusive and cost-effective methods, which have been enhanced through advances in satellite, multispectral, and hyperspectral imagery for detecting, mapping, predicting, and interpreting both visible and subtle traces of past human activity across diverse landscapes (Alexakis *et al*. 2012; Nsanziyera *et al*. 2018; Alhamamy 2023).

Among the various applications of remote sensing, Light Detection and Ranging (LiDAR) has become one of the most widely utilized technologies in archaeological surveys, owing to its remarkable ability to detect and analyze surface irregularities and terrain features efficiently. LiDAR is an active remote sensing technology that uses laser pulses emitted from an airborne platform to measure precise distances between the sensor and the Earth's surface. By recording the time it takes for laser pulses to return and combining this data with positional and orientation information from Global Navigation Satellite System (GNSS), LiDAR generates highly accurate three-dimensional representations of the terrain and surface features (Lohani & Ghosh 2017).

Over the past two decades, the analysis of topographic surfaces generated through LiDAR technology has significantly transformed the study and documentation of cultural landscapes, with pioneering applications emerging in the early 2000s and demonstrating its remarkable effectiveness in detecting surface archaeological features concealed by dense vegetation, leading to the discovery of monumental remains in previously unexplored forested regions (Vinci *et al*. 2024). LiDAR has demonstrated its remarkable capability to detect hidden archaeological features across a range of climatic regions, from the dense tropical climates of Central America (Chase *et al*. 2012; Chase *et al*. 2014) to the Mediterranean landscapes (Grammer *et al*. 2017), temperate zones of Europe (Caspari 2023), and the tropical environments of Asia (Evans *et al*. 2013). In addition, LiDAR is not limited to dense forest environments but has been successfully applied across diverse land-use settings, such as savannas (Prümers *et al*. 2022), agricultural landscapes (Inomata *et al*. 2017), deserts (Richter *et al*. 2012), and built environments (Masini *et al*. 2011) to identify and analyse previously hidden archaeological features.

Despite the widespread adoption of LiDAR technology by archaeologists globally for detecting and analyzing archaeological features, its application within the South Asian region remains comparatively limited. Although several references to LiDAR surveys in India can be found (Kamalakannan & Rajagopal 2025), detailed research publications on this topic remain limited. In Nepal, LiDAR technology has been explored through mobile-based survey (Bhatta *et al*. 2025), while in Sri Lanka, a limited number of studies have employed LiDAR data to investigate historical defensive structures and palace complexes (Mendis, 2022; Gunarathna *et al*. 2025; Madduma Arachchi, 2025; Madduma Arachchi *et al*. 2025).

In addition to LiDAR and other remote sensing methods, Geographic Information Systems (GIS) have become essential in contemporary archaeological research, supporting a wide range of analytical, interpretive, and conservation applications. In particular, GIS facilitates advanced spatial, network, and statistical analyses, enabling researchers to examine spatial relationships (Verhagen 2018), model connectivity (Meynard *et al*. 2022), and interpret complex patterns (Katugampola 2021) within archaeological landscapes.

A map is a scaled graphical representation of spatial information used to communicate geographic concepts. The earliest known maps date back to Babylonian clay tablets around 2300 B.C., while Greek and Roman scholars, particularly Ptolemy, significantly advanced cartography through their understanding of the spherical Earth. During the Age of Exploration in the 15th and 16th centuries, mapmaking evolved rapidly, and maps became vital instruments for navigation, trade, and political strategy, often regarded as classified or proprietary documents (Perocho, n.d.). Although Sri Lanka occupies a small area geographically, it has held significant importance in the history of cartography for over two millennia. Known to the Greeks and Romans as Taprobana Insula, the island featured prominently in Ptolemy's Geographia and continued to appear on world maps due to its strategic position along major sea trade routes between Europe and Asia. Mapping of Sri Lanka advanced substantially during the Dutch occupation in the 17th and 18th centuries, when Dutch cartographers employed innovative techniques to produce some of the earliest accurate and detailed maps of the island (Jayasuriya 2003).

During the Dutch occupation of Sri Lanka in the 17th century, numerous maps and architectural plans of the island were produced, particularly detailed representations of fortifications that provide valuable insights into their form, scale, and spatial organisation. As these plans were created with a high degree of accuracy and proper scale, they can be georeferenced and overlaid onto contemporary maps, enabling a comparative analysis of spatial transformations and offering a deeper understanding of how these historical landscapes have evolved. Georeferencing is another function of GIS, which can be defined as the process of aligning spatial data to a recognised coordinate system, thereby enabling it to be accurately visualised, queried, and analysed in conjunction with other geographic datasets (Wade & Shelly 2006).

Several studies have employed various georeferencing techniques to align historical maps with modern spatial data, facilitating a deeper understanding of past human landscapes and terrain characteristics (Podobnikar 2009; Affek 2013; Petrie *et al*. 2019). Additionally, several studies have utilised historical Dutch and Portuguese maps, applying georeferencing techniques to examine the spatial organisation, architectural layout, and functional characteristics of colonial fortifications in Sri Lanka (Madduma Arachchi 2023; Madduma Arachchi *et al*. 2025).

The Negombo Fort, situated on the western coast of Sri Lanka, represents a significant element of the island's colonial heritage. Initially constructed by the Portuguese in the early seventeenth century, the fort was later captured and substantially reconstructed by the Dutch and subsequently modified under British rule (Asseldonk 1993). Its strategic location near the Negombo lagoon and along vital coastal trade routes made it an important defensive and administrative centre during successive colonial periods (de Silva 2024). At present, only a few structural remnants, including portions of the rampart and the main entrance, are visible, while much of the original fortification has been obscured or altered. This transformation presents both a challenge and an opportunity for archaeological investigation, particularly through the application of advanced spatial technologies capable of revealing subsurface or modified architectural traces.

Although LiDAR has been effectively utilised in archaeological research to detect features hidden beneath vegetation or sediment cover, its potential within urbanised or redeveloped landscapes in Sri Lanka remains underexplored. Consequently, there exists a research gap in understanding how LiDAR, when integrated with georeferenced historical maps, can be employed to interpret and reconstruct colonial-era built environments that have been extensively transformed through time.

With this background, the objective of this study is to identify and analyse the remaining structural elements of the Negombo Fort through the integration of LiDAR-derived terrain data and historical Dutch cartographic records. The research focuses on processing and analysing LiDAR point cloud data to generate a detailed Digital Elevation Model (DEM) of the fort area, georeferencing and overlaying historical Dutch maps onto the LiDAR-derived DEM to identify spatial correlations and surviving structural alignments, followed by interpreting these features in relation to historical documentation to assess the evolution of the fort's spatial configuration over time.

2. Materials and Methodology

2.1. Study Area

Map 1: Location of the Negombo fort (Base map source: Open Street maps)

Negombo is located on the western coast of Sri Lanka, approximately 30 kilometres north of Colombo, at latitude 7.208845° N and longitude 79.831872° E (Map 1). The town is situated adjacent to a lagoon, a geographical feature that contributed significantly to its prominence as a major maritime port long before the arrival of the Portuguese. During the 16th century, the Negombo port was one of the most prosperous harbours under the Kingdom of Kotte, generating the highest revenue among its coastal ports. Historical records suggest that in the early part of this century, Negombo was governed by Taniyavallabahu, the brother of King Vira Parakramabahu VIII of Kotte (1477–1489 AD) (de Silva 2024). By the 1560s, much of the Kotte Kingdom had fallen under the control of the Sitavaka forces, after which Negombo became a key port for the Kingdom of Sitavaka.

Following the decline of the Sitavaka Kingdom and the subsequent Portuguese conquest of the Negombo region after 1592 AD. Around 1600 AD, the Portuguese constructed a fort to secure their dominance (Asseldonk 1993; de Silva 2024). The original fort, built Portuguese, was triangular in shape with three bastions (Asseldonk 1993). However, competition for control of the coastal regions intensified between the Portuguese and the Dutch, leading to repeated conflicts. In 1640 AD, the Dutch captured the fort but lost it later that same year to a Portuguese counterattack. The Portuguese subsequently reinforced the fortifications, but in January 1644 AD, the Dutch once again seized control, maintaining their presence in Negombo until their expulsion by the British in 1796 AD (Asseldonk 1993; de Silva 2024).

Under Dutch rule, the fort was reconstructed and expanded into a pentagonal plan, although the fifth bastion on the western seaward side was never completed, leaving the structure with four bastions (Asseldonk 1993). The Dutch fort was surrounded by a moat and featured a drawbridge on the eastern

Map 2: Current Negombo fort area (Image Source: Google Earth)

side. Two main entrances were established: the primary eastern entrance, known as the Land Gate, and a smaller western entrance, known as the Sea Gate (Amazing Lanka n.d.).

During the late nineteenth century, the British demolished most of the fortifications and used the stones to build a prison, which still functions today (Asseldonk 1993). The only parts of the fort that remain are part of the eastern rampart (Figure 1) with the main gate and two mounds marking the former northern and southern bastions, now home to the Negombo District Court and the St.Stephen's Anglican Church. A section of the original moat also remains, still connected to the lagoon (Map 2). A clock tower, constructed by the British during Queen Victoria's Jubilee, stands behind the remnants of the gateway (Figure 1), symbolising the layered colonial history of the site.

2.2. Materials

2.2.1. LiDAR Data

The LiDAR dataset used in this study was obtained from the Survey Department of Sri Lanka and covers the Negombo Fort area. The dataset, provided in ".las" format, contains a total of 518,725 points classified into ten categories, representing various surface features such as different levels of vegetation, built-up areas, and bare ground. The average point spacing is 0.475 m, ensuring a high spatial resolution suitable for detailed topographic and structural analyses. The elevation (Z) values range from 0.092 m to 25.354 m, effectively capturing the subtle variations in terrain and the remnants of fortifications within the study area. This classified LiDAR dataset serves as the primary source for generating the Digital Elevation Model (DEM) and conducting subsequent spatial and morphological analyses.

Figure 1: Remaining part of the Negombo Dutch fort (Remaining part of the Eastern Rampart, Gate, and British clock tower) (Image credit: A.Y.N.H. Tharushika)

2.2.2. The Dutch Plan

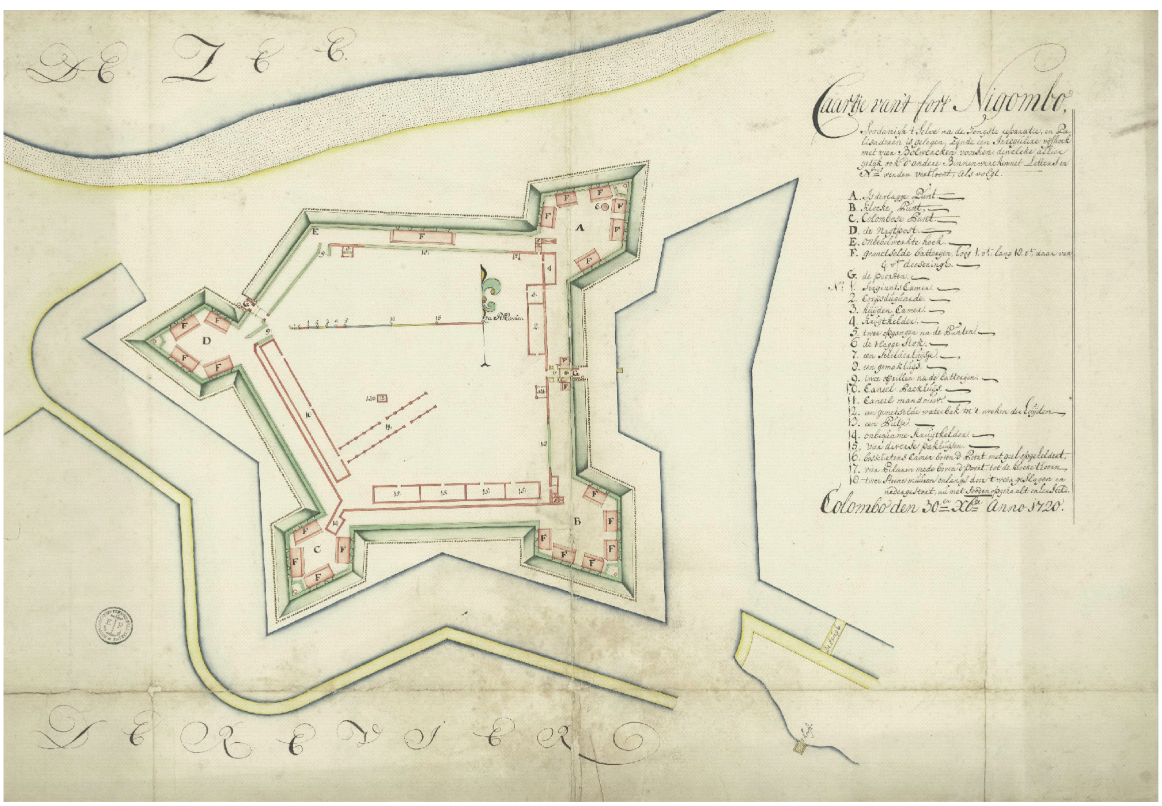

Figure 2: The 1717 Dutch plan of Negombo Fort (Source: National Archives of the Netherlands, VEL_990)

The historical Dutch plan (Figure 2) of the Negombo Fort used in this study was obtained from the National Archives of the Netherlands (inventory number VEL_990; reference NL-HaNA_4.VEL_990). This plan is also reproduced in the Comprehensive Atlas of the Dutch East India Company – Volume IV: Ceylon (Diessen & Nelemans, 2008). The map was originally compiled by the Dutch surveyor Christiaan Pieter Boomgart, based on various duplicate reports from the inspection of Negombo conducted by Governor Isaac Augustijn Rumpf in 1717. According to archival records, repairs previously ordered by Rumpf were completed in 1720, and these modifications are described in the map's legend (Diessen & Nelemans, 2008).

The plan depicts the fort as an irregular pentagonal structure with four bulwarks, labeled and annotated through an extensive legend detailing its structural and functional elements. Key features include Flag Point (A), Clock Point (B), Colombo Point (C), the guard post (D), the Gates (G), and various internal structures such as guard rooms, gunpowder cellars, warehouses, and water troughs. The legend also records repairs to masonry and batteries, providing valuable insight into the fort's architectural configuration and maintenance during the early eighteenth century.

This historical plan serves as a critical reference for georeferencing and comparative spatial analysis with the LiDAR-derived Digital Elevation Model (DEM), enabling the identification of surviving structural elements and assessment of spatial continuity within the modern landscape.

2.3. Methodology

The methodology adopted in this study comprised two major components: (1) the processing of LiDAR data to generate a detailed Digital Elevation Model (DEM) of the Negombo Fort area, and (2) the georeferencing of the historical Dutch plan to enable spatial comparison and interpretative analysis of the fort's configuration and evolution.

2.3.1. LiDAR Data Processing

The LiDAR dataset, obtained from the Survey Department of Sri Lanka in ".las" format, was processed using ArcGIS 10.8 to derive a high-resolution DEM. Initially, the LAS point cloud was reclassified using the Change LAS Class Codes tool, where all ground points were assigned to the Ground class, while non-ground points, which represent vegetation and built structures, were designated as Unassigned. Subsequently, the Classify LAS Ground tool was used to refine ground classification and ensure that only true ground points were retained for terrain modelling.

Using the classified ground points, the DEM was generated through the LAS Dataset to Raster tool, which interpolated the ground surface to create a continuous elevation model. The resulting DEM was then projected into the SLD99/Sri Lanka Grid 1999 (EPSG:5235) coordinate reference system to maintain spatial accuracy and compatibility with other geospatial datasets.

To enhance terrain interpretability, the DEM was imported into QGIS, where a hillshade model was created using the Hillshade tool with parameters of 315° azimuth, 45° altitude, and a Z-factor of 1. Additionally, a colour-coded elevation map was developed by classifying the DEM into 25 elevation intervals with a "Single band pseudocolor" render type in QGIS. The classified elevation raster was subsequently blended with the hillshade Layer using the blending functions in QGIS to produce a colour hillshade visualisation, allowing subtle terrain variations and possible archaeological features to be visually distinguished.

2.3.2 Georeferencing of the Historical Dutch Plan

The historical Dutch plan of the Negombo Fort (VEL_990) was georeferenced against the LiDAR-derived DEM to establish spatial correspondence between the fort's historical and present-day landscape. Since the physical landscape of Negombo has undergone substantial alterations over time, particularly due to coastal transformation and urban development, accurate Ground Control Points (GCPs) were challenging. The eastern gate of the fort, the only surviving architectural element visible both in the historical plan and the present landscape, served as the principal GCP.

To improve georeferencing accuracy, two additional points were identified from the DEM corresponding to the northern and southern bastions on the eastern side of the fort, both faintly discernible in the LiDAR elevation data. Using these three GCPs, the plan was georeferenced using the Georeferencing toolbar in ArcGIS 10.8. This process enabled the historical plan to be accurately aligned and overlaid with the modern LiDAR data for further analysis.

2.3.3. Analytical Interpretation

Following georeferencing, the aligned datasets were examined to identify spatial correlations between the LiDAR-derived features and the mapped elements in the Dutch plan. Analytical tools within QGIS and ArcGIS, including Contour, Hillshade, Swipe, and Transparency, were employed to visually inspect alignments and detect subtle terrain anomalies potentially representing remnants of bastions, ramparts, and moats. Comparative spatial analysis enabled the identification of structural correspondences, the assessment of fort boundary preservation, and the recognition of alterations in landform resulting from later construction and environmental change. This integrative approach combining LiDAR-derived topography and historical cartography provided a base for interpreting the fort's original spatial organisation and its transformation over time.

3. Results and Discussion

3.1. LiDAR analysis

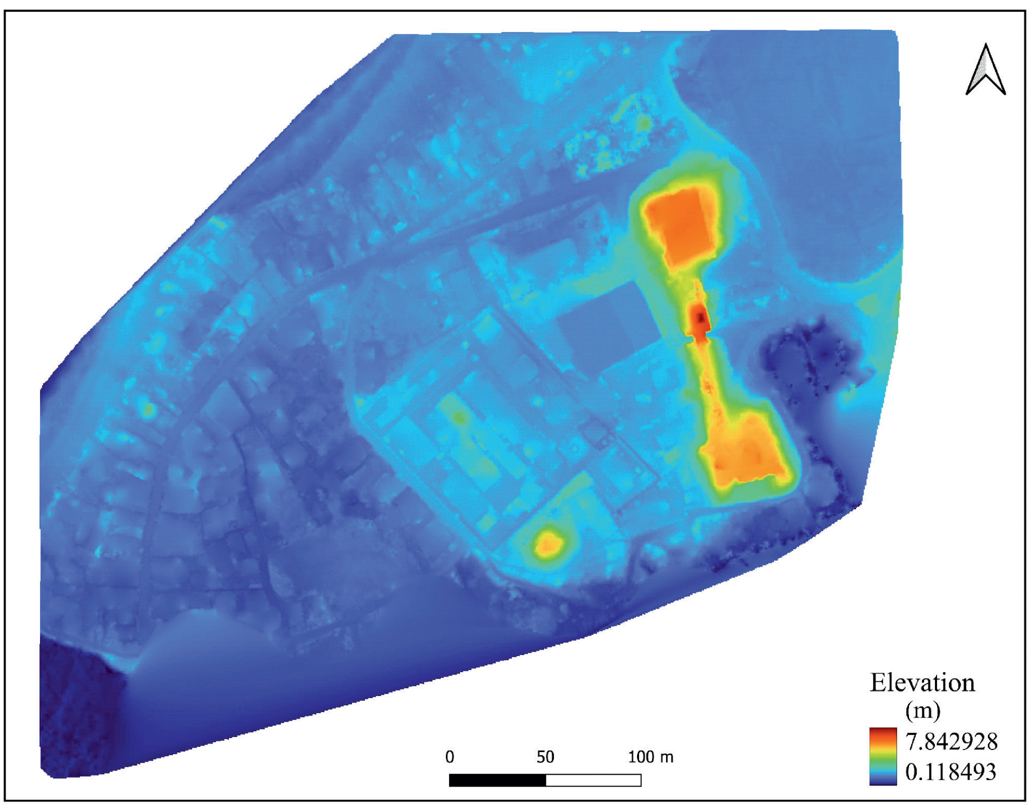

Figure 3: Colour DEM of the study area

The LiDAR-derived DEM (Figure 3) produced for the study area has a spatial resolution of 0.5 m and records elevations ranging from 0.1 m to 7.8 m above mean sea level. As expected in a low-lying coastal environment, overall elevation variability across the landscape is minimal. This relative flatness, however, allows topographic anomalies to stand out clearly. The DEM distinctly reveals the elevated mound corresponding to the surviving eastern section of the Negombo Fort (Figure 3).

Despite extensive modern construction, most notably the District Court complex on the northern rampart and the Anglican Church on the southern rampart, the underlying terrain signature of the fort remains visible. The northern and southern bastions, together with the connecting eastern rampart, appear as clear, well-defined rises in the DEM and hillshade visualisations (Figures 4 and 5). Importantly, both bastions retain their characteristic rectangular shape, indicating that substantial portions of their original earthen forms survive beneath modern land use.

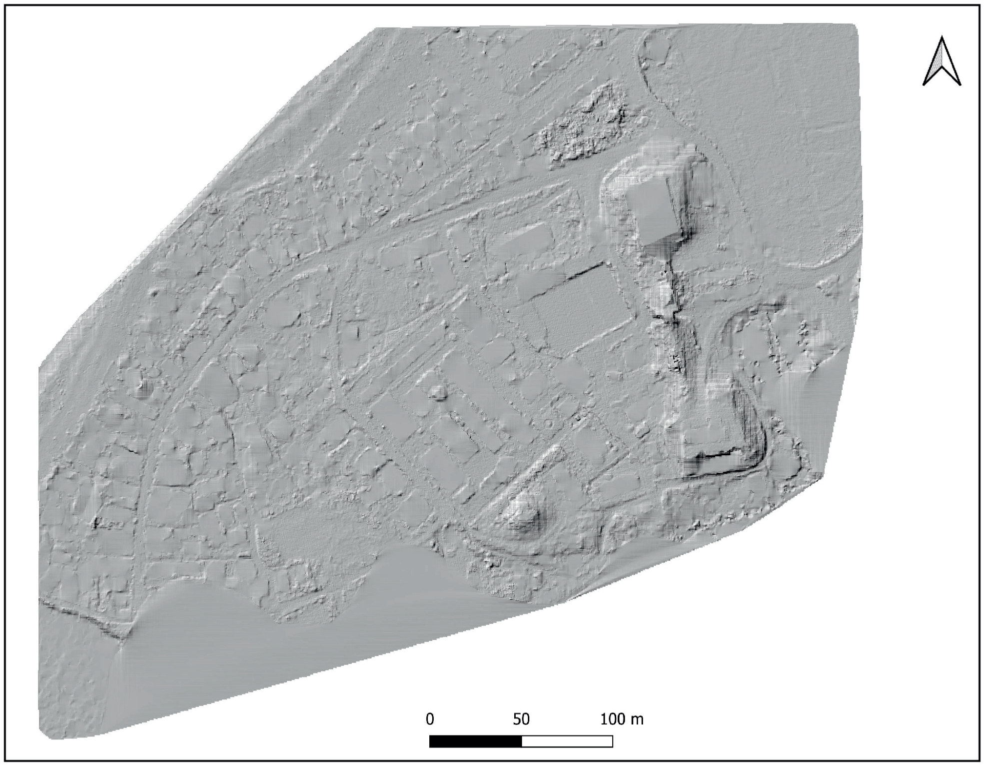

Figure 4: Hillshade of the study area

Morphometric measurements derived from the DEM further clarify the preservation of the fort's defensive architecture. The northern bastion retains a perimeter of approximately 150 m, enclosing an area of about 1,500 m^2, while the southern bastion exhibits a perimeter of roughly 125 m with an internal area of around 1,100 m^2. The eastern rampart, which links these two bastions, extends for approximately 80 m. These measurements collectively demonstrate that the east line of defense remains largely preserved, with much of its original geometric configuration intact, despite substantial modern development overlaying it.

The hillshade (Figure 4) and colour hillshade (Figure 5) models provide further clarity, highlighting the fort's eastern defensive line as a continuous, elevated feature beyond the portions visible on the ground today. These visualisations confirm that the bastions and rampart segments survive not only in isolated fragments but as an integrated structural unit, preserving their original geometry despite later modification.

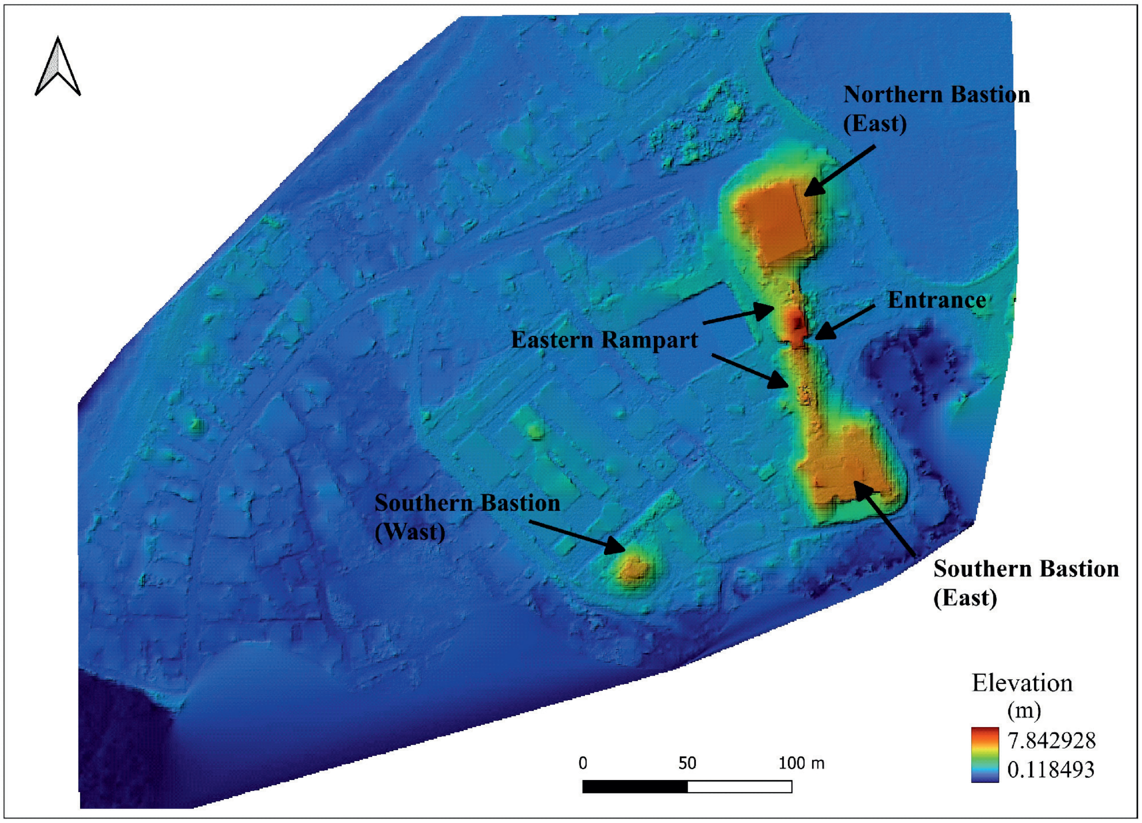

Figure 5: Colour Hillshade of the study area, which is a combination of Hillshade and colour DEM

In addition to the well-defined eastern section, the DEM also reveals an isolated mound on the southwestern side of the study area (Figure 5). Based on its position, form, and elevation profile, this feature is likely to represent the southern bastion of the fort's western side, now largely obscured by other constructions. Although not as clearly preserved as the eastern elements, this mound suggests that further remnants of the fort's western defenses survive in altered and partially buried form.

Overall, the LiDAR analysis demonstrates that substantial components of the Negombo Fort's defensive architecture, including bastions, ramparts, and possible western-side elements, remain preserved within the modern landscape, often concealed beneath vegetation or contemporary buildings.

3.2. Georeferencing

The georeferencing of the Dutch plan resulted in notable geometric transformations, as the original rectangular outline of the scanned map shifted into a rhombus-shaped form once corrected for spatial distortions. Its orientation also changed significantly during the alignment process (Figures 7 and 8). When the georeferenced plan overlaid onto the colour hillshade derived from the LiDAR-based DEM, it provided a clear visualization of the fort's original spatial layout in relation to the surviving landscape features (Figure 6).

The overlay demonstrated a strong correspondence between the historical plan and the LiDAR analysis. It confirmed that the eastern rampart and its two bastions, previously identified as mounded features in the DEM, accurately align with their positions in the historical map. The georeferenced plan also revealed that a portion of the former moat still survives on the eastern side of the fort. This remnant, which appears today as a narrow water-filled channel, remains hydrologically linked to the Negombo Lagoon from the southwestern side of the fort area.

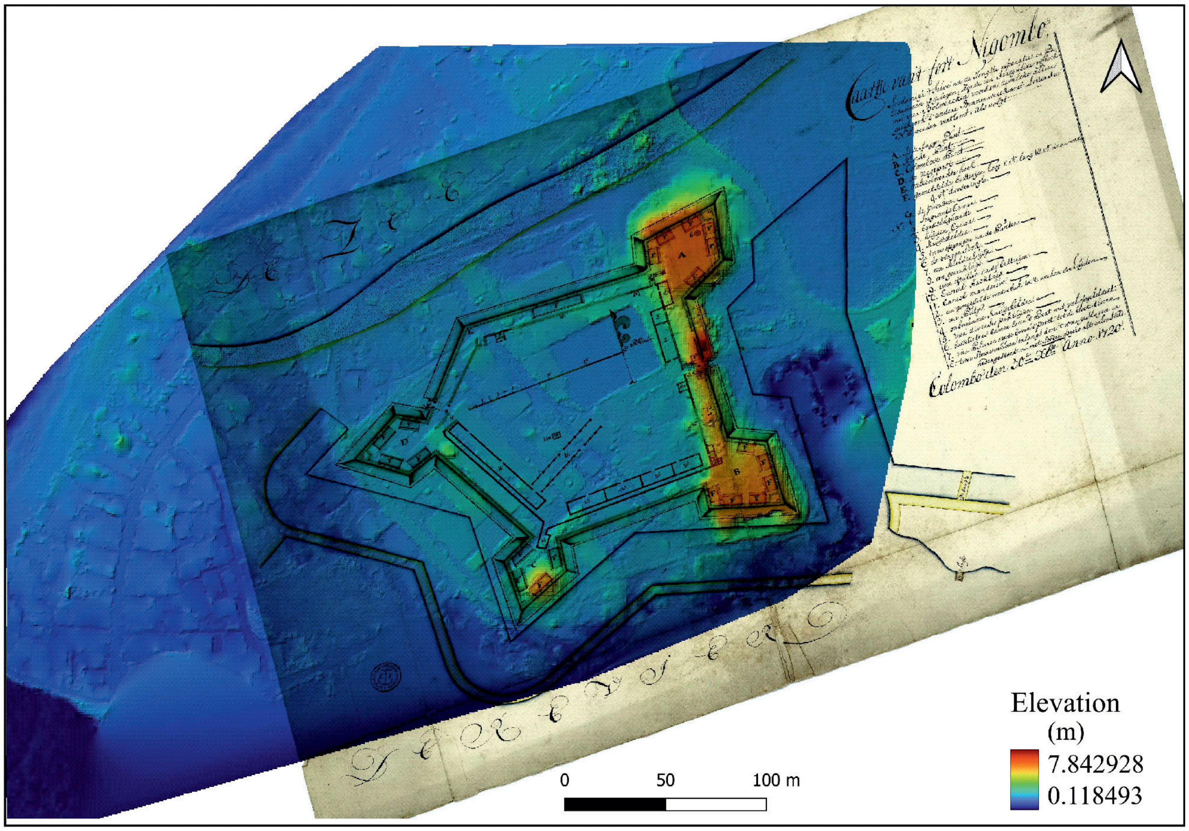

Figure 6: Georeferenced Dutch plan overlayed on the colour hillshade

Figure 7: Georeferenced Dutch plan overlayed on Google Earth

One of the most significant outcomes of this process is the confirmation that the isolated mound visible south of the eastern rampart corresponds to the southern bastion of the fort's eastern side, rather than a natural elevation or later modification. The spatial agreement between the hillshade, the DEM, and the Dutch plan provides strong evidence that this feature is a surviving structural remnant of the original fortification (Figure 6).

When the georeferenced historical plan was overlaid onto Google Earth, the extent of spatial transformation over the centuries became clearly visible (Figure 7). The comparison highlighted the degree to which colonial-era structures have been altered, obscured, or replaced by modern development, while also illustrating how certain elements, such as bastion mounds and segments of the moat, have persisted within the contemporary urban landscape.

3.3. Discussion

The results of this study demonstrate the effectiveness of integrating LiDAR-derived elevation data with georeferenced historical cartography to reconstruct the spatial configuration of an urban, highly altered colonial fortification. Earlier work by Asseldonk (1993) identified two surviving mounds as the northern and southern bastions of the fort's eastern side. Yet, these features were not mapped in detail, and their physical form remained poorly understood. The present analysis provides the first fine-resolution morphological evidence that the eastern rampart and its associated bastions survive as substantial earthen mounds, retaining their original geometric configuration despite later demolition, infilling, and surface modification. Although the stone structures have long disappeared, the LiDAR-derived DEM reveals that the underlying earthworks still preserve the fort's outline, indicating that even heavily altered colonial features can endure in the terrain (Figure 6).

Georeferencing the 18th-century Dutch plan further substantiates these findings. The corrected spatial alignment confirms that the mound underlying the present District Court corresponds to the bastion labelled A (Flag Point), while the mound on which the Anglican Church stands aligns with B (Clock Point). The third mound identified through LiDAR, a previously unrecognised feature on the western side, correlates with C (Colombo Point), revealing the remains of the southern bastion of the fort's western rampart (Figures 7 and 8). This is a significant contribution, as prior scholarship had not identified any surviving elements of the western sector of the fort. The overlay also confirms the partial survival of the moat system shown in the Dutch plan. Although today it appears as an extension of the Negombo Lagoon, the surviving segment on the southwestern side is consistent with the moat's original configuration.

These results highlight the value of combining LiDAR with historical sources to interpret colonial landscapes that have undergone extensive transformation. While LiDAR has been widely applied in forested or non-urban contexts, this study demonstrates its equal value in dense, modern urban settings where archaeological features are obscured, fragmented, or repurposed. Historical plans provide spatial reference points that aid the interpretation of subtle elevation anomalies, while LiDAR provides the terrain detail necessary to validate and refine the historical record. The integration of these datasets allows for a more accurate reconstruction of the fort's spatial organisation than either source could achieve independently.

Overall, this research not only confirms earlier identifications but also expands the understanding of Negombo Fort by revealing additional structural remnants and validating the accuracy of early Dutch mapping. It demonstrates that even in heavily modified coastal urban environments, LiDAR combined with historical cartography can successfully recover hidden archaeological information, offering a powerful methodological framework for future studies of colonial and post-colonial landscapes in Sri Lanka and beyond.

4. Conclusion

The combined analysis of LiDAR-derived elevation data and the georeferenced early eighteenth-century Dutch plan provides new and definitive insights into the spatial configuration and preservation of the Negombo Fort's defensive system. Although centuries of demolition, infilling, and intensive urban development have heavily transformed the site, significant components of the fort's earthen architecture remain embedded within the modern landscape. The DEM clearly reveals the northern and southern bastions and the connecting eastern rampart as coherent geomorphological features retaining their original rectangular and linear forms. These findings corroborate earlier identifications but substantially refine previous interpretations by providing detailed morphological evidence of the fort's surviving geometry.

Georeferencing the historical Dutch plan further strengthens these results, confirming that the surviving mounds correspond precisely to the bastions labelled A (Flag Point) and B (Clock Point), while also revealing the presence of a previously unrecognised mound aligned with C (Colombo Point), representing part of the western defensive sector. This discovery marks a significant advancement in the understanding of the fort's spatial extent, which past scholarship had overlooked. The partial survival of the moat system, particularly the segment hydrologically linked to the lagoon, adds further evidence to the persistence of the fort's original defensive layout beneath modern urban modifications.

More broadly, this research underscores the analytical value of integrating LiDAR with historical cartography for urban archaeological investigations. While LiDAR is frequently associated with forested or rural settings, this study demonstrates its capacity to reveal obscured archaeological features even in highly altered, densely built environments. The complementary use of historical maps enables more confident interpretation of subtle elevation anomalies, allowing researchers to reconstruct complex and transformed colonial landscapes with greater accuracy. The methodological approach presented here offers a robust framework for future studies of colonial fortifications and other archaeological sites in Sri Lanka and comparable regions, highlighting the enduring potential of topographic and cartographic datasets to recover traces of the past in the present-day cityscape.

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