MANIPAL ACADEMY of HIGHER EDUCATION
(Institution of Eminence Deemed to be University)

ADVANCING ARCHAEOLOGICAL AND GEOMORPHOLOGICAL UNDERSTANDING OF THE INDIAN COAST USING OLD CARTOGRAPHIC AND VISUAL RECORDS

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DECLARATION BY THE CANDIDATE

I declare that this thesis, submitted for the degree of **Doctor of Philosophy** to Manipal Academy of Higher Education, is my original work, conducted under the supervision of my guide **Dr. M. B. Rajani**. I also wish to inform that no part of the research has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

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CERTIFICATE

This is to certify that the work incorporated in this thesis **"Advancing archaeological and geomorphological understanding of the Indian coast using old cartographic and visual records"** submitted by **Ms. Ekta Gupta** was carried out under my supervision. No part of this thesis has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

ABBREVIATION

AMS	Army Map Service
BCE	Before Common Era
CE	Common Era
CP	Control Points
DEM	Digital Elevation Model
DF	Dutch Fort
DSAS	Digital Shoreline Analysis System
EIC	East India Company
GCP	Ground Control Points
GIS	Geographic Information System
ICMAM	Integrated Coastal and Marine Area Management
INCOIS	Indian National Centre for Ocean Information Services
KAE	Kodungallur-Azhikode Estuary
NCESS	National Centre for Earth Science Studies
PF	Portuguese Fort
PMC	Portugaliae Monumenta Cartographica
RS	Remote Sensing
SGM	Scaled Grid Method
SRTM	Shutter Radar Topography Mission
USGS	United States Geological Survey
VOC	Vereenigde Oostindische Compagnie

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ABSTRACT

Indian coast has been charted and mapped extensively for navigation, safe landing, political and military interest by various European colonisers such as Portuguese, Dutch, British, and French, since the 16th century. The maps and charts produced by them often depict geomorphic features such as shoals, lagoons and coastlines, and historical sites as landmarks. However, the geomorphic and archaeological context of these early cartographic documents is mostly neglected and undervalued.

The present study attempted to explore and critically evaluate these early maps with the following objectives – 1) to provide a methodology to integrate information from the historical sea- charts, maps, paintings and satellite images using Geographic Information System (GIS) and remote sensing (RS) to derive meaningful geomorphic and archaeological information; 2) to explore the usability of historical maps in the investigation of the lost or unidentified archaeological features with respect to the dynamic shoreline; and 3) to advance the understanding of the long-term (few centuries) coastal geomorphology.

The study has made an original contribution in demonstrating the richness and potential of these historical cartographic documents in advancing the archaeological and geomorphological understanding of few stretches of the Indian coast by integrating knowledge, concepts and methods from different disciplines (i.e. RS, GIS, cartography, archaeology and geomorphology) to a coherent methodology. More specifically, the present work led to finding hitherto unknown remains of colonial forts on coasts of Goa, Karnataka, and Kerala, while it also helped in understanding and dating the long-term dynamics of spits of central Kerala; the evolution of the Thamirabarani delta; and the formation of the Thoothukudi tombolo. The present study demonstrates the ability to extend the spacio-temporal analysis of coastal areas from around 50 years (limited by the period of availability of satellite images) to the last few centuries by using historical maps. The interdisciplinary approach used in this research has fetched multifaceted outcomes and paved the way for more follow-up efforts for future research that has great potential to address some of the very important present-day challenges in the study of coastal heritage and geomorphology.

CHAPTER 1

INTRODUCTION

"Scholars across the humanities and social sciences increasingly find the study of maps to be intellectually challenging and the interdisciplinary insights their study generates to be academically rewarding."

- Matthew H. Edney, 2005

'Maps are more easily recognised than defined' (Andrews 2009). This statement by Andrews is very apt and identifies the complexity in defining maps. Maps have been understood differently throughout history and defined variedly across disciplines (Harley 2002; Edney 2005). Brotton (2015) has broadly defined maps as 'graphic representation that presents a spatial understanding of things, concept, or events in the human world'. Edney (2005) defined '*mapping*' as 'the representation of spatial complexity and '*map*' as its product where the term 'representation' means 'the process by which meanings are constituted and communicated' and 'continually interpreted and reinterpreted by their users'. Due to their inherent equivocacy, maps offer multiple interpretations and possibilities of newer insights. When repackaged and distributed many centuries later, historical maps have transmuted meaning and are understood very differently from what they were first made for (Edney 2005). Maps are broadly understood from two perspectives: 1) maps are 'factual statement of geographical reality' and mirror representation of some aspect of the real world while acknowledging the constraints of cartographic techniques and skills; and 2) maps are social, political and cultural construction of the world expressed through the medium of cartography (Harley 2002).

The present study investigates historical maps (primarily colonial maps) of the Indian Coast from both perspectives with two premises: 1) maps[1] correspond to the topographic reality in a simplified, reduced and abstract form and hence can be carefully used to study changes in coastal geomorphic features in the past few centuries; 2) maps preserve in them human actions or events particularly construction, destruction or restoration of colonial forts and other structures built during that period, thus, can be studied to explore and investigate the bygone historical sites with respect to geomorphic changes.

1.1. BACKGROUND

This section briefly informs about the central material that this thesis is based on - colonial maps of Indian coasts - the sources (physical and digital archives and libraries) to acquire them and explains how the present thesis was conceptualised in the beginning.

1.1.1. MAPS OF INDIAN COAST

European exploration of sea routes to India and subsequent colonisation led to extensive charting, mapping, and visual recording of the Indian coast from the 16th century to the early 20th century by various European agencies (ref. Chapter-2 for details). Cartographic data and visual records such as historical maps, coastal profiles, views, and landscape paintings represent the spatial information of the time. The early nautical charts and maps contain coastal geomorphological details (such as shoreline demarcation, high tide, low tide, shoals, spits, and soundings) and places identified as landmarks along the coast. They provide unique inputs for past geomorphological studies as they were made when there is no direct evidence of shoreline changes. Also, the plan of forts made at different times and depiction of the then important man-made structures as landmarks in sea charts offer the possibility to investigate and explore the built heritage that might have either fallen into oblivion or lost in the natural geomorphic course. Similarly, paintings of topographic view of the coast are a parallel set of historical documents that has the record of the landscape details, buildings, and structures present in the frame. They

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[1] **NOTE:** In the present thesis the term '**map**', in general, is inclusive of historical sea charts, plans, terrestrial maps of coast, coastal views and profiles.

provide a complementary perspective to information gleaned from navigation charts and other kinds of maps.

1.1.2. WHERE ARE THEY?

During the colonial period (16th century to early 20th century), the European cartographic agencies from Portugal, Netherlands, France, England and Denmark had engaged in surveying, mapping, and engraving, printing and publishing maps of different parts of the world (including the Indian coast) (ref. Chapter-2). With advancements in printing technology, maps and their copies were produced and disseminated in large numbers. Later, because of their historical and antique value, maps were donated to the States or libraries, purchased by private collectors and other such public bodies. Archives and libraries such as the National archives in the Netherlands, British Library in the UK have an extensive collection of maps, especially of the maps made in their countries or for the use of their countrymen. However, they are not easily accessible; to access them physically, one has to rely on grants to travel to these countries, and there are very few grants that too highly competitive. India also has a good collection of historical maps. However, coastal maps in India are restricted and inaccessible to researchers. Opportunely, some archives and libraries worldwide are digitising their collection of maps (including maps of the Indian coast) and making them available as open acces via the internet. However, many of these maps do not have complete metadata; therefore, finding them becomes a challenge. The metadata here means the date of survey period, reprint, name of the cartographer, engraver and publisher, which is crucial for using a map for analysis (ref. Section 3.1 in Chapter-3).

1.1.3. GROUNDWORK

The present thesis is inspired by the work of Rajani and Kasturirangan (2013) in which the authors study landmarks marked in a Dutch sea chart of the 17th century using remote sensing data to demystify the erstwhile European toponym *Seven pagoda,* a place on the coast of Tamil Nadu, known as Mahabalipuram. The study also finds that the famous shore temple (built-in 8th century) of Mahabalipuram was disconnected from the mainland about 350 years ago, which is an important geomorphic information. Although the map used by the authors is highly inaccurate in terms of planimetry, the shoreline position relative to the location of landmarks could provide quite reliable information of the 17th century shoreline.

The research towards the present thesis started with an assumption that there would be more such maps of the Indian coast depicting various historical sites (known or unidentified) and their position relative to the shoreline. At the time of the conception of this thesis, the plethora of maps present in archives and libraries and the wealth of information the maps possessed were not known to the author; only a fruitful archival work in Europe was anticipated. With limited funds and time, few archives and libraries in the UK and India were visited (ref. Section 3.2.1.2 in Chapter 3). Apart from the maps and coastal views, historical records, pilots[2] , travel accounts and other related literature were also accessed. Maps were also accessed from some digital archives such as Atlas of Mutual heritage, *Nationaal Archief,* Wikimedia, David Rumsey Collection, Abhilekh Patal and Kalakriti Archive. While exploring these archives and libraries, the richness and diversity of colonial coastal maps of India were realised.

Maps were collected and organised initially on Geographic Information System (GIS) in which polygons of the spatial extent of the maps were drawn and overlaid. This exercise provided a good insight into the availability of variety of maps in various scale. Maps covering a larger area are smaller-scale and vice-versa. Generally, the maps within the range of scale in Representative Fraction (RF) 1: 1000,000 or lesser are small-scale, and between 1: 1000,000 and 1: 25,000 are medium-scale and > 1: 25 000 is large-scale. Coastal maps of various scales, types and purpose are available in abundance for the whole of India, particularly for the stretches that were of interest to the most colonial powers. For the selection of sites for a detailed study, the richness in terms of diversity, map quality, number of maps available, and the geomorphic and archaeological value of sites were considered. Ten coastal stretches in the four states of India, i.e., Goa,

[2] Written description of ports, harbours and the sea route accompanied with nautical charts (ref. Section 3.2.2.4 in Chapter 3)

Karnataka, Kerala, and Tamil Nadu were selected. Out of ten , five stretches are studied with a focus primarily on archaeological investigations. They are Kollam, Cambolim (Gangolli), Barcelore (Basrur/ Kundapur), Onor (Honnavar) and Old Goa, where geomorphological aspects are referred to as supporting information. On contrary, the remaining five sites principally investigate the geomorphological aspects of Chettuva, Kodungallur-Azhikode and Kochi Estuary, Thamirabarani delta and Thoothukudi Tombolo. However, archaeological information is used to provide spatio-temporal context of the past geomorphic changes, although not exclusively.

1.2. WHY SHOULD EARLY COASTAL MAPS BE STUDIED?

Analysis of early maps (in this thesis the colonial maps) can reveal spatial aspects of a place in historical times that are almost impossible to know from any other historical source. Though historical maps have been used to enrich understanding of various aspects of the past, such as political and ecological (Edney 1997; Askevold 2005), they also have immense potential to explore archaeological sites and comprehend geomorphic changes for the following reasons:

1.2.1. UNIQUE SOURCE OF COASTAL INFORMATION OF THE PAST FEW CENTURIES

Coastlines, throughout the world, are highly variable. It changes at a varying rate in response to the local conditions, coastal processes, extreme events, climatic changes, tectonic activities and human action. Several scholars study changes in the coastline that occurred in the past and project future changes using the proxies of thousands/ millions of years old geological data (Church et al. 2013), data from the tidal gauge (consistent data available from around last 60 years) (Horton et al. 2018), archaeological records (Tripati and Gaur 1997; Gaur, Vora, and Sundaresh 2007), biological indicators such as corals and salt marsh flora and fauna (Ramsay 1996; Woodroffe and Horton 2005) and decades old satellite data (Rajawat et al. 2015). Attempts have also been made to reconstruct sea-level change at a global level from 200 CE to 1900 CE and to predict future changes in sea level using past temperature scenario (Grinste, Moore, and Jevrejeva 2009; IPCC 2014). Paleo sea-level proxies are dated using radiometric and optically stimulated luminescence (OSL) dating methods that provide a chronology for the past relative sea-level changes (Rink and Thompson 2015; Horton et al. 2018). Although, OSL dating is considered suitable for the study of young sediments (even for <100 years) (Costas et al. 2012), sediment coring and dating demand expensive instruments and elaborate field and lab facilities; and thus, are difficult to conduct on larger areas.

Certainly, there is a dearth of direct evidence of shoreline changes in the past. In this scenario, the historical cartographic documents from the 16th century onwards become critical geospatial data to visualise the regional geomorphology of the time for which we do not have other direct evidence and inform us about the sequence of physical changes. As mentioned earlier, the historical sea charts or maps often contain a graphical description of coastal geomorphic features. Some of them show the area of sand that gets exposed at the time of low tide or display if a coastal feature is rocky or sandy or if the sea has a soft bed to hold the anchor. Even sandbanks that change their position over time are marked in some cases (Schilder and Hans 2010). Sometimes these charts accompany pilots, which are published as a compilation; these can jointly provide the information of the coast as experienced by mariners of that time (Blake John 2004). Figure 1.1 is an excellent example of such charts. It shows the profile of the coast (given in an inset), bathymetry data, hills and sandbanks; it also has explanatory text that could help sailors avoid dangerous locations or landing points. As these maps (especially hydrographic charts) were used for navigation, the surveyors tried to make the information as accurate as possible with the available technology and knowledge they had at the time (Robinson 1952; Manning 1988). Thus, such maps could be of great use in geomorphological studies.

1.2.2. COASTAL LANDMARKS AND IMPORTANCE IN ARCHAEOLOGY

Another vital piece of information found in the sea charts/ coastal views/profile is the depiction of manmade structures (mostly defence and religious structures) as landmarks These landmarks were strategic locations that directed sailors towards their destination. Thus, these maps are a storehouse of spatial record of prominent buildings that had existed when maps were made. Some maps depict landmarks with unique symbols representing the shape and extent of built structures that further enhance their value in historical studies (ref. Figure 3.2 in Chapter-3).

Colonial written records discuss extensively of construction, restoration, destruction, and modifications to defense and other related structures of the coast. Though they do not clearly describe the location and extent of the structure. Thus, the identification of those sites and locations are heavily contested by scholars and remains ambiguous. On the other hand, when left abandoned or unattended, the structures and its sites get smothered with vegetation, buried under sediments, and at times their built material are carted for newer construction (Rajani 2021). The thick growth of vegetation over the old ruins obscures the identity of the site. The character, context and identity of such sites are often lost with time.

Sometimes, these sites create a palimpsest of events of successive occupation and modification of land occurred at different time. Historical maps are snapshots of the space and time they represent. GIS enables the chronological juxtaposition of these snapshots, and remote sensing data facilitates the correlation of map features to their corresponding remains (conspicuous, subtle and imperceptible) on the ground. Therefore, historical maps could be of high value in exploring archaeological sites that are unidentified or got obliterated by present human activities.

1.2.3. ADVANCEMENT IN THE TECHNOLOGY TO USE THEM

Four significant technological advancements, i.e., high-resolution scanning of early maps, wide and easy accessibility of material via the internet, development of Geographic Information Systems (GIS) and acquisition and dissemination of a wide range of satellite images in recent decades, have revolutionised the study of early maps (Rumsey and Edith 2005; Askevold 2005; Jenny and Hurni 2011; Rajani 2021). The high-resolution digital version of maps, when magnified on screen, makes the information visible in an unprecedented way and enable a much more detailed study of maps (Rumsey and Edith 2005).

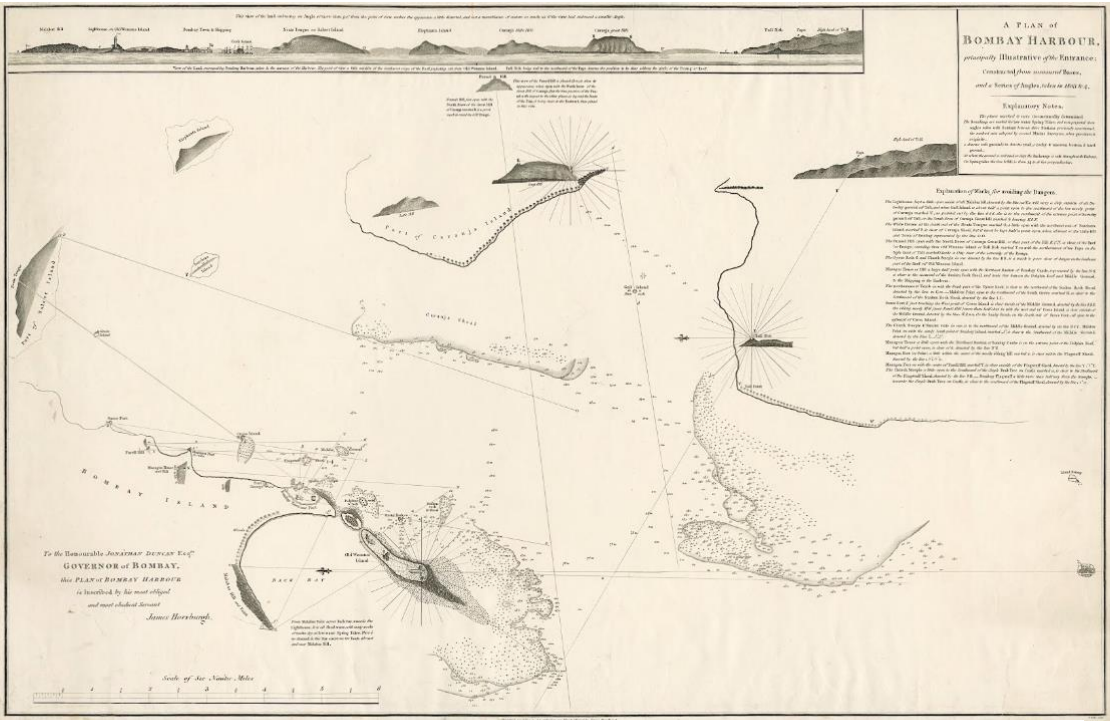

Figure 1.1. A plan of Bombay Harbour, 1803–4. Image courtesy: Kalakriti Archives, accessed on 5th May 2021 (https://artsandculture.google.com/asset/mumbai-maharashtra/GQFiBvR3O-a4kA)

GIS offers integration and analysis of a variety of spatial data by bringing them to a standard geographic coordinate system through georeferencing and their visualisation at different scale (Rumsey and Williams 2002; Rajani 2021). GIS is found to be a powerful tool to visualise and understand past changes and explore the lost archaeological sites by integrating early maps (Crowell, Leatherman, and Buckley 1991; Rumsey and Williams 2002; Levin 2006; ; Rajani 2007; Suganya and Rajani 2020; Rajani 2021). Furthermore, GIS has been found helpful in assessing the accuracy of semantic and geometric information

(Jenny and Hurni 2011). There are more specialised tools available to analyse and visualise the planimetric property of historical maps (Jenny 2006). Also, some internet-based GIS platforms are available to provide remote access to data stored in extensive digital libraries across the world (Rumsey and Williams 2002).

Similarly, a wide range of remote sensing data available from coarse resolution such as 250 m MODIS data to very high-resolution LiDAR data; and from a single band panchromatic data such as CARTOSAT-1 PAN to hyperspectral data with hundreds of bands (Joseph and Chockalingam 2017). Satellite images are used to trace paleo features such as beach ridge and swales, strandlines, paleo deltas, paleochannels and to study coastal dynamics (Chandramohan & Nayak, 1991; Narayana & Priju, 2006; Rajawata, *et.al.* , 2014). Integration of satellite data, GIS and historical maps has been greatly useful for archaeological investigations (Gupta, Das, and Rajani 2017; Suganya and Rajani 2020; Rajani 2021).

1.3. EXISTING RESEARCH AND GAPS

The above section presents strong reasons to study early maps for archaeological and geomorphic studies. This section provides a literature review on early maps as historical evidence and how scholars have studied them as a historical source of information in archaeology and geomorphology. The following literature review also points out few research gaps that guided the purpose for setting the objectives of the thesis discussed in Section 1.5.

1.3.1. SCEPTICISM UPON HISTORICAL MAPS

Maps are equivocal and fallible (Carr 1962). The reconstruction of the historical event solely based on early cartographic evidence is often looked up with scepticism (Skelton 1965). It is because maps as final products go through a chain of complex processes which includes: the assemblage of information from direct observation or surveys, from other textual and graphical sources; the abstraction of the information that depends on how the cartographer assimilated the information; representation of selected features that depends on the purpose for which the map is drafted or on political motives; and finally, compilation, production and making copies of maps (Skelton 1965). The construction of a map is both a scientific and an artistic exercise. They are based on surveys and geometric understanding of spatial objects on the one hand; the choice and representation of objects are dependent on selective representation and abstraction of space and its objects, on the other hand. Therefore, maps are often recommended to be used in the presence of this background information (Skelton 1965; Askevold 2005). Finding this information is most often a challenge. Even if we have some background information, the question of subjectivity and accuracy of maps remains a challenge.

Harley (1968) presents methods and techniques to evaluate the accuracy and validity of early maps. His methodology has three stages. The first stage considers 'evidence on maps' such as identification of the cartographer through physical examination of material of the map, dating of watermark, study of paleography and cartographic style, understanding of mathematical properties of maps (scale, projection, orientation), direct comparison of topographical detail of early map with the modern maps and comparative cartography. The second stage considers 'evidence about maps' such as information on the cartographer's intention, on the making of maps (survey technique and means of production) and contemporary assessment of maps. The third is to inquire how the study of early maps is different from other documents.

Harley's theoretical framework of placing maps in social and technical context is applied to a new domain of historical ecology using GIS by R. Askevold (2005). Askevold finds that maps, if studied without understanding the context, maybe misused, misinterpreted, or ignored. However, in many cases very limited background information is available for understanding the social and technical context. There comes the question- can historical maps be used effectively even if the background information is very limited?

1.3.2. HISTORICAL MAPS AND GEOMORPHOLOGICAL STUDIES

One of the early and most systematic studies of series of sea-charts to understand the geomorphic changes was conducted by Oldham (1925), who studied early maps of the Rhône delta in France by: 1) critically analysing information about the maps such as their publishing year, their author, whether they were original or copied; 2) identifying places and geomorphic features marked on the maps; 3) understanding the change relative to an identified fixed feature; 4) comparing the spatial information with recent maps, and 5) corroborating observations with historical text and geological studies. Boer (1969) also used a similar approach while studying a spurn point of a spit at the mouth of river Humber, England. Carr (1969) attempted to apply a quantitative approach to measure the shifting position of the distal point of spit from maps made in the 19th century. The method involved redrawing all the maps to a common scale and then comparing the distance relative to each other. Oldham found the early sea charts he studied as acceptable evidence of change. Boer suggested sea charts as a source of valuable information when other kinds of evidence are sparse. Such studies did not gain much attention from geomorphologist as the authenticity of early maps has always been a question.

The studies mentioned above were conducted before the emergence of GIS tools and technology or when it was still in its initial development phase. The advancement in scanning technology, easy access to internet and GIS have revolutionised the ability to use early maps as an important historical document. The early instance of GIS-based study of older historical maps for shoreline change analysis was carried out by Crowell, Leatherman, & Buckley (1991). This study, for comparison, brings the maps to a common coordinate system and datum using manual, computerised, and hybrid manual-computerised techniques (now known as georeferencing). It soon became a valuable tool for quantitative studies that require measurement of past areal changes in landcover or landuse by georeferencing and overlaying historical maps (McBride, Byrnes, and Hiland 1995; Bromberg and Bertness 2005; Levin, 2006; Jabaloy-Sánchez et al. 2010).

GIS also enables quantification of planimetric errors that a map may have. However, GIS as a tool to study historical maps has its own limitations. Georeferencing of a map requires correct identification of Control Points (points for which latitude and longitude are known or can be ascertained). Ideally, the Control Points (CP) should be a stable point feature such as a crossroads a building, a bridge and an intersection of a canal and a road. Also, these points should be evenly distributed on the map. However, most coastal maps and charts provide only coastal information and show only dynamic features such as shoreline, islands, estuaries, creeks and lagoons. The absence of fixed identifiable features in many coastal maps and charts makes it impossible to georeference them accurately. In addition, the coastal maps would have half the map area marked with the sea, which makes it impossible at times to provide a evenly distributed CP. Sometimes, even if georeferencing is possible, some georeferenced maps show very high error (from 200 to > 400m), making it difficult to trust them in the absence of other evidence.

In addition to the technical challenges of georeferencing, maps carry inherent subjectivity (briefly discussed in Section 1.3.1). The GIS does not take subjectivity present in maps into account. The subjective and nonstandard nature of early maps has constantly challenged scholars to use them in scientific studies. Some scholars caution that scientific studies of early maps without considering their metadata such as date, purpose, cartographer/draughtsman, publisher, patron, technology, etc., can be misleading (Askevold 2005). Moreover, there are very few studies in India where historical maps are used to study past geomorphology due to limited research on cartography, less awareness of the availability of historical maps of coastal India in foreign archives, and restricted use of early maps of coast within the Indian archives. Therefore, it is essential to popularise historical cartographic documents as an important historical source by conducting experiments and more research using them, and improvising methods to better deal with the existing challenges.

1.3.3. HISTORICAL MAPS AND ARCHAEOLOGICAL INVESTIGATIONS

Before GIS tools became available in academics, the use of early maps in archaeological studies was minimal. At that time, maps were primarily used as auxiliary data to supplement some spatial information about the site. (Wedel and Robison 1938; McCary and Barka 1977). With the advancements in computer science and introduction of GIS in archaeology in the second half of the 20th century, studies such as location analysis, spatial autocorrelation, simulation of settlement, trend surface analysis were conducted to understand ancient settlement patterns (Haggett 1965; Cliff A.D. 1973; Chadwick 1978; Feder 1979; Wheatley David 2002); Peterman 1992; Kvamme 1999). However, not much progress was seen in the use of historical maps in GIS-based archaeology during that time. The reasons were the lack of high-quality scanners, the availability of prepared digital images to the public domain, and less awareness about the importance of old maps (Rumsey and Williams 2002). However, this scenario is changing now. At the beginning of the present century, immense efforts were made on large projects of digital dissemination of historical maps and views. At present, thousands of digital copies of historical maps are available online, and in some online portals, they are embedded in GIS software.

Also, recent advancements in remote sensing technology, easier availability and affordability of satellite data, and non-invasive nature encouraged archaeologists to experiment with the data (Ebert 1984; Shennan and Donoghue 1992; Brivio, Pepe, and Tomasoni 2000). Since then, remote sensing data have been extensively used to explore surface and subsurface archaeological features and understand the site in a larger spatial context, managing cultural heritage (Parcak 2009; Opitz and Herrmann 2018; Rajani 2021). Recent studies show that the integration of historical maps with RS and GIS is extremely useful in unveiling the footprints of lost traces. For example, Gupta, et. al. (2017) explores Tipu Sultan's lost palace and armouries using an 18^{th} -century British map and satellite images. Rajani (2021) finds archaeological mounds and remains in ancient Buddhist sites Nalanda and Sarnath by analysing 19^{th} -century maps made by Alexander Cunningham in RS and GIS environment. Similarly, Suganya and Rajani (2020) identifies and delineate the Mughal's riverfront gardens and other components of Mughal city of Agra such as fort wall, gates and mansions by integrating early maps with satellite images. Satellite images play a crucial role in making the early maps a valuable source of historical information. It is now possible to relate the map features with the features on the ground and validate contents of the map. Thus, early maps, often suspected for being erroneous, can now be studied with more confidence.

There is a massive pool of early cartographic data of the dynamic Indian coast containing a great wealth of historical information that is yet undiscovered and has a tremendous untapped potential to inform about the past geomorphic changes when studied in relation to a fixed historical site.

1.4. RESEARCH MOTIVATION

Following are the four key points extracted from the previous sections.

1. Colonial maps of the Indian coast are a unique primary source of past geomorphic information and important spatial document of some of the historical sites that existed in the past but are now unidentified or lost due to abandonment or subsequent human or natural actions.
2. Coastal maps in India are not easily accessible. Access to archives and libraries requires colossal funds. Therefore, there are very limited studies, so far, of historical maps of Indian coasts. However, many digital maps (from various international archives) are now available online, opening new possibilities to use them. At the same time, it also presents a risk of maps being misused if not studied carefully. Hence, it is crucial to understand the critical aspects and the context of early maps.
3. Coasts are dynamic; both constructive and destructive forces continuously keep adding new lands and removing parts of the existing ones. However, archaeological features are static and stable. Historical sites along the coast are good reference points to understand any geomorphic changes. On the other hand, knowledge of geomorphic changes along the coast has potential for archaeological investigation. Therefore, to study both the aspects of these maps together is crucial
4. Integration of early maps in science-based studies has always been challenging, and the methods to study them are limited. There is a need for improvised methods so that content present in the maps can be validated and information from them can be extracted at its best.

1.5. OBJECTIVES OF THE THESIS

The present study attempts to critically evaluate early coastal maps of various kind and their use in the two interlinked disciplines, i.e., Archaeology and geomorphology, with the following objectives:

- To provide a conceptual and analytical framework for integrating information from historical sea charts, maps, paintings and satellite images using GIS to derive meaningful geomorphic and archaeological information.

- To investigate the lost or unidentified archaeological sites or features with respect to the dynamic shoreline through systematic integration of maps of diverse nature prepared at different time.
- To explore the usability of historical maps in understanding long term (few centuries) coastal geomorphology
- To assess whether the record from these historical documents matches relative sea level and coastline changes deciphered from other sources, such as excavation of ancient sites, petrology and mineralogy.

Evaluation of maps should be carried out based on the questions one is trying to answer from the maps. In the context of evaluation of maps and its content, Harley (1968) made a very apt remark "elaborate techniques may be unnecessary to verify simple facts". The present study adopts different approaches from very simple visual interpretation using logical reasoning to more elaborated remote sensing and GIS approach and their combinations. The formulation of the question and selection of the methods to address them was primarily based on the details and accuracy of the maps in hand and on the presence of recognisable features (both paleo or extant) in the current maps or satellite images.

The proposed methodology consist of: 1) extensive archival work in India and abroad to find historical maps and descriptive geographical records of Indian coast; 2) categorisation of collected maps based on chronology, scale, place, extent and types; 3) selection of a few coastal stretches for detail study; 4) assessment and interpretation of map content; 5) cartometric techniques which includes assessment and conversion of scale, georeferencing, comparison between direction and distance; 6) methods to analyse maps that could not be brought into GIS (includes comparative cartography, grid analysis and corroboration with paleo features in satellite images); 7) GIS techniques including image overlay, shoreline extraction and shoreline change analysis using baseline, transects and extracted shorelines; 8) Satellite image analysis and interpretation; 9) reconstruction of geomorphic past by relating the results with existing theories and scholarly understanding; 10) tracing of archaeological remains and ground validation; and 11) critical evaluation of proposed methods and results.

1.6. THESIS ORGANISATION

The thesis presents interdisciplinary research in which knowledge, concepts and methods from different disciplines and sub-disciplines viz. Geography (cartography and coastal geomorphology), history, archaeology and remote sensing and GIS are integrated. The thesis is organised as follows:

Chapter 1 – Introduction

This chapter introduces the research topic and sets the context. It briefly explains how the present research topic was conceived and evolved as a full research proposal. It discusses the significance of the proposed study, identifies research gaps that motivated the present research, defines proposed objectives, provides a brief note on the proposed methodology and presents an overview of all the chapters.

Chapter 2 – Maps and mapping of Indian Coast and their historical context

Before exploring historical maps of the Indian coast for the proposed objectives, it was necessary to look into some historical questions such as how Indian coastline has been perceived and mapped since the classical era (6^{th} century BCE)? When did the rigorous and most accurate mapping of the Indian coast begin? Who are the pioneer and prime historical cartographers who surveyed and mapped the Indian coast? What country do they belong to? What kinds of maps are available? How did cartographic techniques evolve in historical time? This chapter addresses these questions. The answers to these questions provided a direction for focused archival work and set the historical context of maps.

Chapter 3 – Research design and methodology

This chapter critically analyses historical maps and discusses the challenges in studying them as a historical source. Critical aspects of historical maps are discussed in detail. An interdisciplinary methodological framework is conceptualised and the methods (both adopted and proposed) are explained and justified.

Chapter 4 – Coastal maps as a source of geomorphological information

The chapter demonstrates how early cartographic documents can be studied to understand past coastal geomorphology using different methods discussed in chapter 3. The chapter is formalised into two main sections based on location– 1) Tamil Nadu coast, and 2) Kerala coast. In Tamil Nadu, Thamirabarani Delta and Toothukudi Tombolo, and in Kerala, a stretch from Kodungallur to Fort Kochi and coast around Chettuva estuary are investigated. The results are found promising and hence, used for reconstructing geomorphic evolution of Thamirabarani delta, Toothukudi Tombolo and spits of central Kerala, which occurred in the past few centuries or millennia, in light of other published literature. The value of historical maps in coastal studies and the proposed methodology is critically examined and discussed.

Chapter 5 – Coastal maps as a source of archaeological information

This chapter demonstrates the value of the multifarious historical cartographic documents in advancing archaeological and historical understanding of the Indian coast using the case study method in which four sites are investigated. One of these four sites is selected as a principal site to lay the foundation for a broader understanding of the methodology through an in-depth analysis, interpretation, and discussions. Thus, covers a substantial portion of the chapter. Apart from the interesting archaeological findings, this chapter brings out the critical aspects and challenges in the methodology and discusses the significance of such studies.

Chapter 6 – Concluding remarks

This chapter highlights the key findings and integrates conclusions obtained in other chapters to address the objectives coherently. Afterwhich, it reveals further research gaps and discusses the scope for further research in the field of cartography, archaeology, geomorphology, remote sensing and GIS.

Note: A list of all historical maps referred in this study with their thumbnails and respective sources are tabulated in '**Appendix**'; specific ones are referred to in the manuscript and figures with the word 'Map-' suffixed with the respective serial number. For example, ‘Map 1’, serial no. 1 in the Appendix is referred as ‘Map-1’ in the text and figures.

CHAPTER 2

MAPS AND MAPPING OF INDIAN COAST AND THEIR HISTORICAL CONTEXT

"The character and technology of mapmaking may have changed over the centuries,... But the potential of maps has not. Maps embody a perspective of that which is known and a perception of that which may be worth knowing"

-John Noble Wilford (2001)

2.1. INTRODUCTION

Having a rich culture and ancient civilization, India had been involved in overseas maritime trade. India was known to the other contemporary civilization around the globe since the dawn of the Indus Valley civilization during the 3rd millennium BCE. (Jairazbhoy 1963). There have been no doubts on Indian landmass finding a place in the 'mental or figurative conception' of early civilizations (Madan 1997). Geographical understanding of India to the Europeans dates back to the classical era that has improved slowly in the next millennium and drastically after the age of discovery. The most extensive mapping in India through scientific surveys and direct observations started during the colonial period (16th century to 20th century) primarily by the five European powers (Portuguese, Dutch, English, French, Danish) who set up their colonies on the India Coast.

Since the present thesis is centred on historical maps of coastal India, which are less known and most of which are not studied at all. Therefore, before studying historical maps of the Indian coast for the proposed objectives, it was necessary to look into historical questions such as How the Indian coastline was perceived and mapped since ancient times? When did the rigorous and most accurate mapping of the Indian coast begin? Who are the pioneer and prime historical cartographers who surveyed and mapped the Indian coast? What country do they belong to? What kinds of maps are available? How did the cartographic techniques evolve in historical times? The present chapter attempts to address these questions.

2.2. HISTORY OF MAPPING OF INDIAN COAST

2.2.1. CLASSICAL ERA

Hecataeus, a Greek traveller and geographer from Miletus during the 5th and 6th century BCE, is considered the first scholar to produce a systematic textual description of the world. This text is believed to have included a map (Irby 2012). He is regarded as one of the earliest scholars to map the coastline of India on a world map, though very poor and vague. The geometric study of the earth's sphere during the Hellenistic period spearheaded mathematical geography and scientific cartography (Dilke 1987). Pytheas (4th century BCE) is believed to be the first to use parallels of latitude to mark all the places where the same astronomical phenomenon can be observed (Aujac 1987). This idea laid the foundation for the scientific use of latitude and longitude as a positioning system in mapping compilation. However, there were large errors in the value of longitudes[3]. Gradually, scholars started adopting principles of elementary geometry in mapping to measure angles and distance between the places (Aujac 1987). Dicaearchus (350-285 BCE), an Italian Scholar from Messana, Sicily and a disciple of Aristotle, was one of the first map-makers to combine science with records of Greek exploration. His map (reconstructed) is the first to project the peninsular characteristic of the Indian coastline (McPhail 2011). However, it is Eratosthenes of Cyerene (c. 285-205 BCE) – who came after Dicaearchus and adopted the idea of using coordinate axes from the work of the latter – who is credited for depicting the peninsular shape of India for the first time (Lach 1965) (ref. Figure 2.1). Two centuries later, Strabo (63 BCE-21 CE) referred to and corrected earlier works and his representation of the Indian coastline that looks more or less the same as Eratosthenes's. Alexandrian geographer Claudius Ptolemy (90-168 CE), in his

[3] It was necessary to observe an eclipse of the moon or celestial body simultaneously from different places to obtain exact longitudinal distances between them which was very difficult to acquire in those days (Aujac 1987).

famous work *Geographia,* describes a map of the world where the Indian coast is outlined in a horizontal line with no peninsular formation (Madan 1997). There hasn't been much progress in cartography until the late medieval period.

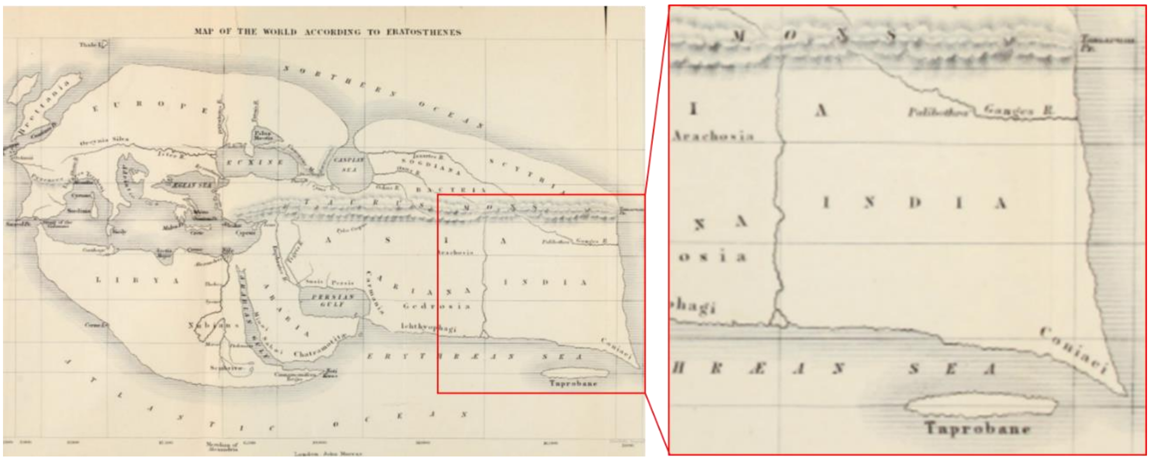

Figure 2.1. 19th-century reconstruction of Eratosthenes' map of the known world (for the Greeks), c. 194 BC; India is highlighted and zoomed in red boxes. (source: https://en.wikipedia.org/wiki/Early_world_maps#/media/File:Mappa_di_Eratostene.jpg)

2.2.2. MEDIEVAL PERIOD

Soon after the rise of the church power in Europe and fall of the Roman empire in the 5th century CE, the advancement of scientific ideas and studies held a back seat in front of religious dogmas, and we do not see any improvement in the representation of the world map in Europe till 15th century. The world maps during the medieval period in Europe (known as *mappamundi*) were "mythical," "non-scientific," or "influenced by Christian dogma" and did not have any practical use. Instead, the purpose of these maps was 'philosophical and didactic' (Harvey 1987; Dalché 2007). During the Renaissance(15th - 16th century) in Europe, Ptolemy's work was 'rediscovered' and reworked after more than a millennium of its creation (Woodward 2007a).

2.2.3. MIDDLE AGES AND THE ARABS

During the 7th century CE, Arabs became a great power and soon expanded their geographical, cartographical and astronomical knowledge. In the early 9th century CE, Baghdad became a learning centre. It had established a 'House of Wisdom' (*Bayt al-Hikmah*) where ancient knowledge from Greece, Persia, India and China has been translated into Arabic, and a new corpus of knowledge was being crafted (Hobson 2004, 175). This included Ptolemy's work lying hidden for about six centuries and was ultimately rediscovered and translated. Motivated by Ptolemy's scholarly work, Arabic geographers became interested in map-making (Madan 1997). The depiction of the Indian coast in the world maps prepared by Al Biruni (11th century) and Al Idrisi (12th century) was no better than Eratosthenes's. However, it was superior to Ptolemy's horizontal portrayal of the coast. Idrisi's work had been used as a reference map by other cartographers for about four centuries.

2.2.4. PORTOLAN CHARTS OF THE LATE MEDIEVAL PERIOD

Around two centuries before the rediscovery of Ptolemy's work, Europeans had developed meticulous ways to map coastlines from geometric measurements (Nicolai 2015). Such maps made for navigation during the later medieval (13th – 14th century) and early modern period (15th -16th century) were referred to as *Portolan*[4] charts. The earliest extant copy of a *portolan* chart titled *Carta Pisana* is dated to the end of the 13th century (Campbell 1987). Not much is known about the origin and construction methods of these most accurate charts of the time. Their close resemblance to modern maps based on Mercator's projection and amazingly accurate delineation of the coastline astonish everyone. The earliest *portolan* charts have been found representing the coast of the Mediterranean sea, Black sea, Atlantic coast from Cap Draa up to the south coast of England (Nicolai 2015). However, we do not find any early sea charts depicting the Indian coast because plotting such charts requires ground surveys and detailed measurement. In the case of India, most of its land was terra incognita to European surveyors till the 15th and the 16th century. Whatever knowledge they had was through travellers' accounts.

2.2.5. MAPPING AND CHARTING BY INDIANS

Arab and European texts of the 15th and 16th centuries, such as those of Arab navigator Ahmad ibn Majid (fl. 1460-1500), Portuguese writer Joao de Barros (c.1540) and Italian traveller Ludovico di Varthema (c.1508), refer to Indian navigation chart (Sheikh, 2009).

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[4] The word portolan is derived from *portolano* or *portulano* which refers to an Italian pilot book with sailing directions, notes on coastal geomorphology and navigational hazards (Vincent 2007; Blake John 2004)

The available references about these charts suggest that charts, comparable to the Portuguese charts of the late medieval period, were already in use in the northern Indian Ocean when vessels from Europe entered the Indian Ocean (Arunachalam, 2008). However, it has not been ascertained when did such charts come into use for the first time in this region. There are only a few examples known to have survived. The collection of Gujarati manuscripts of the later century is in the National Museum, New Delhi. It consists of *pothis (*a set of indigenous sea manuals) and maps of parts of Indian and Sri Lankan coast. It is dated to 1664 CE, and thus, is the oldest known Indian coastal map (Sheikh, 2009). Another 18th century Gujarati navigation manual with a map of the Gulf of Kuchchh is available in St. John's College, Oxford. Due to the small-scale of the available maps and unavailability of maps of the selected coastal stretches, indigenous maps have not been used in the present study.

2.2.6. EUROPEAN AGE OF DISCOVERY AND EXPLORATIONS

The beginning of the 15th century marks the onset of the 'Age of discovery' or 'Age of exploration' in western Europe, and consequently, the expansion of documented spatial knowledge and cartographic techniques. These discoveries initiated primarily as a 'second round' of medieval age Crusades by Spanish and Portuguese with a plan — to contact the Mongols and the pro-Christian Grand Khan in the East; desire for Guinea gold; and opening of new trade routes to the South and East Asia bypassing the Islamic empires (Hamdani 1981; Afonso 1989; Hobson 2004). In 1487-8, Bartholomeu Diaz (a Portuguese explorer) discovered the Cape of storms (later renamed the Cape of Good Hope) and convinced Dom Joao II (Portuguese ruler) of the feasibility to reach India by sea routes via the Cape (Hamdani 1981). A decade later, another Portuguese explorer Vasco de Gama, with the help of a Gujarati Muslim Malemo Cana or Canaqua at Malindi on the East Africa coast, sailed to cross the Arabian sea and reached Calicut on the west coast of India (Nowell 1940). Portuguese were the forerunners in finding out the new sea routes from Europe to the East, circumnavigating the continent of Africa and enjoyed trade monopoly with the East for nearly a century (Afonso 1989). The discovery of the world unknown to Europe has greatly contributed to its more accurate representation in contemporary maps.

Age of exploration also witnessed the process of colonization of the 'newly discovered' world by European powers, and maps served as a prerequisite tool to navigate to these far lands and to acquire, conquer, expand and control their colonies. Parts of coastal India was first colonized by the Portuguese at the beginning of the 16th century and a century later by Dutch, British, Danish and French, and this also marks the beginning of rigorous mapping of the Indian coast and later the entire sub-continent. The following section discusses the cartographic skills, endeavours and achievements of these five colonial powers and their contribution to mapping the Indian coast.

2.3. MAPPING OF INDIAN COAST BY EUROPEAN COLONIAL POWERS

2.3.1. THE PORTUGUESE

With the knowledge gained from the discoveries and sailors of the East, Portugal became the European centre for geographical and cartographic knowledge in the 16th century, especially due to the contribution by the noble families of Reinel, Homem and Teixeira. The earliest Portuguese map of the then known world is Alberto Cantino's planisphere dated to 1502 (Afonso 1989). This map depicts Africa very close to its modern-day representation, but the Red sea, India and other Asian countries are marked with large distortion. However, in this map, India was represented better than in any other known contemporary or earlier European maps.

Portuguese nautical cartography (production of views, maps and charts) of the Indian coast can be broadly divided into three phases (Algeria et al. 2007) –1) from 1511 to 1533 during the time of Albuquerque, Francisco Rodrigues and Gaspar Correia; 2) from 1538 to 1580 when the most representative cartographers were João de Castro, Fernão Vaz Dourado, Diogo Homem, and Gaspar Correia; and 3) between 1610 and 1660 when the major cartographers were Manuel Godinho de Erédia and Teixeira Albernaz I. These phases are elaborated below:

Maps between 1511 and 1533: Under the governance of Afonso de Albuquerque in India, vast expeditions to identify strategic points to control trade over the Indian ocean were carried out. Francisco Rodrigues, one of the pilots in Albuquerque's fleet, copied and translated Javanese maps (it may be worth noting that Javanese were into map-making before the arrival of Europeans, however, no Javanese map of India was found during this study). Portuguese soon started making their own views, profiles and maps in 1511-12. The oldest Portuguese charts and coastal views and plans of India were made by Rodrigues and were included in a codex called 'Livro de Francisco Rodrigues' (Winter 1949; Algeria et al. 2007). Among these oldest maps are maps of the island of Goa, Diu and Gulf of Cambay. These are the places that Albuquerque sought to establish factories and fortresses. After the death of Albuquerque in 1515, cartographic activities of India went through a slowdown and resumed in 1538 till 1580, which again reactivated in 1610. However, bird's eyes views of some of the coastal sites were made by another important cartographer Gaspar Correia between 1513 and 1533. In his work '*Lendas da India'* published in 1563*,* he included nineteen views of coastal places important to the Portuguese, which he drew. Out of nineteen, eight were Indian sites, i.e. Kollam (Coulao), Calicut, Kochi, Cannanor, Dabul, Chaul, Diu and Bassein (Algeria et al. 2007). His illustrations depict only terrestrial elements and do not contain the nautical aspects such as scale and direction. Some of his drawings were made by him from his observations, while others were prepared using second-hand data.

Maps Between 1538 to 1580: João de Castro's cartographic accomplishments during his first voyage to India provided a new collection of original maps in 1538. He had a background in mathematics and literary education. He 'combined theory with observation and concrete experimentation' and had a great sense of graphic representation of reality (Algeria et al. 2007, 1015). He authored three maritime rutters– 1) the *roteiro* from Lisbon to Goa (April 6, 1538- September 11, 1538); 2) the *roteiro* from Goa to Diu (November 21, 1538- March 29, 1539); 3) the *roteiro* of the Red Sea from Goa to Suez (December 31, 1540-August 21, 1541). The original second *roteiro,* which has illustrations, profiles and bird's eye views of estuaries, harbours, forts and other prime locations in India, is lost. However, its facsimile was made in 1588 and later replicated in the 19th century (Algeria et al. 2007, 1015). In addition, atlas *Civitates Orbis Terrarum* published by German cartographers John Braun and Frans Hogenberg in 1572, contains maps of a few Indian cities obtained from unidentified Portuguese manuscripts (Braun and Hogenberg 1572).

Maps between 1610 and 1660: Following the Portuguese succession crisis, Spanish king Philip II became the ruler of Portugal in 1580-81, and this event is known as the 'Union of crowns' that continued until the restoration of Braganza in 1640 (Subrahmanyam 2007; Cueto 1992). This period had been a constant struggle for the Portuguese as their routes in the Atlantic faced threats by the English fleets, and the formation of the Dutch East India Company made their eastern voyages unsafe. Effect of these events has been noticed on their cartographic activities, which are said to suffer a slowdown for around three decades (1580-1610) and resumed again in c. 1610 (Algeria et al. 2007). However, the Portuguese central government was continuously demanding the information of places important to the Portuguese and knowledge of safe routes to India. The information was supplied to them in reports, route itineraries, maps and drawings (Algeria et al. 2007). Nevertheless, little is known about the maps made in the state of India during this time.

In 1610, Manuel Godinho de Erédia prepared a collection of plans of coastal places in India by order of the viceroy. Some of his maps of places in India made at different scales are published in *Portugaliae Monumenta Cartographica*. His technique seems to have innovation; however, not much is known (Algeria et al. 2007). João Teixeira Albernaz I, whose Atlas of 1630 is thought to have based his maps on the surveys conducted by Erédia as the former was aware of the latter's work. António Bocarro the author of the manuscript '*O livro das plantas de todas as fortalezas, cidades e povoações do estado da Índia Oriental'* also seem to have referred Erédia's map for there is a similarity between his text and a known map of Erédia; also, discrepancies are noticed between Bocarro's text and the figure accompanying it. He had also used maps supplied by Pedro Barreto de Resende to him. Eredia is regarded as the last 'creative' Portuguese cartographer in the East to perform surveys. Bocarro's map of 1635 (Map-54 in Appendix 1) is similar to Teixeira's map (Map-53), which looks like an artistic copy (with intricate architectural details) but does not depict map elements such as title, north arrow and labels as present in Teixeira's maps (Algeria et al. 2007). The six-volume Atlas *Portugaliae Monumenta Cartographica* (PMC) covers Portuguese cartography of more than two centuries (16^{th} and 17^{th} century) and provides vital information related to maps (Davies 1962).

Unfortunately, the study of Portuguese maps was limited by the inaccessibility of maps (particularly those made by important cartographers Rodrigues and Erédia) and the atlas PMC. Furthermore, the unavailability of the English translation of Portuguese Codices and itineraries made it difficult to relate the text with maps. Views and maps by Correia, Texeira and Boccaro were available online and thus, have been used for detailed analysis.

2.3.2. THE DUTCH

The 16th century witnessed immense circulation of printed and engraved maps and views of Portuguese origin, especially in the Netherlands and Italy (Algeria et al. 2007). Jan Huygen van Linschoten's[5] travel account of his first voyage to the east 'Itinerario' published in 1596 was the only detailed geographical account at the time of early Dutch expeditions and has been known as an eye-opener for the Dutch in terms of igniting interest by revealing immense potential and possibility of trade and commerce in India and Indonesia; also exposed the debilitating condition of Portuguese imperial empire. His book carries the five regional maps etched by Arnoldus and Henricus van Langren and one world map produced by Dutch cartographer Petrus Plancius in 1594. Among the five regional maps was one bird's eye view of Goa, which is considered as one of the most detailed views of Goa produced in history (Saldanha 2011).

Dutch seems to have taken a serious interest in cartography and production of maps by the mid of the 16th century. Jacob van Deventer's manuscript plans of Dutch towns, surveyed in 1555-75, is one of the earliest orthogonal representations of the topography of a town (Bendall and Speed 2002; Koeman and Egmond 2007). However, the style was first epitomized by the famous Italian artist Leonardo da Vinci in his manuscript plan of Imola of 1502 (Koeman and Egmond 2007). The Netherlands, in the last three decades of the 16th century, superseded Italy's cartographic industry and established itself with a strong scientific foundation and meticulous methods of compilation and presentation. In the 17th century, they became a key supplier of maps and atlases in the international

[5] Jan Huygen van Linschoten was a Dutch man; while working in Lisbon got an appointment for a post of accountant under the Portuguese Archbishop of Goa in 1583.

market. Map-trade in other western countries such as France and England developed more slowly (Humphreys and Skelton 1952).

The Dutch East India Company (*Vereenigde Oostindische Compagnie* or VOC) was established in March 1602. VOC's hydrographic department was divided into two branches. One, in their own country at Amsterdam - where renowned cartographers such as Plancius, Augustijn Robert (1608-17), Hessel Gerritszoon (1617-32), the Blaeu's family (1632-1705) and Isaac de Graaf (1705-43) were Company's official map-makers - producing charts and maps for the outward-bound ships. The other one at Batavia (present-day Jakarta, Indonesia), the Dutch trade headquarter in south-east Asia, where charts were supplied to the vessels returning to the home country or navigating to other trading posts. Gerritszoon compiled an atlas of maps of forts and trading posts of the East Indies on the Company's demand, which unfortunately has not survived. Originals of several of the Vingboons' collections and Van der Hem atlas are unknown; mostly, copies survive (Gunter Schilder 1976). Hem's atlas, which is in the Austrian National Library in Vienna, has few small to medium scale maps of the Indian coast and view of Dabul[6]; all of them were created by Vingboons. It is understood that Hem probably procured maps and views from Joan Blaeu. In 1691, Isaac de Graaf was given the task of copying maps to compile a newly updated atlas by the chamber at Amsterdam, which he completed after joining the Company's official cartographer post in 1705. His compilation titled – 'Atlas Amsterdam' was of great value to the Amsterdam Chamber. However, later in the 20th century, this atlas got disintegrated (Gunter Schilder 1976).

Maps surveyed and made by military engineers in the late 17th century and 18th century viz. Hans Georg Taarant, Pieter Gijsbert Noodt and Johannes Wilhemus de Graaf depict the important stretches of the Indian coast and the main settlement such as Quilon, Cranganore, Chetwai and Cochin with high accuracy (G Schilder and et al. 2006). However, the Company did not print its charts and pilots until the mid-18th century (Zandvliet 1987).

[6] This information is based on search in the online map portal- Atlas of Mutual Heritage (www.atlasofmutualheritage.nl/en), accessed on 16 Sep 2020. This website has 330 images from Van der Hem's Atlas.

Between 2006 and 2010, a seven-volume large comprehensive Atlas titled '*Grote atlas van de Verenigde Oost-Indische Compagnie'* or 'Comprehensive atlas of the Dutch United East India Company' covering all territories and possessions under the Charter of the Company from 17th and 18th century has been published (G Schilder and et al. 2006 -10). It contains facsimiles of maps, plans and views primarily from the Netherlands National Archives, Utrecht University and the Royal Dutch Geographical Society. The first and the sixth volume of this atlas with large numbers of medium and large scale maps, town plans and topographic views of the Indian coast are extremely useful for the present study. Dutch maps were also accessed from the online portal -Atlas of Mutual Heritage and National Archives, Netherlands.

2.3.3. THE ENGLISH

The English, like the Dutch, entered the European cartographic arena and East indies trade in the second half of the 16th century and beginning of the 17th century respectively. Before 1550, they were either not in the practice of using charts or were acquiring foreign charts and pilots, notably from Portuguese. Like Dutch, they were also publishing their maps in the manuscript form until the 17th century. However, they could not compete with Dutch publishers till mid-18th century (Tyacke 2007). The realization of the rich potential of the spice trade[7] and the fear of domination of the Dutch in European trade created an impetus for the British traders to form a union. In Dec 1600, the Queen granted a charter to establish the East India Company (EIC) (Riddick 2006; Shngreiyo 2017). The Company made its formal entry in India through Surat in 1608 and set up its initial factories in Masulipatnam, Andhra Pradesh in 1611 and Surat by 1612. In 1626 Masulipatnam became Company's first fortified factory in India (Riddick 2006). By the end of the 17th century, the English had their hold on Bombay, Madras and Bengal.

The activity to survey and publish maps and charts of the Indian coast by English hydrographers and cartographers is observed from the second half of the 17th century. The earliest notable cartographer/hydrographer was John Kempthorne, John Thornton, Samuel Thornton, John Seller and William Hack. The earliest English Pilot books

[7] Captain James Lancaster conducted a voyage around the Cape of Good Hope to India in 1591-94 and exposed the rich potential of the spice trade in East in his country (Shngreiyo 2017).

accompanying charts, plans and views of the Indian coast are John Seller's *Oriental Navigation, William Hack's A Description of Sea Coasts (*also known as Bucaneer's Atlas*)* and John Thornton's *The English Pilot: The Third Book,* published in 1675, 1690 and 1703 respectively (Dalrymple 1783; Bhattacharya 2004). On 1st April 1779, the EIC appointed Alexander Dalrymple (1737-1808) to a new post 'for examining the Ships Journals', which Dalrymple proposed in January 1779 to the Company, until then there was no formal system for official chart publication (Cook 1993). Dalrymple, the first 'Hydrographer to the East India Company[8], was involved in chart-making and collection of pilot books and charts before. However, he started meticulously examining and collating existing charts, pilots and ships' journals to produce and publish more cohesive, coherent and correct charts on safe navigation routes soon after accepting his responsibility as Admiralty Hydrographer. Apart from the work of Seller and Thornton, he constantly referred to work from foreign sources such as D'Aprea de Mannevillette's *Le Neptune Oriental* (French) and Van Kulen's *Zee-Fakkal* (Dutch). The other contemporary surveyors and cartographers whose work Dalrymple referred to or compiled in his atlas (of Indian coast) are John Mc Cluer, Lt. Skynner, Captain John Ritchie, Sir William Hewett, William Herbert, De Funk, William Stevens, Charles Knapton, Thomas Taylor, James Rennell. (Dalrymple 1783).

Parallelly, in 1767, James Rennell was appointed as Surveyor-General of Bengal. By 1774, Rennel completed a set of provincial maps, though the survey was found far from complete or accurate in details; nonetheless, his maps were one of the most accurate of the time. The Company soon realized an urgent need to have more accurate and detailed geographical knowledge of the country to facilitate its military operations and thus, appointed surveyors and engineers such as Charles Reynolds, Robert Kelly, Reuben Burrow, Michael topping, John Mather (Phillimore 1945). Lt. Gen Charles Reynolds and Col. Colin Mackenzie was appointed as Surveyor-General of Bombay (1796) and Madras (1810), respectively. The latter was appointed as the first Surveyor-General of India in 1815 (Edney 1997). Extensive surveys and astronomical observations were carried out in

[8] The title 'Hydrographer to the East India Company' was first use by Dalrymple for his newly appointed position, though this position never found in the Company's salary book (Cook 1993). He was simultaneously serving as Hydrographer to the Admiralty.

a strategically important areas and unknown territories. Detailed maps of rivers and military routes were also produced. The marine service also conducted special surveys of coast and estuaries. By the end of the 18th century, revenue and topographical surveys were conducted; the use of theodolite was also commenced. From 1802, the Great Trigonometrical Survey was initiated by Col. William Lambton. This marks the beginning of the first modern scientific production of highly detailed and accurate topographical maps of Indian territory (Edney 1997).

In 1810, James Horsburgh was appointed as Hydrographer to the Company, and his service ended with his death in 1836. During the same time period, the Admiralty Hydrographic Office was also publishing charts of the East. In 1861, the hydrographic surveying activity of the then Government of India was transferred to the Admiralty Hydrographic Office (David 2008). The Office, initially republished Horsburgh's charts and later started publishing large-scale admiralty charts as the use of steam propulsion enabled vessels to navigate much closer to the coast and thus, created a demand for detailed maps of the coast (David 2008). Usually, large-scale charts are published as an inset in the small-scale charts. In 1874, the Indian Marine Survey Department was established in Calcutta. The department continued to carry out its service after India's independence from the British. In 1954, the department was relocated as Naval Hydrographic Office to its present address in Dehradun and continues publishing up to date charts[9]. British had thoroughly mapped almost the entire subcontinent and produced very detailed and accurate maps at different scales.

2.3.4. THE DANISH

Following the success of Dutch and English East India Company in the spice trade, Danish also endeavoured in establishing commerce with the East. The charter to create a Danish East India Company was issued in 1616, the first expedition to the East began in 1618, and in 1620 they obtained permission to construct a fortress at the village of Tranquebar (Tarangambadi) (Subrahmanyam 1989). Unlike the Dutch and English, they were limited to a few sites in India's east and west coast, viz. Masulipatnam, Dannemarksnagore,

[9] https://hydrobharat.gov.in/home/brief-history/ (accessed on 25 June 2021)

Serampore, Balasore, Pipli, Calicut, Colachel and Oddewat Torre (Dörnbach 2005). Danish had gained expertise in the cartographic representation of the land by the 16th century. However, for navigation, they were dependent on Dutch rutters and British charts and had a close relationship with the former. By the mid-17th century, Danish had acquired expertise in mapping and printing large-scale maps of the Nordic world. For the Indian coast and territory, there are very few Danish maps and views (Mead 2007). We find a two-section map with a plan and a view of Tranquebar Fort produced by Matthias Seutter from an original map of 1671 by Jacob Storzel; a large-scale map of Danish land around Tranquebar produced by Matthias Seutter in 1744; a large-scale map of land parcels of Serampore from 1762 and few more views of its colonies.

2.3.5. THE FRENCH

France was the last country to arrive in India among the European colonial powers, though attempts to establish a French India Company were made from 1604. In 1644, the French East India Company (*Compagnie française pour le commerce des Indes orientales*) was formed by the French King Louis XIV and established its first step in India by acquiring trade rights at Surat in 1666. The Company made rigorous attempts to procure trading rights competing with the English and Dutch and expand its trade volume with India. In this process, the Company established its factory at Surat, Rajapur, Mahe, Karaikal, Yanam, Pondicherry, Masulipatnam, Tellicherry and Mirjan (Kadam 2005). Among the noteworthy French Travellers who produced precious information about India are Francois Valentyn (who visited India and published his voluminous work accompanying his maps in 1726), Jean Thevenot, Francois Bernier, and Tavernier. The latter three arrived in the mid of eighteenth-century (Madan 1997; Kadam 2005).

In the 17th century, France produced maps by borrowing information from foreign maps and the information sent home by missionaries. For example, Je Sieur Sanson d'Abbeville (described as a pioneer of geography in France by Clement Markham) produced a map of the Indian peninsula published in 1652 (Phillimore 1945). However, till the end of the 17th century, France was mostly reliant on the Dutch for nautical charts. France produced its own first national maritime atlas *Le Neptune François* in 1693 (Petto 2015). Jean-Baptiste-Nicolas-Denis d'Apres de Mannevillette, Jean-Baptiste Bourgignon d' Anville, Pierre Joseph de Bourcet[10] and Jacques Nicolas Bellin are among the famous French cartographers who mapped the coast of India and important colonial forts along the coast.

D'Apres, who started collecting charts and memoirs on the Indian ocean from 1735, prepared and published his atlas *De Neptune Oriental* in 1745. His maps were corrected by Jean-Francois Denis de Trobriand, and his revised edition was published in 1775 (Filliozat 1994). The maps produced by D'Apres and D'Anville are considered of a good standard and was adopted by English cartographer Dalrymple and Renell in their work and are said to have replaced the 17th century's pilot by English cartographer Thornton and charts by the Dutch hydrographer Kuelens (Cook 1993; Filliozat 1994; Chester 2000). However, from a practical point of view, D'Apres' *De Neptune Oriental* was considered faulty and dangerous for navigation by the French Admiralty (Filliozat 1994).

J. N. Bellin was considered a serious scientific cartographer and known for using the most reliable information (Madan 1997). He produced maps and charts of India in the 1760s and 1770s. His Atlas *Petit Atlas Maritime,* published in 1763, includes 18 maps of the India’s coast. Bellin has also been found producing copies of about a century-old Dutch maps, and in some cases, he produced mirror-reversal copies of plans of fortified cities (for detail ref. Section 5.2.3.2.3 in Chapter-5 and Map-62-66). Not much is known about Bellin from Dalrymple and Renell, who appreciated his contemporary cartographers D'Apres and D'Anville. We find Bourcet's map titled *Theatre de la Guerre Dans l'Inde sur la Coste de Coromandel (1770)* represents southern Coromandel coast and the interior areas which was a theatre of the Carnatic and the first Anglo-Mysore war during that time (ref. Map-75). This map (which is a collage of several maps) provides plans of nineteen fortified cities that were important during the war. The maps look very similar to the ones produced by Bellin and are most likely copies of his work. However, it is difficult to comment on how these French maps were created, copied and circulated. The French maps of the sites studied in the present thesis are found exemplary in the negative sense

[10] Bourcet was the Chief French military engineer and chief of fortification in Pondicherry, the headquarter of French East India Company.

and have been pointed out for their flawed character, which is based on the limited maps available for the present study.

2.4. DEVELOPMENT IN CARTOGRAPHIC TECHNIQUES

Following the rediscovery of Ptolemy's *Geography* in the first half of the fifteenth century, cartographic activities such as collecting and calculating the coordinates using astronomical methods became prevalent. Soon after, it was realized that these coordinates alone are of little use to measure the geographical location of spatial objects in close vicinity and hence, insufficient to produce a large-scale map. At the same time, there was an increased interest in Europe for education, especially for mathematics, geometry, astronomy and geography, that encouraged the establishment of new universities there. This period also corresponds to the beginning of the age of exploration that led to further improvement in navigation techniques and nautical charting.

The advancement in cartography occurred in two ways: 1) large-scale mapping of the smaller area such as a town, city, fort, river estuary, through land surveys; and 2) improvement in charting of sea and coast by measuring latitude and longitude acquired with their best knowledge. These two parallel signs of progress are discussed in some detail as follows:

2.4.1. LAND SURVEYS (TERRESTRIAL METHODS)

The concept of field survey was known during ancient times. The Romans relied on squares and rectangles for the measurement. The idea of using Euclid's Elements and adopting the principles of triangles for the land measurement was effectively propagated by Sebastian Münster in the fifteenth century. He also proposed joining survey maps to cover a large area (Koeman and Egmond 2007, p1260). His contribution laid the foundation of the early modern triangulation method for land surveys that consist of a combination of geometrical components from Euclid's *Elements* and trigonometric functions. The most thorough explanation on constructing a map using astronomical and terrestrial principles, necessary instruments, and land measurements was provided by Gemma Frisius in 1533, which became a widespread manual for map-makers and instrument makers of the 16th and 17th centuries. Gemma's work was just one step behind the invention of the surveyor's plane table. Although the theoretical framework of mapping based on the triangulation network was known by that time, the observational practice remained a challenge until the 18th century due to hard outdoor conditions and the unavailability of easy-to-use mapping instruments. Therefore, we find very few maps in the fifteenth, 16th and early 17th century based on triangulation. In India, the earliest maps based on triangulation surveys were made by the Dutch military engineers and cartographers (such as plan maps made by Hans Georg Tarrant) from the second half of the 17th century. Before that, for representing a small area such as a town, city and fort, we mostly (or only) have geographical drawings in the form of bird's eye views and landscape paintings that are eyewitness evidence of the time. At the beginning of the 19th century, high-quality revenue and topographical surveys were carried out using both astronomical and triangulation methods. The military route surveys were also used as the basis for the maps. Soon, with the availability of theodolite (a sophisticated surveying instrument), folding chain method to measure the distance with great accuracy and under the strong leadership of British officer William Lambton, the Great Trigonometrical Survey was undertaken. These maps are considered as one of the most accurate terrestrial maps produced ever through ground surveys.

2.4.2. NAUTICAL CHARTING

Nautical charts or sea charts are different from the terrestrial charts in their geneses and evolution. The former has developed independently much earlier than the latter. The earliest nautical charts, also known as Portolan charts (ref. section 2.2.4), are examples of Middle-Age ingenuity for their cartometric accuracy. There is still no unanimity on views of its method of construction. According to the latest cartometric study, the makers of these portolan charts knew a projection similar to the Mercator's projection (discussed below); however, the use of compass was limited to establish the orientation of the charts (Nicolai 2015). If that is true, then the network of lines present in these early charts were true rhumb-lines[11] and not just the wind-roses[12]. The distances were measured by

[11] Rhumb-line is an imaginary line that intersects all the meridians at a same constant angle on the globe, as a straight line on the map (with Mercator's projection)
[12] The most common view is that the network of line in the early sea charts was wind-roses where directions were referred to the prevailing winds until the magnetic compass came into the use. After the introduction of the magnetic compass, such networks were understood as compass-rose.

dead-reckoning[13]. However, this scientific method of constructing very accurate nautical charts did not reach the cartographers of the subsequent centuries and has been lost forever.

In the fifteenth century, the Portuguese introduced the science of astronomical navigation and determined latitude from the position of stars using hand-held measuring devices such as quadrant, astrolabe or cross-staff (Campbell 1987). Subsequently, measurement of latitude became more accurate with the invention of back-staff, octant and the sextant. Longitudes were determined by calculating the angular displacement of the moon from other celestial bodies and later in the 17th century from the observations of the eclipses of Jupiter's satellites. It involves tedious calculation and high chances of great inaccuracies in lunar tables. In the 18th century, following the invention of the chronometer by John Harrison and fifty years of its improvements, accurate determination of longitude became possible (Gunter Schilder and Hans 2010). By the fifteenth century, knowledge of variation between true north and magnetic north was known (Bhattacharya 2004). In the mid-16th century, Gerardus Mercator introduced the method to project the three-dimensional earth into a two-dimensional flat surface (with some degree of distortions), which because of its ease of use in navigation, became very popular as Mercator's projection. By the 16th century, mariners started keeping logbooks with astronomical observations (Andrews 2009). These sailors' logs were used as direct input for chart making. By the end of the 18th century, the widespread use of improvised instruments (such as quadrant, sextant, octant, astrolabe, high-quality chains, perambulators, circumferentors, azimuth compasses, pocket chronometers and theodolite) under the supervision of motivated hydrographers, engineers and surveyors led to extensive and the most accurate surveys (coastline, topographical, revenue and route) in the 19th century. At the same time, colossal efforts were taken to update, compile and produce large number of charts and maps at different scale.

[13] Dead-reckoning refers to a method to estimate the position in terms of the direction and distance traveled.

2.5. TYPES OF HISTORICAL COASTAL MAPS

The available historical cartographic material (mainly in the context of the Indian coast) can be broadly divided into the following categories:

2.5.1. SMALL-SCALE OR LONG-RANGE NAUTICAL CHARTS

Mariners used long-range nautical charts for long-distance navigation across the sea/ocean. They depict the coastline of the intended place with the important ports, coastal cities, landmarks, islands, estuaries, and lagoons. In addition to these, the charts include title, explanatory note, wind roses (present in the earlier charts), compass roses, scale with description, latitude coverage, longitude coverage (in the later period chart) and sometimes profile view of a few stretches of the coast. For instance, a map of the northern part of the Coromandel Coast by Mannevillette, Jean-Baptiste-Nicolas-Denis (1707-1780) is an example of a small-scale chart (ref. Figure 2.2).

Small scale charts can broadly be classified into- 1) the plane charts which are true neither angle-wise nor distance-wise, yet the most popular in the fifteenth and 16th century; and 2) the Mercator charts (also known as the Mercator projection map of 'increasing latitude') in which all the lines of constant bearing (rhumb-lines or loxodromes) are straight lines that could be followed easily based on a single compass setting (corrected to magnetic declination) to navigate from the point of departure to the point of destination (Synder 2007; Gunter Schilder and Hans 2010).

The small-scale charts are not very useful for the detailed research work undertaken in the present study. However, they are important to understand the larger spatial context, presence-absence of bays, headland, islands, tombolo and other geomorphic features, especially when there are not many maps available for the given time and place. Thus, they must not be disregarded without any assessment.

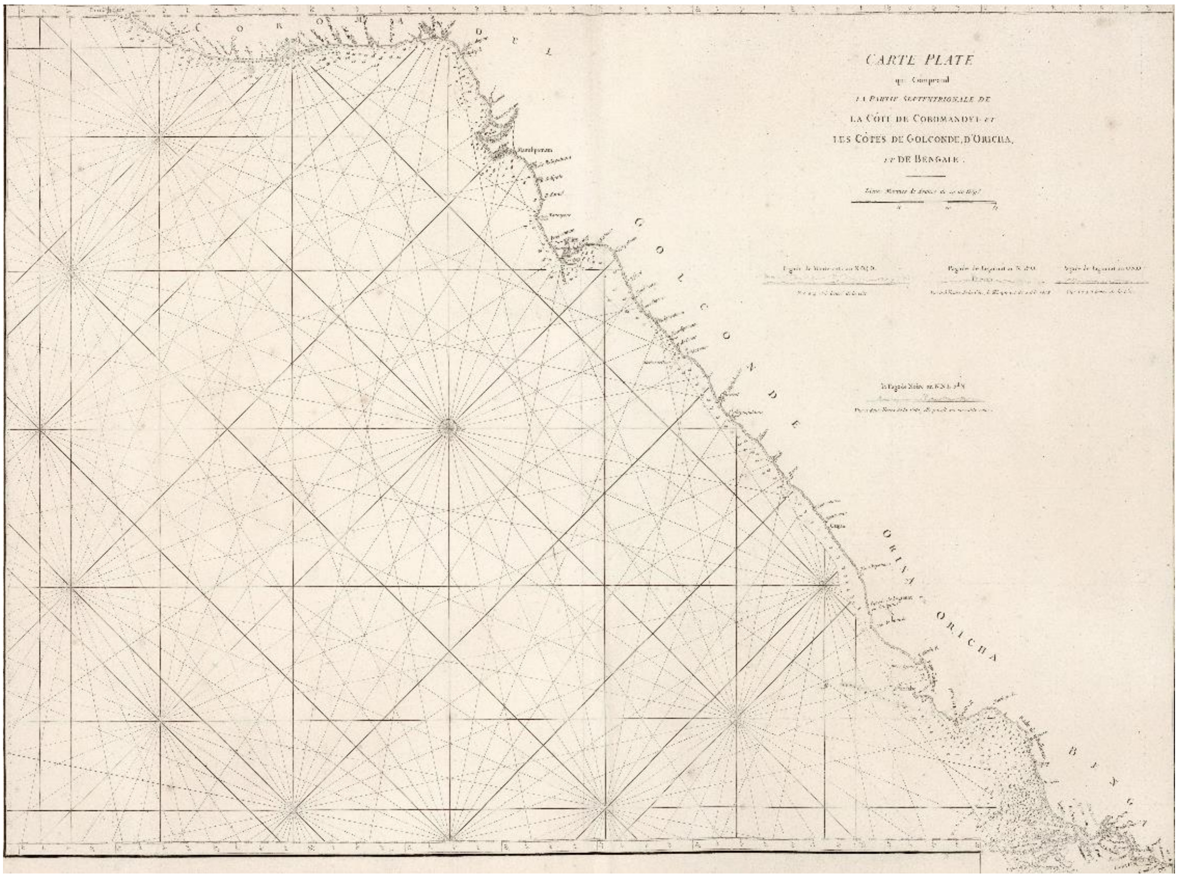

Figure 2.2. Long-range or small scale chart, 1810 (north is down). ©David Rumsey Map Collection, David Rumsey Map Center, Stanford Libraries (for source: refer Appendix Map-74)

2.5.2. COASTAL VIEWS

Depending upon the viewpoints used in representing the landscape, coastal views can be categorized into oblique/bird's-eye view and profile view.

Oblique/bird's-eye view illustrates coastal towns, ports and cities with a low angle aerial or bird's-eye perspective that 'requires a mathematical construction and an understanding of perspective geometry in which positions on a planimetric map are plotted onto a perspective grid' (Woodward 2007b). The oblique view is also suitable for representing the built structures in three dimensions and topographical undulations on a flat surface in a 'lifelike manner' (Nuti 1994; Woodward 2007b, 16). For example, bird's-eye view of Casablanca, Azemmour, Diu, Goa, by Georg Braun (1541-1622) and Franz Hogenberg (1539-1590) (ref. Figure 2.3). There was a general preference for the oblique view over planimetric views in the 16th century. Later, interestingly, these two forms were merged to give a hybrid map with a plan view and an oblique and 3D depiction of the built structure on it (Nuti 1994). An example of this hybrid category is Albernaz, Joao Teixeira's map (ref. Figure 2.4)

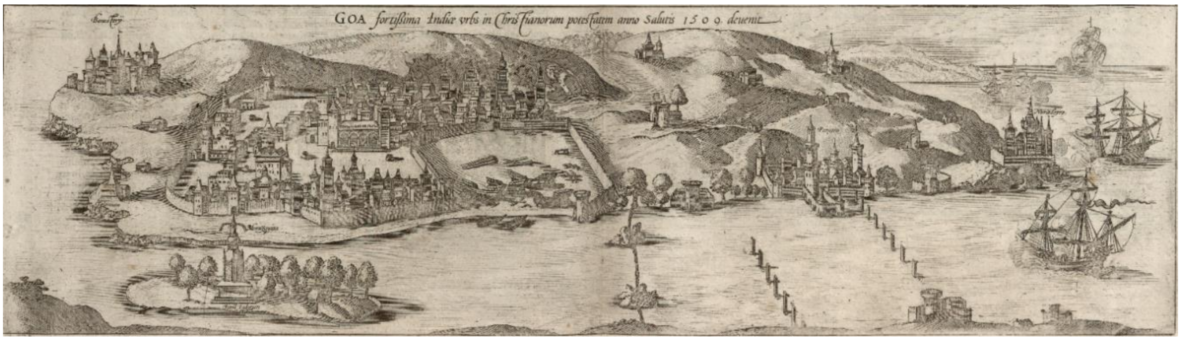

Figure 2.3. Bird's eye view of Goa, 1575. ©David Rumsey Map Collection, David Rumsey Map Center, Stanford Libraries (ref. Appendix, Map-48)

Figure 2.4. A map of Covlao (Kollam) in Albernaz et al., 1630 (Geography and map division, Library of Congress, USA) (ref. Appendix, Map-53)

Profile views depict a side view of the coast as observed by sailors approaching land showing mountain range, trees and buildings, which can be in the form of a simple outline of the profile of the coastal features (natural and artificial) or a descriptive painting. Apart from the information of how a land looked at the time it becomes first visible above the horizon, coastal views also describe the topography of the place, position of the landmarks concerning each other, and show 'commodious places to land, or for wooding and watering' (ref. Figure 2.5). The use of the non-photographic camera (camera obscura), in the 16th century, made it possible to trace the projection of the perceived view falling on a vertical surface by light-rays passing through a small hole on a screen, which with the help of a lens and a mirror could be projected at a more convenient scale on a horizontal surface. A more convenient and portable device called camera lucida came in the 19th century that can directly project the image onto the horizontal surface by just adjusting the mounted lens. However, it is difficult to know if a view was made using these devices or free-hand, but this suggests that they were serious about the true depiction of the landscape.

While expressing disagreement to the 'absurd notion' of the uselessness of these coastal views, Dalrymple writes 'Can the best mode of expressing the forms and appearance of land, which are essentially necessary to be known, be useless? Perhaps no man has in words a competent power to describe the marks of land' (Dalrymple 1783). As rightly pointed out by Dalrymple that words can perhaps never express what a single view of a place can, and hence, are an important source of spatial information of the place and time they represent. In the present study, these views have been found highly valuable for archaeological studies.

Figure 2.5. Profile view of Jaggannath temple, Orissa coast, 1810. ©David Rumsey Map Collection, David Rumsey Map Center, Stanford Libraries

2.5.3. PLAN MAPS OR TRUE PLAN VIEW

Plan maps here refer to the large-scale two-dimensional plan of coastal cities and towns, depicting the area of interest as viewed from directly above the ground. They are drawn to a constant scale. Sometimes elements present in a landscape such as buildings, streets and the layout of a fort or town are represented from different views, i.e. buildings are depicted in three dimensions (as seen in an oblique view) on a background of a planimetric view of a town. Generally, plan maps depicts the layout of colonial forts already existing or in the form of blueprint and were essentially produced by architects and military engineers. Some of the proposed designs of the fort layouts were never executed in reality and hence, should be not be called maps. By the 17th century, the adoption of true plan view became more common (Delano-Smith 2007). For example, a map of the Kollam fort (1687) by Hans Georg Tarrant is a correct plan map with a detailed layout based on planimetric measurements (ref. Figure 2.6) Some of the large-scale charts are also titled as 'plan'. Thus, to avoid confusion in further discussions, the term 'plan' is used exclusively to refer to the ones explained in this section.

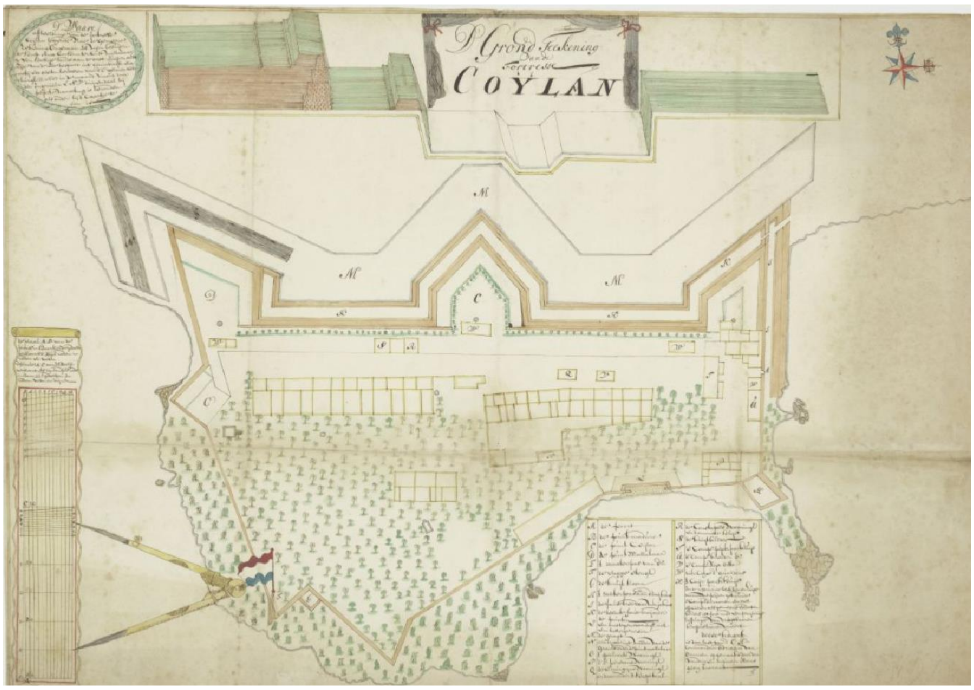

Figure 2.6. Plan map of Kollam (Quilon) Fort, 1687 © Nationaal Archief, Netherlands (ref. Appendix, Map-57)

2.5.4. LARGE-SCALE OR SHORT-RANGE SEA CHARTS

These are the large-scale navigation charts representing a smaller area, mostly around the ports, harbours and river estuaries, with a good amount of detail. Most often, they have soundings, marking of important buildings, the shape of the coastline and depositional features. Large-scale maps cannot be produced from coordinates alone (Lindgren 2007). Instead, they were produced through triangulation surveys using the bearing compass, steering compass and speed log. An example of a large-scale sea chart is the map of the Bay of *Cochin River* surveyed by Lt. A. Channer (ref. Figure 2.7).

Figure 2.7. Large-scale chart of Kochi (Cochin) River (ref. Appendix, Map-31)

2.6. CONCLUSION

The peninsular shape of India was mapped using astronomical methods as early as the 3rd century BCE. However, the detailed and extensive mapping of the Indian coast commenced during the colonial period. Colonial powers produced various kinds of cartographic records that include small-scale (long-range) nautical charts, coastal views, plan maps, and large-scale (short-range) nautical charts. Portuguese were the earliest to map the most accurate representation of the Indian coast. They produced and published maps and views of the Indian coast and port towns from the early 16th century to the early 17th century, after which the Dutch became the masters. Dutch mapped the Indian coast from the late 16th century to the 18th century and produced high-quality sea charts and plan maps. In the 17th and 18th centuries, the French also contributed to the mapping of the Indian coast. Around the same time, Danish too produced few maps; mostly, of their colonies. The large scale maps, views and plans made by the Portuguese, Dutch, French and Danish were mostly limited to the coastal sites they were interested in. Therefore, those regions have great potential for early map based studies. In the 19th and 20th centuries, the British dominated the survey and mapping of the coastal regions and the Indian territory. With highly advanced cartographic techniques and strong leadership, they produced maps of different scales with great accuracy. Their maps are very useful for the quantitative analysis of shoreline change. With the limited space assigned in this thesis, this chapter could present an overview of this vast topic. More research needs to be done on the production and content of maps produced in the late medieval and early modern periods.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

"...even if we accept the need to work out a methodology for early maps - in the sense of a simple procedures and rules - it is very doubtful if they will be applicable in all cases. All too often a theoretical method is irrelevant to the particular map, and there may be no substitute for the judgement, intuition commonsense of the moment."

-J. B. Harley, 1968

Historical maps are convoluted spatial records and, thus, difficult to study. Before working on a research design and methodology, it is imperative to be aware of all the possible flaws maps can have. Therefore, this chapter is segmented into two parts. The first part discusses the challenges and critical issues of studying early maps as a source of historical information of the physical and cultural aspects of the coast [14]. The second part presents and explains a comprehensive research methodology that integrates the theoretical understanding discussed in the first part, methods adopted from different disciplines, and new methods proposed and executed in the present study.

3.1. CRITICAL ASPECTS OF MAPS: ERRORS AND ACCURACY

As already discussed in Chapter-1, maps are not exactly conformal to truth rather equivocal and fallible by design. Maps represent distorted reality – to represent the complex three-dimensional world into a two-dimension; to scale down the spatial entity

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[14] A part of this section has been published in Gupta & Rajani (2020a).

on a sheet of paper; and to ensure the readability of maps, they present selective and incomplete view of the area of interest (Monmonier, 2018). Moreover, the complex process of map-making introduces errors at every step from survey to production and reproduction. The type and magnitude of errors vary depending on various factors. A map user should be aware of the accuracy of maps in hand and know the factors that cause errors. Therefore, this section is dedicated to this very important aspect of maps and discusses the factors that lead to errors in maps as follows:

3.1.1. TECHNOLOGY

The expansion of the knowledge of world geography and the progress in cartographic techniques had intensified at an accelerated rate after the 14th century. Historical maps before the 18th century were made with very limited geographical knowledge, primitive surveying methods and nonstandard cartographic techniques (Humphreys & Skelton, 1952). Cartography steadily improved in its methods, techniques and standards in the 18th century. By the 19th century, cartographic techniques have made significant advancements (for detail ref. Chapter-2).

Though technical advancement in cartography follows a chronology, its adoption and use are not parallel to it. Instead, show some lags for various reasons such as availability of instruments, skills to use them, the purpose of the map, willingness to adopt new technology. Therefore, it is even more difficult to gather information on survey methods, the competence of the surveyor, and the skill of the cartographer. Information about these aspects that can be gathered from the text accompanying the sea charts; if available, can provide some understanding of maps' content, possible errors and its limitations. For instance, A. Dalrymple (1783), in his atlas *General Collection of Nautical Publication* acknowledges the limitations of charts in terms of accuracy at his time and writes:

> […] I am so sensible from experience, that *Oversights* will happen, notwithstanding all *possible attention,*[...] What I have here said may *discredit* the *charts published* by *me* as *defective* and *erroneous*: I can only say I would much rather that the *Publick* should be *disappointed,* by finding them *better* than was *expected*, than by *finding* them *worse*; [...] Many men will at random condemn a *Chart*, constructed on the *most precise Bearings*,

> without having themselves laid down *even* a *rude sketch*, or perhaps without having made *Observations* sufficient for the purpose. No man is *competent* to *judge* of the *merit* of a *Chart* who never made *One*; the more *Practice* any man has, the greater will his Candour be, on perceiving mistakes to which all men are liable.

This scenario is most likely to be true for all the early charts made before the 19th century. It is important to understand the technological expertise and limitations of the time before using the maps as a source of historical information.

3.1.2. PURPOSE

The accuracy and quality of a map get affected based on the purpose they are made for. Maps made primarily for furnishing hydrographic/topographic information to the seamen, travellers, army/navy are likely to be the most accurate to the cartographer's best knowledge for the purpose of navigation. On the other hand, the maps produced for people interested in using them to beautify their walls, chambers, galleries and libraries are likely to be more artistic than being geographically precise. Map-makers preparing maps for business purpose hardly cared for their authenticity. Moreover, there are instances where charts were produced to misguide the Mariners (Humphreys & Skelton 1952, 9[15]). Even the hydrographic charts considered to have up-to-date information may not have uniform accuracy for the entire coastline; coastline and channels that were of prime interest are likely to be more accurate (Carr, 1962). Lt. James Cook, while commanding *the Endeavour* on his first Pacific Voyage in 1770, carried the last edition of *The English Pilot the Third Book*. He sailed to Java using one of its charts and was impressed with its accuracy and stated- "a very good chart" in which "everything is very accurately delineated" (Thornton, Seller, Verner, & Skelton 1970). Remember Cook was a sailor, and accuracy for him primarily means accurate direction, notable landmarks, and relative locations. His comment on accuracy may not hold while considering the planimetry of the map. Here, it would be apt to give an example of the modern schematic

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[15] Although largely (Author, date) format is used in this dissertation, for a few references (Author, date, page number) has been given for ease of readers, especially in the cases where the author had difficulty in finding these.

guide map of London Tube designed by Harry Beck in 1933, which with several more edition has evolved into what it is at present. London tube map or Delhi Metro map is geographically inaccurate but provides the correct relative location of tube/metro stations and lines, therefore they are accurate and convenient for the purpose they are made. Therefore, it is crucial to know who made a particular map and for what purpose it was made.

3.1.3. CARTOGRAPHIC MIS/REPRESENTATION

Today, accuracy is perceived in a very strict sense of true geographic coordinates. However, for a practical user such as a sailor, accuracy can mean just a true bearing on maps and representation of the coast as viewed from offshore that may not have true coordinates.

In historical maps, sometimes we find scale variations within a single canvas, especially in small scale maps. Important locations, in some cases, are depicted larger than what they should be with the given map scale. Based on the importance of the places, variation in scale has been referred to as the 'scale of importance' (Gole 1976). For instance, in some of the 17th & 18th century's maps, the depiction of the Gulf of Kutch, Gulf of Khambhat, port city of Goa and Kochi is disproportionately large for better representation.

3.1.4. THE ERROR OF COMMISSION AND OMISSION

Another important point to note is the error of commission and omission. It refers to unintended inclusion (commission) and exclusion (omission) of spatial object or feature on map. Such errors can occur due to false perception and misinformation. Perceptions are usually based on our previous experiences, and we tend to relate things with our prior knowledge. Such perceptions sometimes lead to deception. John Bryon shares one such experiences in his journal of circumnavigation (1764-1766), where he and the men onboard mistook a fog bank for a landmass with a great degree of certainty. Their preconceived brains saw an island with two scraggy hummocks and an extended landmass, and many of them even saw the breaking of waves upon sandy beaches off the coast of Brazil in 1764. They thought to have found blue hills, as it sometimes appears from a distance in dark rainy weather. However, after travelling quite a while towards that, they found nothing but a fog bank. Such illusions sometimes find a place in maps without ground validation (Andrews 2009). Therefore, one needs to consider such issues when studying these maps.

3.1.5. ORIGINALITY AND TEMPORAL CONTEXT

As mentioned earlier, map-making in earlier times was a complex process that involves several skilled people such as surveyors, draughtsman, engravers and publishers. The information collected by surveyors is the primary data and, hence, considered original. It is not necessary that a map was compiled only from the original source and published immediately after the survey. In many cases, they are found to be published after many years of the survey. In addition, there is much ambiguity on the information about the map's original survey date, if they are compiled only from the original survey notes or are the amalgamation of different maps published at different time.

When engraved copper plates were used for producing copies of the maps, map-makers use to make money by selling the impressions from obsolete plates (Humphreys & Skelton 1952, 8). Sometimes, old plates were updated and then used to produce new maps. For instance, John Seller, known as a famous map-maker, compiler and publisher of his time, had refreshed a worn Dutch copperplate he bought for old copper (Humphreys & Skelton 1952, 8). Some of the famous early cartographers are accused of copying from one another and introducing more errors. There are examples of copying error in maps made in the 18th century by chief French cartographer and hydrographer J. N. Bellin, who reproduced and published maps of few colonial forts in India several times (in different years) as a mirror image (ref. Appendix, Map-62-66). Therefore, the originality and temporal context of maps are important to consider. Efforts should be made to fetch the metadata on the cartographer and engraver of the maps.

3.1.6. PHYSICAL DEFORMATION OF THE MAPS

Colonial maps are around a hundred to four hundred years old. The paper or the medium used at that time to draw or print a map was itself 'unstable'. The paper of maps goes through uneven expansion and contraction due to changes in the temperature and humidity that distort the maps (Carr, 1962). It may not be a problem if these physical changes on paper occur uniformly in all directions as that would only change the map scale and can be easily handled in mapping softwares. Unfortunately, these changes are not the same in both directions as the paper tends to shrink more along the grain than across the grain. Not only that, older maps may also have defects due to folds and creases including tears (Crowell et al., 1991).

From the above discussion, it may appear that maps are highly subjective and full of various kinds of errors and hence, could be an unreliable historical source to understand the past. This may be true for many of the maps but not for all. Therefore, it would be inappropriate to disregard all historical maps without attempting to study them for the reasons discussed in Chapter-1, Section 1.2.

3.2. RESEARCH METHODOLOGY

There are three broad aspects in the present work- 1) understanding past geomorphological changes using old maps and satellite images; 2) identifying unknown archaeological remains using the same; and 3) studying the former in relation to the latter and vice versa. The present methodological framework integrates these three aspects and allows a coherent study.

Historical maps in archaeological context are generally and broadly studied (though not strictly owing to the uniqueness of each site) using the following steps: 1) Data exploration and acquisition; 2) identification of common points (also known as Control Points) between the map and the satellite image/ ground; 3) Georeferencing of old map using Control Points; 4) overlaying of georeferenced map on a satellite image; 5) incorporating other documents such as paintings and historical texts; 6) understanding and interpreting the archaeological context (Rajani, 2021). The present thesis follows this method. In addition, the present study emphasizes the need to critically evaluate context and content of the historical maps.

In the context of geomorphological studies, the present work identifies strength in the older approach used by Oldham (1925), Boer & Carr (1969) and the lacunae in the modern approach (ref. Chapter-1, Section 1.3.3). Oldham’s method follows basic and standard steps (already discussed in Chapter-1) essential to study early coastal maps. However, at that time, modern techniques such as GIS and remote sensing were not available and hence, their approach was limited.

The study of coastal changes using early maps in the GIS platform involves georeferencing maps and measuring the distances between digitised shorelines (Levin, 2006). There are certain challenges in georeferencing old maps, particularly coastal maps and charts. To georeference a map accurately, we need to correctly identify Control Points (CP) (ref. Section 1.3.2. in Chapter 1). However, coastlines continuously change and most of the coastal maps and charts depict mostly dynamic features such as shoreline, islands, estuaries, creeks and lagoons. Absence of fixed identifiable features (CP) in most of the coastal maps and charts make it impossible to correctly georeference them. Keeping this limitation in mind a fresh methodology has been proposed in the study. The methodology presents ways to analyse non-georeferenceable maps in more logical and systematic ways and methods to integrate heterogeneous sets of historical spatial data with the help of remote sensing and GIS. It also provides techniques to validate maps' content.

The study is largely empirical in approach and inductive in reasoning that assumes maps correspond to the ground reality of the time in a simplified, reduced and abstract form and can be validated. However, the approach also acknowledges the subjectivity that lies in the content of maps and attempts to understand the context of the maps. Refer to Figure 3.1 for the summary of the methodology.

3.2.1. ARCHIVAL WORK AND DATA ACQUISITION

The data used in the present study and their sources are discussed below:

3.2.1.1. Types of data

Data required for this study are of four types: 1. Historical maps and sea charts; 2. Coastal profile views and landscape paintings; 3. satellite images (Multispectral images–LiSS III and Sentinal-2, multi-time high-resolution image) and 4. Historical written records.

3.2.1.2. Sources of data

Historical maps, charts, paintings and views of coastal India, and the written documents related to that, exist in various archives in India and in other countries (such as British Library, London, National Archives, Netherlands, Leiden University Libraries, National Library of France,). With the expanding digital web facilities, many libraries and archives (such as Library of Congress, Atlas of Mutual Heritage, OldMapsOnline, National Archives of Netherlands) provide easy access to high-resolution digital copies of historical maps. The list of archives and libraries visited, and websites frequently referred to in the present study for the acquisition of old maps and historical record are compiled in Table 3.1.

Table 3.1 List of Physical and Digital Archives and Libraries.

Archives in India	Archives in England	Digital libraries and archives
Krishnadas Shama Goa Central Library,	British Library, London	Library of Congress[16]
Directorate of Archives and Archaeology, Goa	Bodleian Library, Oxford	Atlas of Mutual Heritage[17]
National Institute of Oceanography, Goa	Caird Library and Archive London	National Archives of Netherlands [18]
Deccan College Library, Pune	Royal Geographical Society (RGS), London	Kalakriti Archives, Hyderabad[19]
Maritime Museum and Library, Pune	National Archives, London	OldMapsOnline[20]
Nehru Memorial Museum and Library		Internet Archive[21]
National Archives: Delhi and Pondicherry		Biblioteca Nacional Digital[22]
National Hydrographic Office, Dehradun		Barry Lawrence Ruderman Antique Maps[23]

Satellite images have been acquired from ISRO's Bhuvan (LiSS III), USGS Earthexplore (Corona and Sentinel-2) and Google Earth Pro. The name of the satellite data with their source is given in Table 3.2.

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[16] https://www.loc.gov/maps/
[17] http://www.atlasofmutualheritage.nl/en/
[18] https://www.nationaalarchief.nl/en/research/search?activeTab=map_legacy
[19] https://artsandculture.google.com/partner/kalakriti-archives
[20] https://www.oldmapsonline.org/
[21] https://archive.org/
[22] https://bndigital.bnportugal.gov.pt/
[23] https://www.raremaps.com/category/Maps/Asia/India

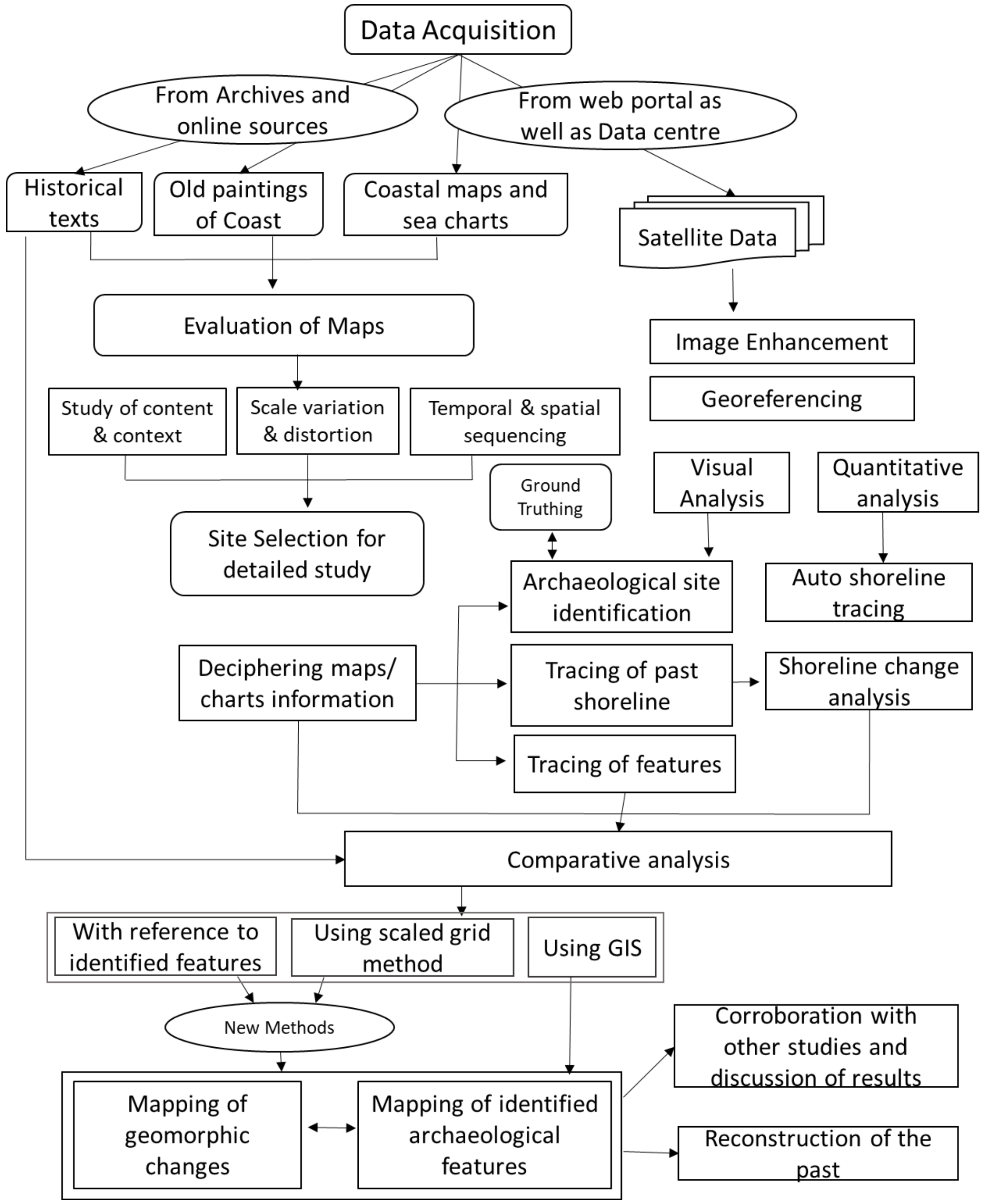

Figure 3.1 Methodology Flow Chart

Table 3.2 Satellites and sensors with their data source.

Data Sources	Satellite and sensors
USGS Earth Explorer data portal	Sentinel 2 (10m), Corona (~3m), Landsat (30m), SRTM DEM (30m)
Google Earth Pro	Very high-resolution true colour image (~0.5m)
ISRO's Bhuvan data portal	Cartosat DEM (30m), LiSS-III (23.5m)

3.2.2. EVALUATION OF HISTORICAL MAPS

After data acquisition the next important step is the evaluation of early maps. Following are the important factors to consider while analysing historical maps of the coast:

3.2.2.1. Understanding the context of the map

As already discussed, information on maps is very selective. The detail of a map depends on the interest of the map maker, patron or the user for whom it was made. The absence of any feature may also be as a result of map maker's choice to exclude that. For instance, sea charts usually omit topographic details of the land. The absence of an important feature or building on a map should not be considered the nonexistence of that structure unless supported by other evidence to reach such conclusions. Therefore, maps should be first understood from cartographers' lens. This involves retrieving of data about cartographers and inquiring the history of mapping.

3.2.2.2. Understanding the content of the map

Maps have various components such as symbols, its legends, labels, scale and orientation marker. Early maps do not follow any common standard. Therefore, reading and understanding all these components can be very challenging and require experience and skills. Fortunately, most often, the European charts/maps preserve local names, as it was possible for them to communicate with the local inhabitants. However, they were spelt based on how the names were heard and written by a person/surveyor whose data the map makers were using. For example, Kollam (a port city) is labelled variedly as Quilon, Caulao, Covlao, Coylon, Cowlang, Covlam; Kanyakumari as Cape Comorin; Kannur as Cannanore for euphonic reasons. The list of such examples is very long. Calligraphy and stylistic fonts used in most 16^{th} to 18^{th}-century maps are sometimes very difficult to decipher.

Reading the place names and identifying the corresponding place is a complicated task and requires some linguistic expertise. For example, a subset of an early Dutch map in Figure 3.2 (a) shows labels, windrose lines and some symbols representing built structures, different forms of vegetation, shoreline and shallow water area. The language in the given map is Dutch. With the availability of online translators, it is now possible to quickly translate the text. However, the meaning of obsolete words is difficult to find. *Coning* in Dutch means King, *Huys* means House, the term *Pagood* is used for word Pagoda meaning a Hindu temple and the last remaining word is interpreted as *bazaar,* a term used for market areas. The number '*7*' & '*3*' are soundings showing the depth of water. Nevertheless, the other subset of the same map was difficult to comprehend (ref. Figure 3.2 [b]). The same Figure also shows a graphical scale in an Old Dutch unit *Roeden* (meaning rod). It is also known as *rijnlandse roeden*. The unit of one *rijnlandse roeden* is equals to 3.767 m. However, some old maps were found to have internal inconsistency in the scale of the area they represent. Hence, historical maps should be read and interpreted with care.

3.2.2.3. Screening of maps

Not all maps are suitable for detailed analysis. However, one should collect as many maps as possible and then review all of them. Screening of the maps can be done based on originality, date of publication, scale and most importantly, the research question for which they are being assessed. Sometimes newer thematic maps use old maps as their base maps and hence, represent the boundaries or topography of the time older than the publication date. If there are many copies, the oldest one is considered original or closer to the original, especially if the cartographer is found to be physically present at that location around that time through historical records.

Usually, the larger the scale, the more detail we get in a map; therefore, larger-scale maps are preferred. However, some small scale maps are found to be very useful in giving information, such as the position of a town/fort/islands with respect to another town or river or shore (ref. Figure 4.8 in Chapter 4). Therefore, selection of maps for detailed investigation depends on their content, originality and availability of metadata.

Figure 3.2 Parts of a Dutch map of 1697 (for source: refer Appendix, Map-19)

3.2.2.4. Referring pilots and travellers' account.

Pilots and ship logs are the textual records maintained by sailors on their voyages. These records describe their journey, which includes weather conditions, rocky or sandy shoals, possible dangers, information about landing sites. Travellers' account also gives a geographic description of the places visited by them. It is suggested to check whether the chart has its accompanying pilot and other accounts of the same time that describe the geography of the area represented in the concerned map. These accounts are important to know the spatial knowledge of the time and interest of the sailors who maintained these pilots.

3.2.2.5. Content consistency in contemporary maps.

As already discussed in the beginning of this chapter, it sometimes can be very challenging to decide whether to believe or not some details given on a map. It is not advisable to rely on a single map only. The map's content should be validated by referring to other contemporary maps, textual records, or remote sensing data. For example, in Auke Pieters Jonks's map (1658) of Western Australia, Rottnest Island is depicted as a promontory of the mainland (ref. Figure 3.3 [a]). Recent bathymetric data also shows that if the sea level falls by 5 to 10 m, the island will be connected to the mainland as a promontory (ref. Figure 3.3 [c]). Such coincidences can misleadingly tempt us to believe that the sea level might have been 5-10 m lower in the year 1658 than it is at present.

Interestingly, another contemporary map of the same year by Samuel Volkersen marks Rottnest as an island. The contemporary text also describes Rottnest Island and further confirms that it was an island without a doubt. Similarly, there could be some inconsistency in the content that represent some short term changes. Therefore, if there is any interesting information on a map, conclusions should not be made immediately.

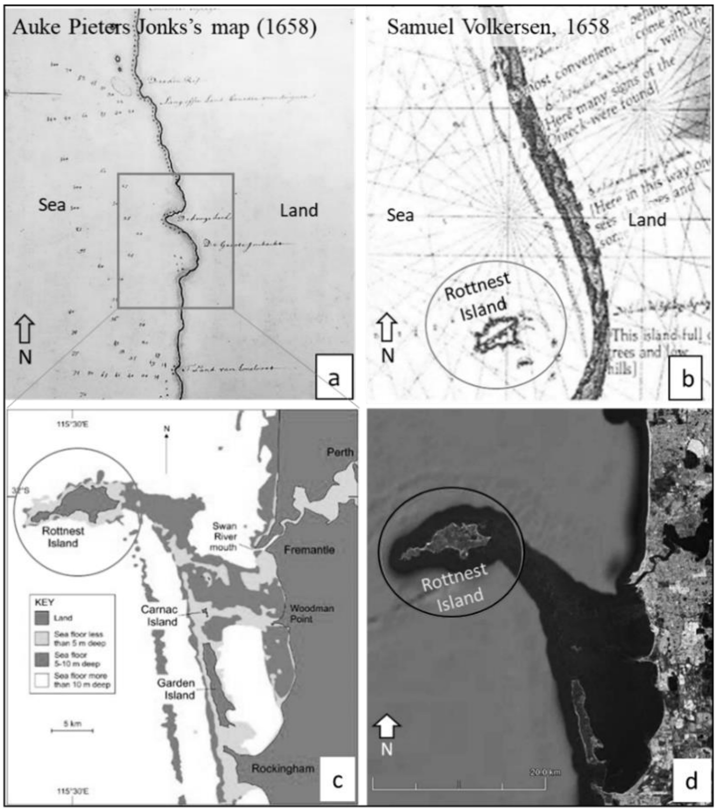

Figure 3.3 a) Modified from Schilder et al. 2006, b) modified from Gerritsen 1953; c) modified from Patrick & Nicholas 2016; d) modified from Google Earth Pro image ©Maxar Technology,

3.2.2.6. Referring published text on history and geomorphology

As explained in the previous section, maps should not be read as a sole source of information. Historical information extracted from the maps should be corroborated with historical text and geomorphological studies. Information acquired through maps may sometimes contradict other sources (literary and maps) and thus, should be judged accordingly with due diligence.

3.2.3. INTERPRETING MAPS OF DIFFERENT SCALE

Representation of spatial components such as building structure, layout or extent of a town or fort, roads, topography and relative positions depends on various factors such as scale of the map, availability of the space, spatial knowledge, production technique, purpose and intention of map-makers and patrons, etc. Following is the discussion on how coast and built structures are represented in maps of different scales:

3.2.3.1. Representation of natural coastal features in different scales

The scale of a map affects the intricacy and accuracy of the depicted coastline. The smaller the scale, the greater the cartographic license (Monmonier, 2008). The effect of the scale in the representation of the coast has been well illustrated and explained by Monmonier (2008). He elucidates the challenge of representing ground features on smaller-scale maps and transferring details of a larger scale map to a smaller scale map. While doing so, the map-makers have to make choices to – omit some smaller features; combine features that are very close to each other; or, depict the gap wider than the actual distance so that information that they are apart can be displayed. He also points out that outlines of small scale charts are smoothened, and small features that find a place in them are often exaggerated. In that way, maps (particularly small scale) are representation rather than a simple reduction of reality. Figure 3.4 compares details of the Thamirabarani delta and the adjacent coast in the maps of various scale. The smallest scale map (1: 1,500,000) does not represent the delta at all, the 1: 300,000 and 1: 150,000 are almost the same. However, the former is more generalized than the latter and shows the exaggerated width of some channels to make them distinctly visible while omitting some narrow ones. Therefore, it is important to consider this subjectivity carefully as ignorance can lead to misinterpretation.

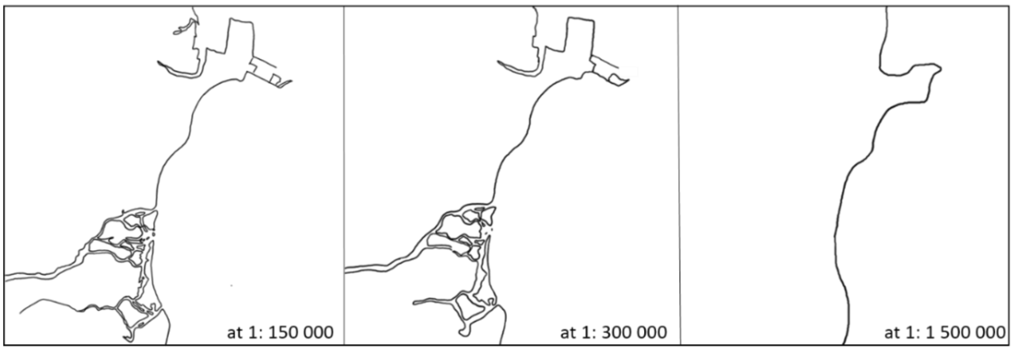

Figure 3.4 Comparison of generalisation of water-channels and shoreline at a different scale (outlines are extracted from hydrographic charts published by the National Hydrographic Office) (for source: refer Appendix, Map-12-14)

3.2.3.2. Representation of man-made structures in different scales

To extract any meaningful archaeological information, it is important to understand how the spatial components on the ground are represented in different scales.

The smaller the scale, the more remote is the map-maker's viewpoint and thus, the spatial entities as big as towns, cities, rivers, etc., are perceived in size reduced to a point or a line. A point on the map may be represented as a single dot or a much more elaborate symbol corresponding to the shape or type of the structure depending on the availability of space on canvas and the cartographer's style (ref. Figure 3.2). Maps greater than the scale of 1: 25.000 are considered as large-scale in which the available space in the paper increases to show a site (which in the small/medium scale maps is just a point data) in more detail in the 2D forms, and hence, are better understood. As the large-scale charts generally show estuary, delta, lagoon, harbour, strategically important locations, fort, lodges and such features. in relation to their immediate surroundings, they provide us with a more vivid spatial context of the local topography. For instance, in Figure 3.5 (a) settlement pattern of historical port Porto Novo in Cuddalore district (Tamil Nadu) is represented in a large-scale map close to its actual layout with its surrounding environment. Therefore, the location and settlement pattern can be easily traced in the satellite image (ref. Figure 3.5 [b]). While the small/medium scale map provides an areal range to locate a site regionally, the large-scale maps take us much closer to the accurate location locally.

In another example, Fort Geldaria, a Dutch fort in Pulicat, Tamil Nadu, and its surrounding environment are represented in a large-scale map in a more symbolic form than a true representation of the fort's extent and shape (ref. Figure 3.6 [a]). In contrast, the plan map provided a detailed top-view sketch of the fort (ref. Figure 3.6 [b]). The representation of the fort's extent and its sub-structures on the plan map corresponds to the ground-based evidence on a satellite image. Therefore, plan maps are considered most suitable for georeferencing, provided there are enough identifiable ground control points. However, plan maps most often do not show the surrounding geomorphological features, as shown in Figure 3.6[a].

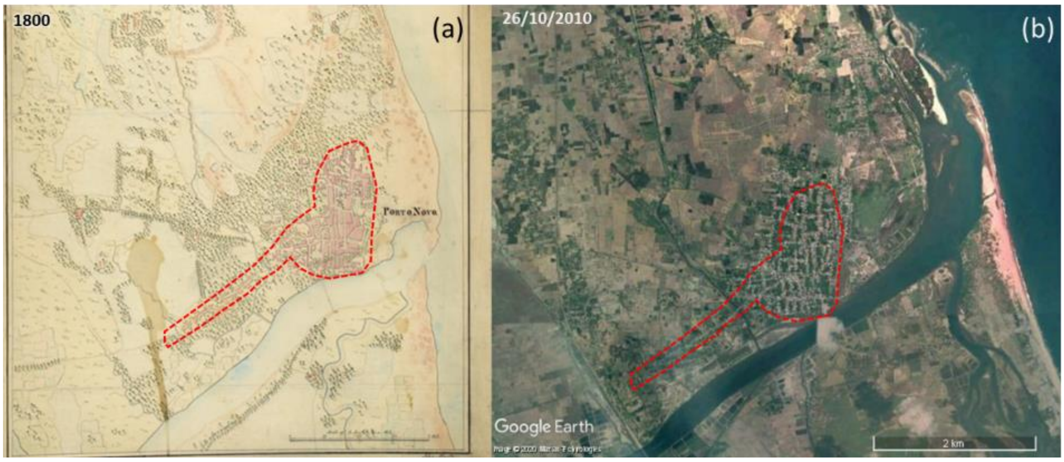

Figure 3.5. a) Large-scale map of Porto Novo (Parangipettai) showing the settlement pattern and its surrounding physical settings by John Mustie in 1800 (Shelfmark: WD2696; © British Library Board), b) satellite image showing the traces of the old settlement.

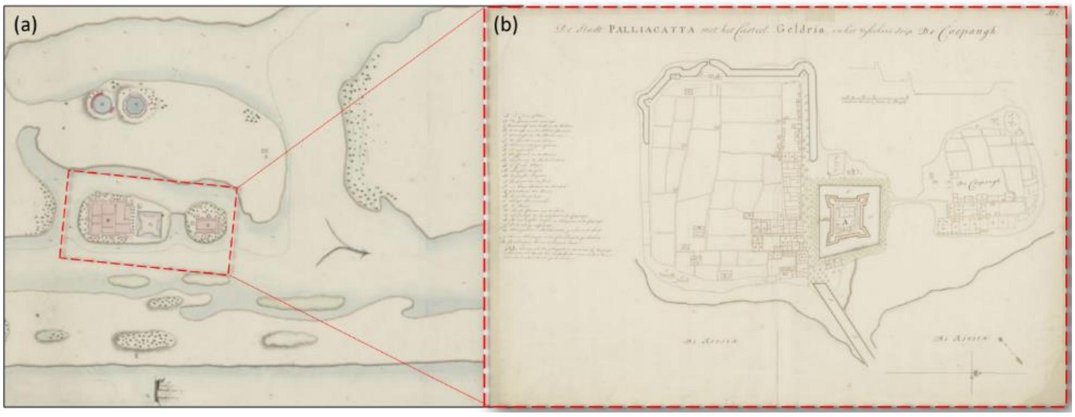

Figure 3.6. Comparison of representation of a fort with its vicinity in the large-scale map and a detailed plan map. a) Large-scale map of Fort Galdria in Pulicat and its environs, 1700-1800 ; b) Plan of Fort Galdria, 1690-1705 (source: ref. Appendix, Map-76 & 77)

3.2.4. SPATIAL ANALYSIS USING DIGITAL GRAPHICS (PROPOSED METHODS)

Digital graphics, here, are referred to graphic design software (such as Sketchbook and Photoshop) that give better control on manual juxtaposition of maps than GIS software. There are maps for which it is almost impossible to find out well-defined stable control points. Chances of misinterpretation are high for the maps whose georeferencing is done using incorrect control points. Therefore, to accommodate these limitations in map analysis following methods can be used:

3.2.4.1. Tracing maps using graphics software

Manually tracing of the digital copies of early maps is carried out on a drawing/illustration software (such as Sketchbook and Adobe Photoshop) using a digital pencil (Apple Pencil). It is done maintaining the same pen size and zoom level. The digital copies are saved on a transparent background to be conveniently overlaid on other maps.

3.2.4.2. Overlay using graphics software

The outlines of maps created from the above method are overlaid on a base map (i.e., recent maps or satellite images) in computer graphics platforms (Sketchbook and Adobe Photoshop). While overlaying on a base map, the digitised outlines are adjusted to fit on the base map. In this process, they are rescaled (stretched whilst maintaining the original proportion), rotated to match the size and orientation of the identified common features and sometimes stretched to make the best fit. In this method, the quality of the map can be judged by visual comparison with the base map.

3.2.4.3. Grid analysis

For the comparative and semi-quantitative analysis of the sequence of maps (both georeferenceable and non-georeferenceable) published at different times, the Scaled Grid Method (SGM) is used. In this approach, a sheet with regular square grids of uniform size and a defined scale (e.g., 500 X 500m or 1000 X 1000 m) is created. A base or reference map (i.e., a digitized outline of the latest satellite image) is adjusted to that scale, maintaining its orientation and proportion of its sides, and then placed on this grid sheet. Digital outlines of other maps and images are, one by one, overlaid on the base map and then rescaled and rotated to attain the best possible overlap with the base map using two or more reference points. Sometimes this adjustment is made based on other best comparable rescaled maps instead of the base map. After that, all maps and images are chronologically arranged side by side on that grid as shown in Figure 4.16 of Chapter4.

In this method, the aim is not to quantify errors rather find out what is accurately represented in a map by making a logical comparison with other maps. This method is subjected to subjectivity and cognitive biases of the interpreter. However, some amount of objectivity is introduced through the logical reference of other maps and systematic comparison of shapes, patterns, relative distances between different features using grid-scale in the background and presence of paleo features corresponding to the map's content. Shape and relative distances of map features are assessed by abstract reasoning of all the maps of the study area. Figure 3.7 shows how the systematic comparisons are made in SGM.

Maps that may seem to have large cartometric errors can be useful to extract some meaningful information. For example, in Figure 4.14 of Chapter 4, the 18th century's map of Chettuva estuary or mouth of river Karuvannur is found to have large cartometric error with reference to the map of 2020. Nevertheless, there is some useful information that can be extracted. The gap between the spit and the land south of Karuvannur River is wider in the 1750 map, and the north part of this land is depicted narrower than its southern part (ref. in Figure 4.14 Chapter-4). The remote sensing and GIS analysis of other maps discussed in Chapter 4 confirms that the same land strip was narrower than the present, and over the last 300 years, the land has extended for around 400 to 800m seaward. In the 1765 map, although the east-west extent is exaggerated (it is known based on the location of Chettuva fort and through the analysis of other maps), the north-south extent, channels, and other water features are well represented. The length of the spit is judged based on its position relative to the other identified comparable features. Studying many historic maps of the same region together helps either verify or question the content of these maps.

Confidence in the evaluation of map is high if there is a good correspondence of shape and extent of the feature with a known accurate map. It is low if there is poor correlation or uncertainty that the changes are due to geomorphic processes or map error. Depending on the accuracy of the map, measurement of certain features such as spit and island is performed. The higher the accuracy, the more objectively the measurements are presented. For instance, spit length and distortion in the EW and NS extent in the 1750 & 1765 map is assessed qualitatively (ref. Fig 4.14 and Table 4.4 in Chapter-4). On the other hand, Figure 3.7 shows an empirical approach in evaluating more accurate maps of 1840 and 1851-53 where observations are validated by the presence of identified paleo features that follow the shape and extent of features depicted on these early maps.

The SGM also helps in avoiding misinterpretation of map content due to wrong identification of control points. This method brings all the maps of a region on a single platform and enables the systematic chronological integration of such maps with other georeferenceable maps. It also enables critical analysis of the representation of the shape of coastline with respect to the relative position of identified active coastal features and paleo features; scale grid allows logical qualitative and methodical quantitative analysis of maps and extent of the features.

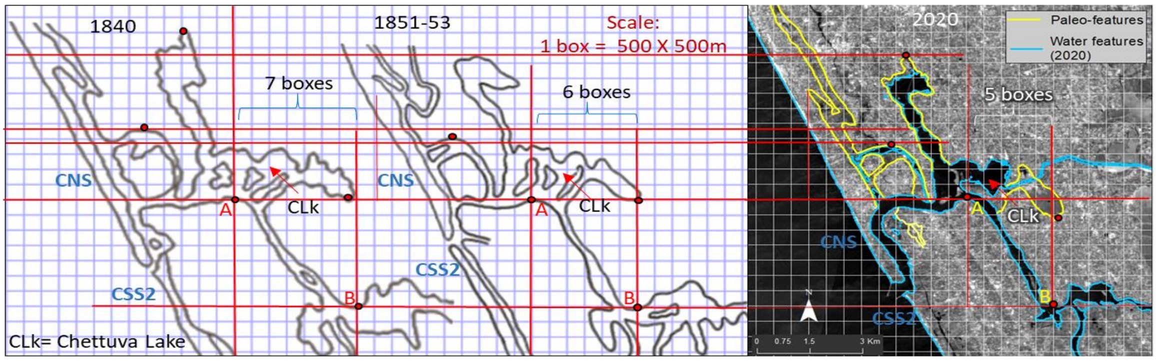

Figure 3.7. A subset of scaled grid analysis of Chettuva Estuary explaining the logical comparison of identified features. A and B are control points; small red dots are common identified points; CNS = Chettuva North Spit; CSS2 = Chettuva South Spit 2.

The SGM is compared with the image transformation methods conducted on GIS software. To compare them, the 1851-53 map of Chettuva was georeferenced using Helmert and Affine transformation in a GIS software. Both the georeferenced maps were digitized and overlapped on a satellite image. A grid of 500 X 500m is created on the GIS platform and overlaid on a base map (recent satellite image) (ref. Figure 3.8). The satellite image is saved with the grids and the shapefile of both the georeferenced maps. The non-georeferenced digitized file is manually overlaid on this saved image as shown in Figure 3.8. The SGM is based on matching the shapes and present the distortion in the map as it is and, thus, found to provide more manual control and a better fit than other methods if georeferencing is based on few points (that too are not well defined).

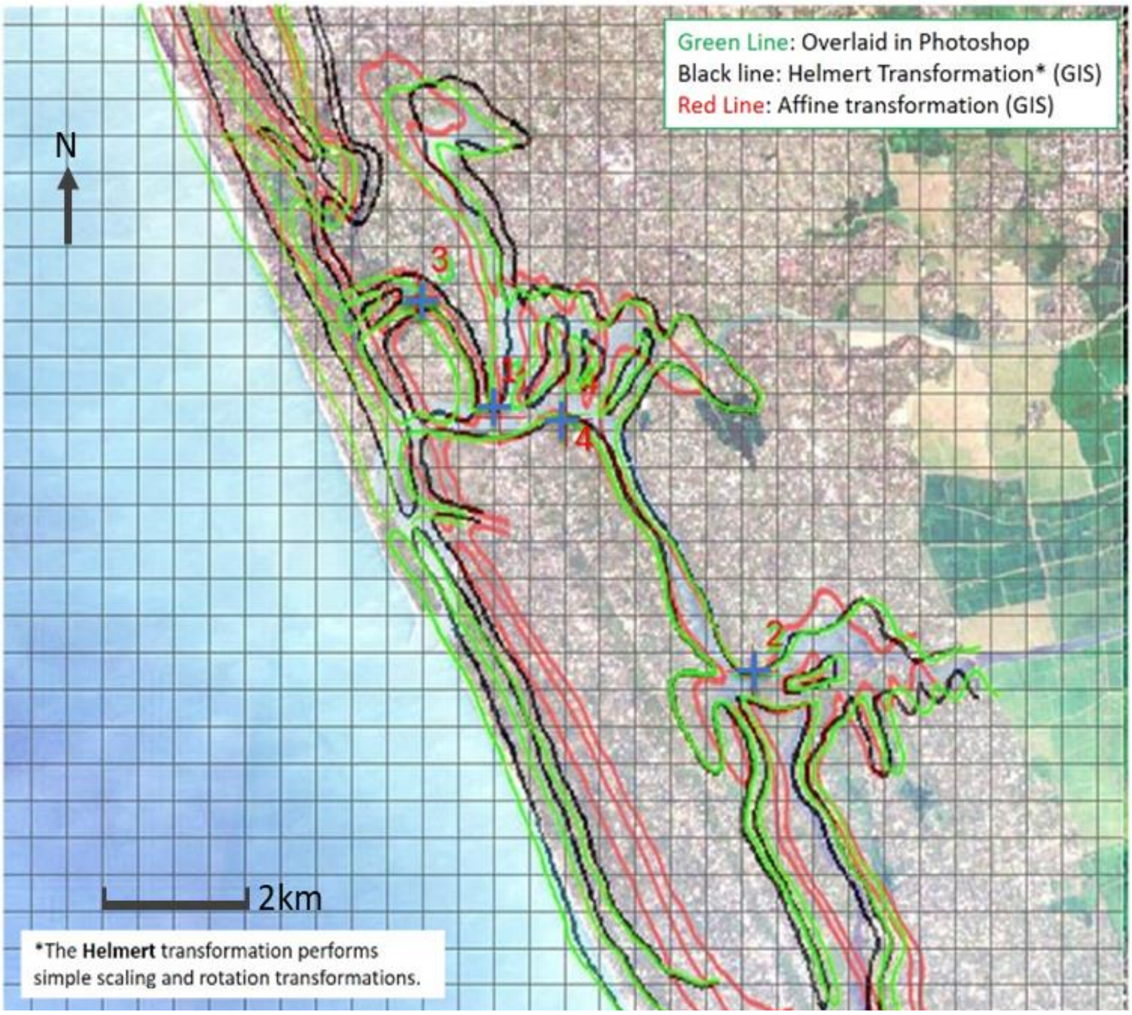

Figure 3.8. Comparison of Scaled-Grid Method with the shapefile delineated from maps georeferenced using Helmert Transformation and Affine Transformation. The outline of shoreline from non-georeferenced map is fitting better to its corresponding location than geo-referenced ones.

3.2.5. GEOSPATIAL ANALYSIS

3.2.5.1. Georeferencing

For quantitative geospatial analysis, all the maps and satellite images must be aligned on the same spatial reference. Georeferencing is the process for assigning real-world coordinates to each pixel in a given raster image by using control points (CP) whose coordinates are known or can be ascertained either from a georeferenced image/map of the same area or in situ ground measurements using handheld GPS devise. In this process, the links between the CP on the scanned maps and their corresponding real locations are used to adjust the map to the selected map projection. The number of links one requires to create depends on the complexity of transformation one selects. The links should be well distributed, typically at least one near each corner and some in the interior of the image-canvas.

Once links between CP and their true geographic coordinates are established, the transformation of the scanned image can be performed. Transformation can broadly be separated as local (spline transformation) versus global (Helmert transformation, affine transformation, second and higher-order polynomial models and projective transformation). Global methods optimize overall accuracy and do not guarantee local accuracy, while local methods transform the source CP exactly to the target, and the accuracy of pixels away from the CP are not guaranteed. There is no way to know the transformation type best for any given map in advance and that one has to try and evaluate the quality of the chosen transformation by making the visual comparison between georeferenced historical map and the recent map/image being used and/or by analyzing residuals of GCP statistically (Brovelli and Minghini, 2012). The georeferencing software provides the total error - the Root Mean Square Sum of all the residuals.

3.2.5.2. Identification of paleo features on satellite images (proposed methods)

Remote sensing data, with the ability to provide a synoptic view of tonal variation and patterns caused by the difference in soil moisture and elevation, helps in tracing the paleo geomorphic features such as buried channel, paleo delta and paleo strandlines. However, satellite images do not help understand the temporal context of the feature if the feature had become inactive before the time any satellite captured it. Several lakes and lagoons have shrunken or disappeared, and channels have changed their courses in the past 300-400 years. Historical maps can be an important and reliable source of information about such changes if used with remote sensing data. Figure 3.9 illustrates a hypothetical scenario of the landscape transformation from stage one to stage three. In this example, a water channel existed 300 years ago and was mapped by Dutch at that time. People occupied the land along the bank of channel. The channel gradually silted, leaving the fertile soil available for cultivation, which got subsequently occupied for agriculture. The occupancy of the dried channel followed its shape. In this way, the shape of the channel got preserved as a field-mark that can be easily identified in satellite images. Field-marks can be defined as patterns emerging out from the sequence of the agricultural fields that appear to have developed along or over the dried channels, silted water features or the prograding coast. Moreover, the availability of field-marks on the satellite images helps validate the content of the historical map and accurately delineate the boundary of identified paleo features even if it is incorrectly depicted in the old map. (ref. Section 4.2.4.3.1 in the Chapter-4).

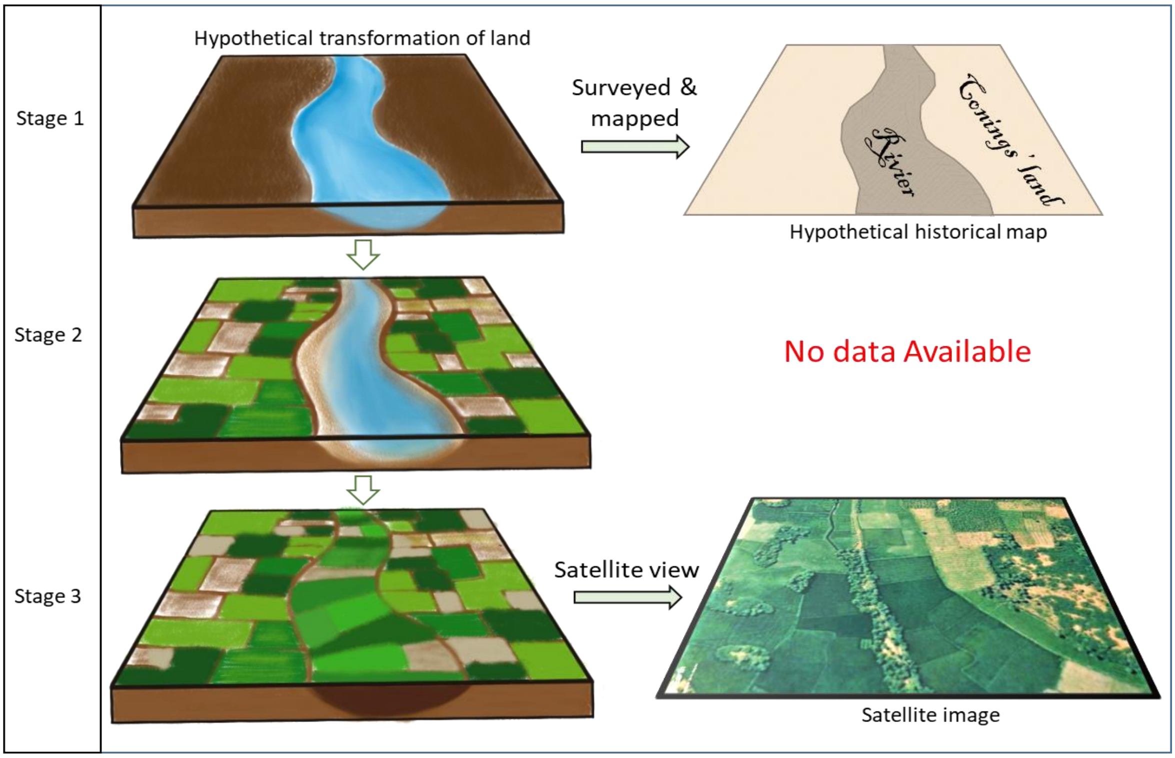

Figure 3.9 An illustrative example of identification of paleochannel from early maps and field-mark on the satellite image.

3.2.5.3. Digitization

Digitization is digital tracing of features of interest on georeferenced maps and images using GIS software. It can be manual or computer-aided. In manual digitisation, a mouse pointer is used to draw point, lines and polygons. In the computer-aided digitization method, shapefile is extracted from a classified raster image using the vectorization tool in ArcGIS. The digitized vector files are stored in individual thematic files. To ensure consistency in on-screen digitization, a constant scale is maintained. However, whenever there was ambiguity in the identification of any feature on the maps or the images, the GIS viewer was zoomed-in for validation and then digitized at the fixed scale. Both manual and computer-aided methods are used in the present study. Further details on the digitisation of maps and images used in each case study are discussed separately in the following chapters.

3.2.5.4. DEM Analysis

Digital Elevation Model (DEM) provides topographic details of the surface. DEM data has been found very useful in discovering the archaeological mounds and paleochannels (Sharma et al., 2014; Rajani, 2016; Gupta et al., 2019). Cartosat DEM (30m) and SRTM DEM (30m) are used to visualize altitudinal variation in the terrain of the study area. A simple 'bathtub' inundation model is used to envisage the flooded area if the relative sea level is assumed to rise to a certain height in one of the study areas, i.e., Thamirabarani Delta (ref. Figure 4.7 in Chapter-4). In this model, all the pixels of the DEM equal and lesser than the assumed sea level are flooded like a bathtub (Yunus et al., 2016). Since this model is used to visualize the past scenario when the topography is assumed to be different from what it is now, hydrologic connectivity is not considered. DEM is also classified based on elevation value to visualize the low-lying area.

3.2.5.5. Shoreline determination and delineation

The coastline of the georeferenced old maps is used as the shoreline of that time. They are digitised using a common scale, which is decided by optimising the details of large and small-scale maps. The ratio of band 2 (Blue) and band 5 (Visible and Near Infrared) provides sharp demarcation of seawater line in multispectral satellite images and hence, has been used for automatic shoreline extraction from the sentinel-2 image (Kankara et al., 2018). The output image is classified into two classes and then auto digitisation is done using vectorisation tool. As per the recommendation of INCOIS, ICMAM and NCESS, the shoreline proxy for corona images will be made using wet/dry line for sandy shore, land and sea boundary if wet/dry line is not visible or available (ref. Section 4.3.5.4 in Chapter-4).

3.2.5.6. Measurement of uncertainty in shoreline delineation

The accuracy of shoreline positions extracted from historical maps and remote sensing data is influenced by several factors. Uncertainties in shoreline delineation can be due to positional errors such as seasonal error, tidal fluctuation, and measurement errors such as digitizing error, pixel error and rectification error. Therefore, these errors need to be recognised and measured. Error types and their uncertainty value with the rationale is given in Table 3.3 (also ref. Section 4.3.5.4 in Chapter-4)

Table 3.3 Uncertainty parameters with rationale and its adopted value.

Error type	**Rationale**	**Uncertainty value**
Pixel Error (E_{px})	As shoreline is a line feature and pixels of the maps & images represent an area, the pixel size is considered as an error	Pixel size of the map and image
Rectification (E_r)	Each of the maps and images is georeferenced, and the Root Mean Square Error (RMSE) is estimated between the points on the map or image and control points.	RMSE
Digitization (E_d)	The thickness of the shoreline depicted on old maps are usually covered by one or two pixels; hence, the uncertainty value of the maps is considered one pixel. Though the digitization is carried out by a single analyst, there is some ambiguity in the identification of shoreline in the Corona satellite images. Therefore, the uncertainty value for that is also considered one pixel. No digitization error is considered for Sentinal-2 data as the shoreline was extracted through the computer.	One pixel
Positional (Seasonal and Tidal) (E_p)	Seasonal changes and tidal fluctuation cause a horizontal shift in the shoreline. A range of 5-10m is given by (Kankara et al., 2018) for the uncertainty value of seasonal error, and the tidal range is taken for tidal error. In the absence of slope data, the tidal range has not been considered. Instead, tidal fluctuations are assumed to be within the range of seasonal fluctuations, and hence the single value of 10 is considered for positional error	10

Total uncertainty (Et) value is calculated for each shoreline using the following equation.

$$Et = \pm\sqrt{{E_{px}}^2 + {E_r}^2 + {E_d}^2 + {E_p}^2}$$

3.2.5.7. Shoreline Change Analysis

Shoreline change analysis is carried out using Digital Shoreline Analysis System (DSAS) version 5.0, a freely available software application that works with ArcGIS versions 10.4 and 10.5. The GIS data is created and organized based on DSAS version 5.0 User Guide. Since the temporal data points (number of maps and images) are few and observed changes are not linear, the analysis of shoreline-change-rate using DSAS has not been carried out.

Shapefiles of all the maps are merged into a single feature class and imported into a new personal geodatabase. A 'date' field is added to the attribute table. The software automatically creates a shape 'length' field. As this study is interested only in the change in the shoreline in time, another mandatory field, i.e., uncertainty, is not created. However, the uncertainty value is calculated for interpretation. A baseline is created onshore parallel to the coast in the same personal database. Baseline is required primarily to cast transects and to provide a reference to measure the distances. Perpendicular to the baseline, transects are generated at an interval of 500m with a distance that ensured that each of them intersects all the digitized shorelines. The distance between these intersection points in each transect is measured and plotted (ref. Figure 4.21 and Figure 4.22 in Chapter-4).

Shoreline change analysis is also carried out for the non-georeferenceable historical maps by measuring the changes with respect to the position of archaeological sites or identified paleo features. Such measurement can be more discrete than the above method; however, they are found very informative in providing insights about past changes.

3.3. CONCLUSION

Studying historical maps is a complex process. There is much subjectivity in their content and their interpretation is prone to an individual's predisposition and prejudice. They may be full of errors of various kinds. However, they are also correct in their own ways. Thus, historical cartographic documents should be studied considering the possible 'errors' and 'inaccuracies' they may have (similar to the hermeneutical reading of classical texts) and deciphered, keeping their subjective nature and context in mind. It would be apt to quote Harley (1968) here once again "All too often a theoretical method is irrelevant to the particular map, and there may be no substitute for the judgement, intuition commonsense of the moment." It was written in 1968, and is still relevant. However, remote sensing data and integration of spatial data (from multiple sources) in GIS have offered ways to logically study and validate the content of the map to some extent.

The present study adopts different approaches from very simple visual interpretation using logical reasoning to more elaborated remote sensing and GIS approach and their combinations. The methodological framework and all the methods discussed in this chapter may not be applicable to all the maps in the same way. There could be slight variations in adopting methods while studying different sites based on the location, types of maps and nature of the information. The following chapters demonstrate how different sites are studied applying the combinations of methods elucidated in this chapter and discusses the challenges confronted while studying them.

Analysis and interpretation of early maps require skill, which comes with practice and experience. The absence of skills and experience may lead to faulty interpretation similar to an instance of wrong interpretation of satellite image that created misinformation about finding a 'bean-shaped island like structure' offshore Kochi and got published in many reputed newspapers[24,25,26].

Historical maps should be studied in a positive light by treating all of them as valuable historical sources of information; and rather than focusing only on their faults, attempts should be made to find their merits.

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[24] N. Joseph, "Google Maps shows 'underwater island' in Arabian Sea near Kochi, experts to probe," The News Minute, Jun. 17, 2021. https://www.thenewsminute.com/article/google-maps-shows-underwater-island-arabian-sea-near-kochi-experts-probe-150798

[25] "Google Maps show new 'underwater' structure in Arabian Sea near Kerala's Kochi, experts to probe formation," Hindustan Times, Jun. 17, 2021. https://www.hindustantimes.com/india-news/google-maps-show-new-underwater-structure-in-arabian-sea-near-kerala-s-kochi-experts-to-probe-formation-101623934600266.html

[26] "Baffling bean-shaped formation spotted along Kochi Coast on Google Earth," The times of India, Jun. 18, 2021. https://timesofindia.indiatimes.com/viral-news/baffling-bean-shaped-formation-spotted-along-kochi-coast-on-google-earth/articleshow/83628831.cms

CHAPTER 4

COASTAL MAPS AS A SOURCE OF GEOMORPHOLOGICAL INFORMATION

"There are operations proper to the surface of this globe, by which the form of the habitable earth may be affected; operations of which we understand both the causes and the effects, and, therefore, of which we may form principles for judging of the past, as well as of the future."

-James Hutton (1795), Theory of the Earth, Volume 2, Edinburgh

4.1 INTRODUCTION

The importance and challenges of historical maps in coastal studies and the methodological gaps in studying them have already been discussed in Chapter-1 & 3. The present chapter attempts to – 1) demonstrate methods, proposed in Chapter-3, to use early cartographic documents in a more structured, comprehensive and logical manner in the study of coastal geomorphology; 2) reconstruct geomorphic evolution of some of the coastal features based on the results of this chapter, and 3) assess the value of historical maps in coastal studies. The framework, conceptual and critical understanding of the devised methodology is discussed in detail in Chapter-3.

This chapter is formalised into two main sections based on the selected stretches of the coast– 1) Tamil Nadu (Thamirabarani Delta and Thoothukudi Tombolo), and 2) Kerala coast (from Kodungallur to Fort Kochi and coast around Chettuva estuary) (ref. Figure 4.1). The selection of the sites was carried out based on the preliminary analysis of the acquired historical maps. The selected stretches of the coast are known for having several historically important ports from ancient times to the colonial period, including some of the most popular ancient ports, Korkai and Muziris. There is a wealth of historical maps available for almost all the parts of the coast at a different scale; though some stretches are richer than others. The Kerala stretch is rich in both availability of early maps and published literature on coastal processes while the stretch of the Thamirabarani delta is less studied. Each main section provides -1) brief introduction on history, physiography and geomorphology of the region; 2) information on the data used (early maps and satellite images); 3) explains methodology adopted for respective studies; 4) presents the results, 5) synthesises the observations and findings from the present study as well as from other published literature; and 6) proposes theory on the evolution of the Thamirabarani delta and growth of spits in the study area. The chapter also presents the synthesis of the critical understanding of historical maps in geomorphic studies.

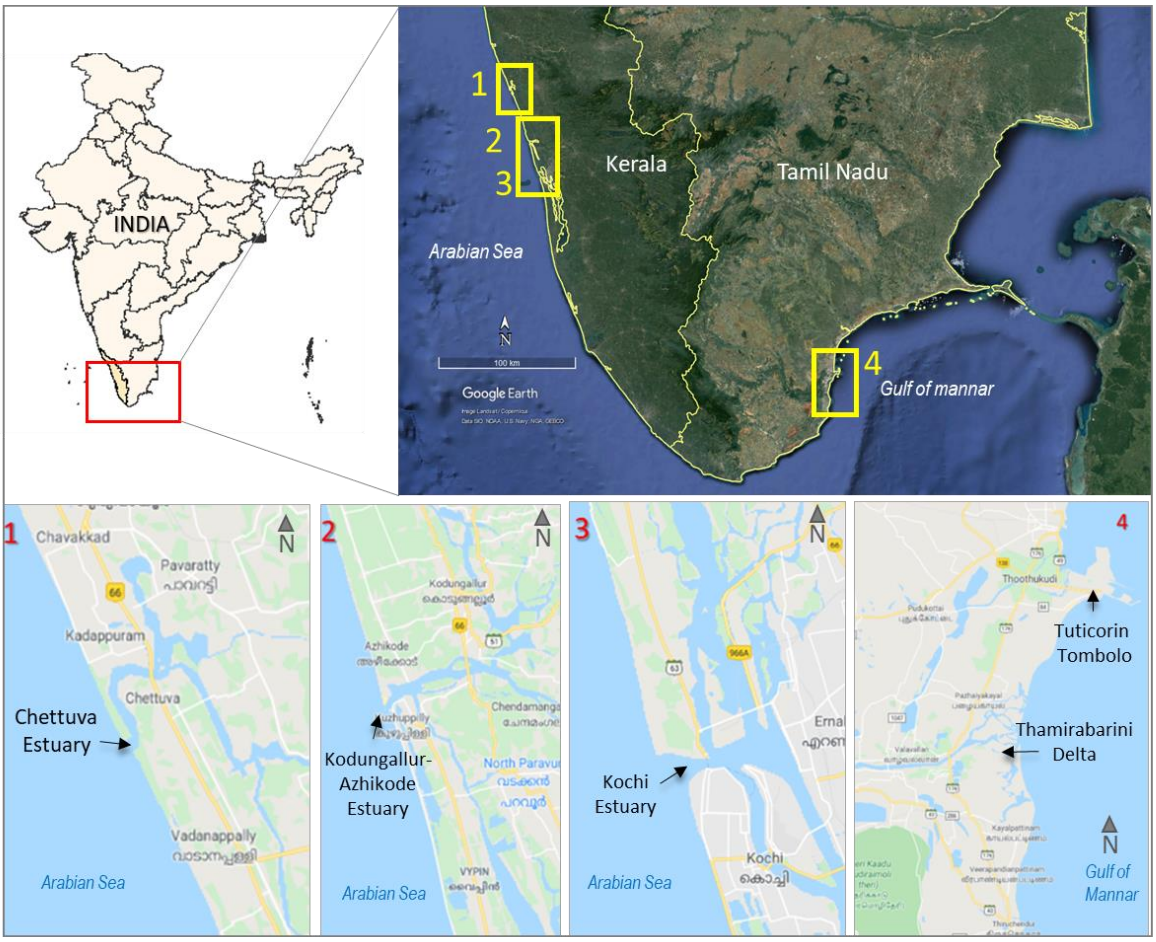

Figure 4.1. Location of stretches of the coast studies in the present chapter. Image data © Google Earth, Maxar Technology, 2020 and Google Maps.

4.2 THAMIRABARANI DELTA AND THOOTHUKUDI TOMBOLO IN TAMIL NADU

4.2.1 SITE LOCATION AND PHYSIOGRAPHY

Thamirabarani delta and Thoothukudi (Tuticorin) tombolo are located on the southern coast of Tamil Nadu facing the Gulf of Mannar. The study area extends from Vadaku Theru in the north (8°29' N, 78° 7') to Tiruchendur in the south (8°49'N, 78° 10'E) (ref. Figure 4.1) The geology of this region is comprised of limestone, sandstone, shell, clay beds, alluvium, fluvio-marine and coastal deposits, sand dunes of recent and sub recent age. During the Pleistocene lowstand, the river carved out its valley through the intense incision (Ramkumar et al., 2019). A compact layer of sandstone with shells lies beneath the unconsolidated beach sands. Tiruchendur, about 13km south of the delta, stands on a sandstone promontory (Subramanian & Selvan, 2001). The coast is micro-tidal, with a mean range of around 0.5m (Ramkumar et al., 2019). Climate is semi-tropical, with an average temperature of 28.2°C. (Sudarsan, 2007; *Thamirabarani River Basin Report*, 2017). As the river has its origin in the Western Ghats and mouth on the eastern coast, it benefits from both SW and NE monsoon. However, extreme eastern parts of the river basin receive rainfall mainly by NE monsoon. The river is susceptible to flood, particularly during the NE monsoon and scanty flow during winter (Duvvuri & Narasimhan, 2013; V. Kumar et al., 1990). Monsoon winds have influences on the wave directions. Predominant wave direction is towards South-West and North-East during the North-East and South-West monsoon (Sudarsan, 2007). In general, river dominating deltas form branching distributary channels and prograde seaward (*Engineer Manual*, 1995, p. 93). Though the Thamirabarani delta has formed multiple distributary channels, it has not prograded seaward, rather forming a seaward concave coastline suggesting the overall dominance of the littoral process. The southern part of the study area has experienced erosion from 1969 to 1999 and accretion from 1990 to 2006, and the northern part has experienced heavy accretion from 1969 till 2006 (Mujabar & Chandrasekar, 2013).

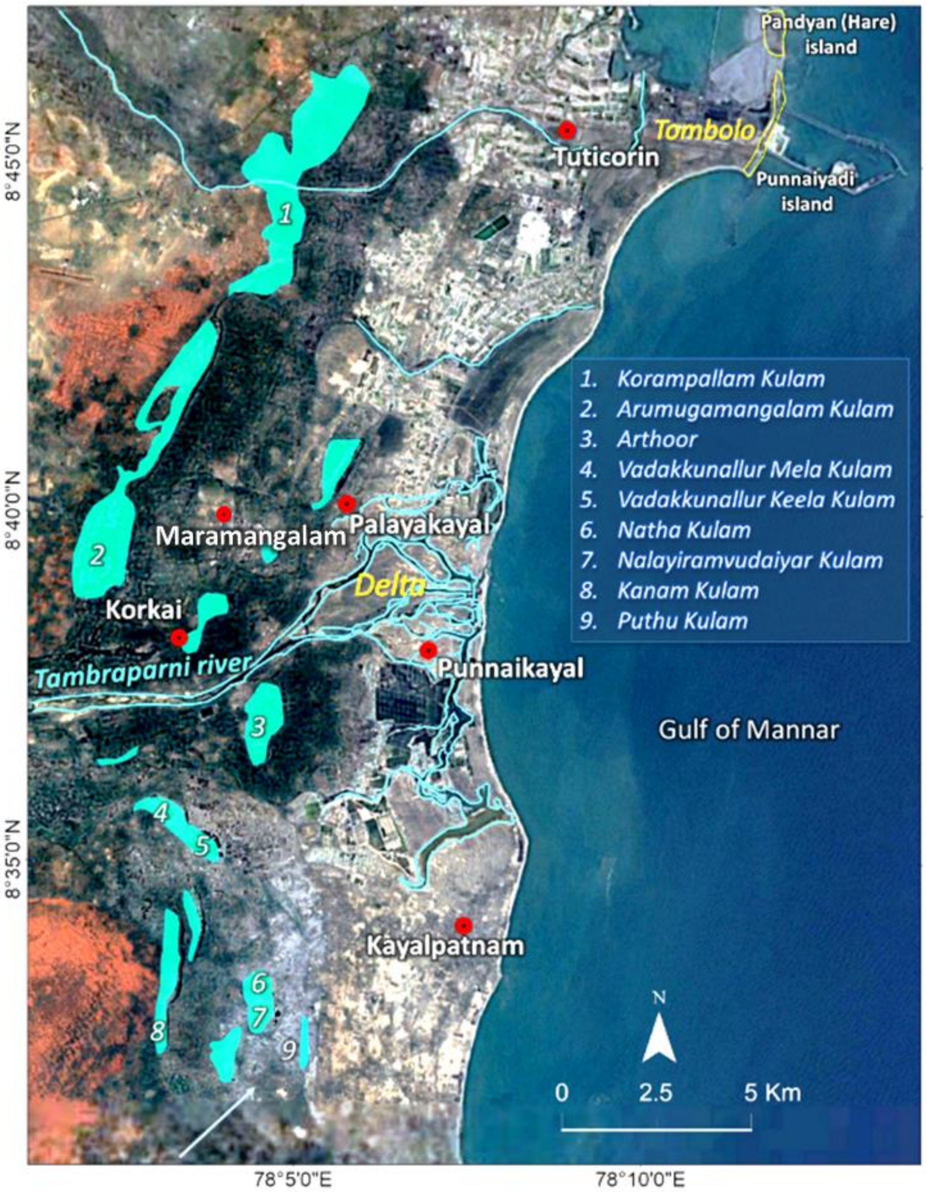

Figure 4.2. Location of Thamirabarani Delta and Thoothukudi (Tutucorin) Tombolo with important sites and tanks. Image data © Google Earth, Maxar Technology, 2020.

4.2.2 HISTORICAL BACKGROUND

Korkai, now 7km inland, was a great ancient port known for its pearl trade and the capital of the Pandya Dynasty in the centuries preceding the Christian era (Sridhar, 2004) (ref. Figure 4.2). A hearth of clay dated to 785 BCE was found in an excavation at Korkai village. The description of Korkai port is also found in Sangam literature and foreign notes. Bishop Robert Cardwell who carried out a detailed scientific investigation on the Thamirabarani delta in 1861, identified 'Colchi' mentioned in *Periplus of the Erythraean Sea* (80 CE) and 'Kolkhoi' of Ptolomy's *The Geography* (130 CE) as Korkai (Cardwell, 1881). Scholars suggest that the Korkai port continued to function until the 5th century CE (Arunachalam et al., 2006).

After the decline of Korkai, the place ‘Kayal’ or ‘Cail’ emerged out as a new port in about the 6th century CE. By the 13th century, it had become a major port. The port site is now located north of the northern distributary of the delta, about 3km inland and around 6km NE of Korkai (ref. Figure 4.2). Cardwell identified it with Marco Polo’s *Cail*[27], Nicolo Conti’s[28] Cahila, Duarte Barbosa’s[29] Kail, Caell of the *Roteire* (itinerary) of Vasco de Gama[30]. They identified Kayal as an important port with notices on its pearl fishery (Cardwell, 1881). Kayal was an active port till the beginning of the 16th century. The Portuguese had lived there before its complete abandonment as a seaport (Cardwell, 1881, p. 41). The first references to ‘’Caelo Velho’’ (meaning old Kayal) appeared in Portuguese records in the 1540s (Flores, 1995).

By the mid-16th century, the Portuguese established themselves in Punnaikayal, Manapad, Tuticorin and Vembar, the places at present situated along the shore. At the same time, Kayal port fell into irreversible decline, and Punnaikayal (an island, southern side of the delta, close to the river mouth) emerged as chief settlement for some time. From about 1580, the Portuguese made Thoothukudi their chief settlement (Cardwell, 1881, p. 75; Flores, 1995). It was taken over by Dutch in 1658 and was ceded to the British by the Dutch in 1825 CE (Cardwell, 1881, p. 83). Pandyan and Punnaiyadi were two islands offshore Thoothukudi that acted as a natural breaker and formed a tombolo by trapping the sediments to its lee-side.

There are eight anicuts on the river Thamirabarani. The oldest anicut (i.e., Nadiyunni anicut) is said to be constructed by ancient Pandya kings. The rest were made between the fourteenth and nineteenth-century (Cardwell, 1881, pp. 63–66; *Thamirabarani River*

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[27] Marco Polo was an Italian merchant, explorer, and writer who travelled to Asia in the later 13th century. Refer: Cordier, Yule (1929) The Book Of Ser Marco Polo Vol Ii. Armorica Book Co Philo Press Amsterdam

[28] Niccolò de' Conti was an Italian merchant, explorer, and writer. who traveled to India during the early 15th century. The reference of Cahila is taken from Robert Cardwell’s book, page 37.

[29] Duarte Barbosa was a Portuguese writer and officer from Portuguese India (between c. 1500 and c. 1516) and the author of the ‘Book of Duarte Barbosa’ (*Livro de Duarte Barbosa*) c. 1516

[30] Vasco de Gama was a Portuguese explorer and the first European to reach India by sea in c. 1498.

Basin Report, 2017b). These anicuts prevent the river water from escaping to the sea and channelise the stored water for irrigation. These anicuts feed a large number of old native reservoirs or tanks through the numerous irrigation channels connecting them. The Srivaikuntham anicut is the closest to the sea (around 24km from the coast) and was constructed by the British in 1874. This anicut provides fresh water to the town of Thoothukudi from the upper end of the Karampallam tank, which is the northern extremity of the series of connected tanks and also up to Tiruchendur, which is the southern extremity (Macgeorge, 1894, pp. 192–193) (ref. Figure 4.2).

4.2.3 MATERIAL USED

Historical maps: A total of 14 maps of this region have been found from different sources (ref. Appendix, from Map-1 to 14). The map found in Yule Cordier's *Book of Ser Marco Polo* (ref. Appendix, Map-10) is excluded as it does not have a date on it and has details similar to the 1828 map (Map-9).

Satellite Image: Corona (10 October 1965) and Sentinal-2 (29 May 2019) images have been downloaded from USGS EarthExplorer web portal. Google Earth Pro has been used to analyse very high resolution (available from 2002), Landsat images (good quality available from 1999), Cartosat DEM (30m) and SRTM (30m).

4.2.4 METHODOLOGY

All the maps obtained from various sources were assembled in chronological order and then studied as follows:

4.2.4.1 CONTEXT AND CONTENT OF THE MAPS

Temporal context: The oldest available map is a small-scale sea chart published in 1695 (ref. Appendix, Map-1). A large-scale map depicts only Pandyan, and Punnaiyadi islands and the mainland opposite to it, dates to 1699 (Map-2). The 1753 map (Map-4) by Van Kuelen is a copy of the 1699 map. Map-7 (1805) is the oldest large-scale map of the Thamirabarani delta. It is a manuscript map drawn in 1000 yards (914.4m) to an inch scale by the British. This map marks the water bodies (rivers, tributaries, distributaries, swamps, tanks and lakes), topography, location of towns and villages, administrative boundaries, roads, agricultural land and vegetation in good detail. The other maps (Map-8 to 11) are dated to 1822 (hydrographic chart), 1828 (atlas sheet), 1883 (geologic map) and 1919 (topographic map), respectively. Though made for different purposes by the British, the content of maps (shape of the delta, distributaries, lagoons, creeks) published in the year 1822, 1828 and 1883 is the same. The 1883 map by geologist Robert B Foote seems to have taken topographical details from the 1828 map as he references this map in his memoir (Foote, 1883).

Map-11 was prepared on a 1: 250,000 scale by US Army Map Service (AMS) in 1953 from one inch series (1:63,360) of Survey of India surveyed in 1919. The three smallest scale sea charts, i.e., Map-1, 3 and 6, were used only to study tombolo as they do not show any information about the delta. The geologic map of 1883 is at a scale of 4 miles to an inch (i.e., close to 1:250,000). Map-8 (1822) does not mention any scale, but from the content and detail, its scale seems to be smaller than the next three subsequent maps. The scale of Map-9 (1829) is considered the same as the geologic map (Map-10, [1883]) as both of the map look the same in topographic details. The scale of Map-7 (1000 yards (914.4m) to an inch) is about six times larger than other maps (Map-5.8-5.11).

Scale and perception: As mentioned in Chapter-3, the scale of a map affects the accuracy of depicted features and the degree of generalisation. Some features are omitted, and some are exaggerated (ref. Section 3.2.3.1 in Chapter-3). The large-scale map of 1805 gave accurate spatial information, while the small-scale map gave an impression of the presence of a large lagoon and wider opening at the mouth of this river. Since this coast also has a history of the existence of an ancient port Korkai (now 7km inland), it was quite exciting to have found a 19th-century map with a 'wide lagoon' that does not exist now. Foote (1883, 6), while comparing an Atlas sheet[31] of the early 19th century with the Revenue Map of the mid-nineteenth century, came up with a judgement of a rapid rate of siltation by noticing the shrinking size of lagoons on the large-scale map. After being informed about the mid-nineteenth century Revenue Map from Foote's record, an online hunt to find such a map was carried out. Fortunately, a large-scale administrative map of 1805 was retrieved (Map-7). This map predates both Atlas sheet and the revenue Map

[31] Foote's document say Atlas Sheet 81 surveyed in 1828, however, it's not clear which map he is referring to. The Atlas of India, 1862 has a sheet (80) published in 1828 depicting the Thamirabarani delta that has same topographical details as found in Foote's geological map. Therefore, I am assuming the Sheet 81 he referred to is similar to Sheet 80 mentioned above.

referred to by Foote. This large-scale map shows narrower channels and choked lagoons[32] compared to the available smaller scale maps (Map-2 to 5) of later periods. It is important to note here that Foote's observation was misled by the exaggerated depiction of features at a smaller scale map of an earlier time in similar ways as described in Chapter-3, Section 3.3.3.1.

4.2.4.2 SPATIAL ANALYSIS USING DIGITAL GRAPHICS

4.2.4.2.1 Tracing maps using graphics software

Due to the absence of well-defined stable features that can be used as control points, the outline of all water features and shoreline from the large-scale 1699 (Map-2) and 1805 (Map-7) map was traced manually on a digital graphics platform such as Photoshop and Sketchbook. These outlines were saved with a transparent background.

4.2.4.2.2 Overlay using graphics software

The digitised outline of the map was overlaid on a recent satellite image on a digital graphics platform. The overlaid outline was rescaled (stretched whilst maintaining the original proportion) and rotated to match the size and orientation of the identified common features.

4.2.4.2.3 Identification of paleo features on satellite images

Visual analysis of juxtaposed outline of 1805 map led to the identification of paleo geomorphic features. These features were traced with the help of fieldmarks (explained in Section 3.2.4.2 in Chapter 3.) observed on the very high-resolution satellite images. In the present site, the conspicuous patterns of these fieldmarks are found corresponding to the shape and extent of the water features marked in the historical maps (Map-7 to 10) (ref. Figure 4.3). Similarly, strandlines of past shoreline have been traced.

To ensure that the identified features are permanently dried and not a seasonal phenomenon, all the very high-resolution images available in the Google Earth Pro from

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[32] Choked lagoons have one or more narrow and long entrance and are found along coasts with high wave energy and significant littoral drift ((Kjerfve & Magill, 1989).

2002 were examined. Paleo features were directly traced from the satellite images referring the digitised outlines.

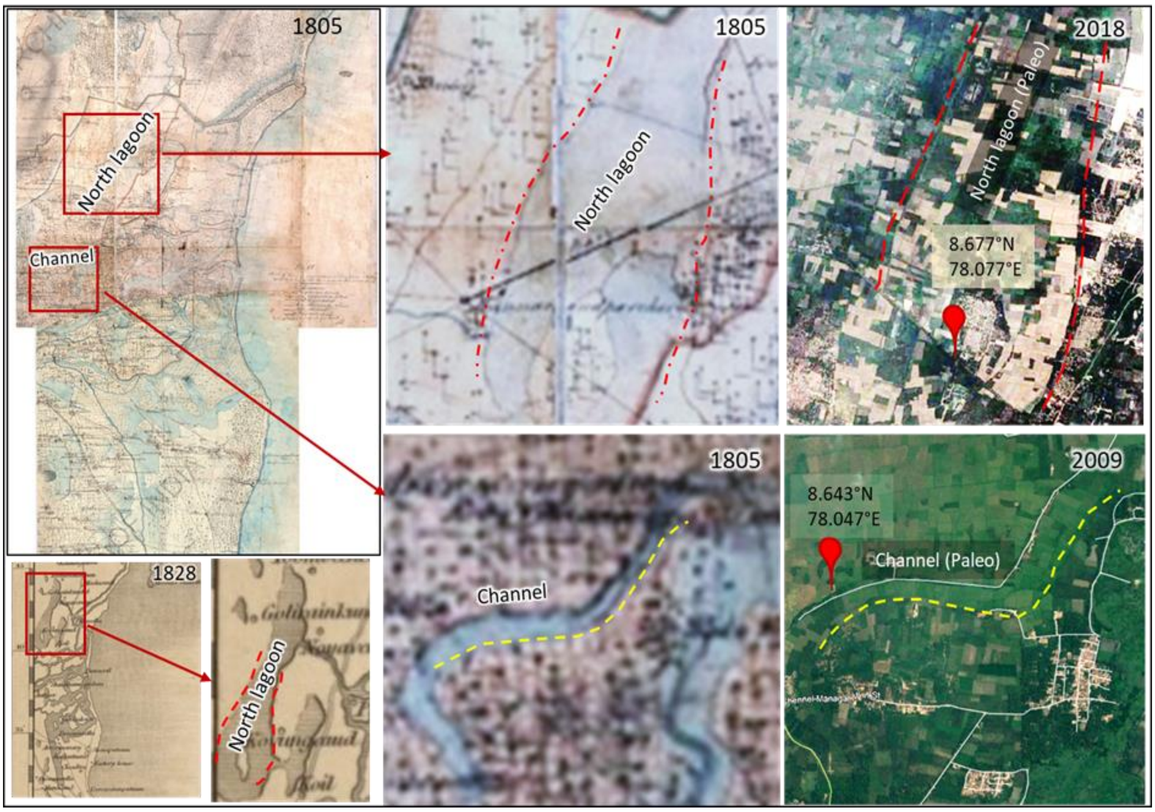

Figure 4.3 Identification of paleo features using early maps and fieldmarks on satellite images.

4.2.4.3 GEOSPATIAL ANALYSIS

Selected map and satellite images were analysed on a geospatial platform which involves the following processes:

4.2.4.3.1 Georeferencing

Historical map of 1919 (Map-11), Corona image (1965) and high-resolution satellite image (2020) were georeferenced using control points from Google earth. Satellite image from the year 2020 was used as a base image. The georeferenced maps were overlaid on the base image to further check the local accuracy and inaccuracy of the maps. Based on visual observations, necessary corrections were made on the location of identified control points, and the map was georeferenced again. Information of total control points, transformation type and errors are given in Table 4.1. For the detailed discussion on georeferencing of old maps refer to Section 3.2.4.1 in Chapter-3.

Table 4.1 Georeferencing parameters.

Map/image	year	Transformation	Total CP	Errors (m)			Pixel size
				RMSE	Highest Residual	Lowest Residual	
NC 44-13 (AMS)	1919	P2	11	77	151	17	38
Corona	1965	P2	7	3.5	5.6	0.07	3

4.2.4.3.2 Digitisation

The paleo features (paleo lagoons, paleochannels and paleo shoreline), identified with the help of the old maps, fieldmarks and strandlines visible on the recent satellite image, were digitised as a polygon shapefile on a geospatial platform. A common scale of 1: 15,000 was adopted to make an equal generalisation of all the maps. However, as discussed in Chapter-3 Section 3.2.4.3, whenever there was ambiguity in identifying any feature, the images were zoomed-in for validation and then digitised at this fixed scale. Some amount of interpolation based on visual assessment is done on the areas where paleo features are found to be inconspicuous. The shoreline from the georeferenced old maps and satellite images were also digitised.

4.2.4.3.3 Measurement of paleo features

The identification of water features, depicted in the old maps, on the satellite image in the form of paleo features provided confidence in the quality of the old maps and enable more accurate measurement of the area of the silted water features. The area of the paleo features is measured from the digitised shapefile in GIS software.

4.2.4.3.4 DEM Analysis

A simple 'bathtub' inundation model without considering hydrologic connectivity is used to visualise the land flooded with seawater if the relative-sea-level (RSL) is assumed to rise to a certain height (for detail, ref. Chapter-3, Section 3.2.4.4). DEM is also classified based on elevation value to visualise the low-lying area. Water features from the 1805 map are overlaid on the classified DEM.

4.2.5 RESULT

4.2.5.1 THAMIRABARANI DELTA

4.2.5.1.1 The coast in the early nineteenth century

The analysis of the old maps of 1805, 1822 and 1828 suggests the presence of two large choked-lagoons connected to the sea through narrow channels during that time. Traces of one of the lagoons are identified on the north side of the river Thamirabarani and the other is noticed on its opposite side, south of the river; twinning together and forming a mirror image with almost the same size covering an area of more than 2500 acres. However, it is difficult to ascertain how shallow was the lagoons and the influence of seasonal variations at that time. Apart from these two lagoons, few paleochannels connecting the river to these lagoons and supplying fresh water have also been identified. The term *Kayal* in Tamil means a lagoon. The identification of these two lagoons also explains the name of the historical port Kayal (Palayakayal) and Kayalpatnam, which lie beside these lagoons (ref. Figure 4.4).

4.2.5.1.2 The coast in the early twentieth century

The analysis of the map of 1919-20 indicates complete siltation of both the choked-lagoons except for a small patch in the northern lagoon (currently known as Palayakayal wetland) and in the southern lagoon (presently it is a freshwater tank named Puthu Kulam). The channels that were supplying river water to them were also found dried by then. However, we see an increase in the area of the Korampallam tank in the 1919-20 map (ref. Figure 4.5). The presence of water in the area of identified lagoon has not been noticed in Google earth historical imageries of recent decades even during the rainy season. To understand the transition of lagoons to agriculture fields, more large-scale maps of the interim period are required.

Heavy siltation has also been recorded in the historical documents of the mid and later nineteenth centuries. Cardwell, who visited the site in 1861, reports a great abundance of seashells on the 'very shallow' alluvium deposited by the river, particularly near Maramangalam (which lies immediately south of the north lagoon). According to Foote (1883, p. 81), the rapid siltation of lagoons is due to sediments brought down by the river. The instances of heavy siltation can also be drawn from the fact that the height of the Srivaikuntam anicut (constructed in 1874) was raised to two more feet twenty years after its construction (Pate, 1917, p. 174). Floods are common in the Thamirabarani river valley. Heavy floods have been recorded almost every decade of the nineteenth-century and early twentieth centuries (Pate, 1917, p. 253).

4.2.5.1.3 The coast at present

The coast has gone through very little change from 1919 to the present (ref. Figure 4.6). There is a slight advancement in the coastline, especially near the Thoothukudi harbour, where the shore has extended to around 350 m (ref. section 4.2.5.2)[33]. The scale of the 1919-20 map was not large enough to analyse distributaries and networks of small lagoons near the mouth of the rivers. Thus, the analysis has not been carried out on changes that occurred along with these features. Overall, the observed changes from 1805 to 1919 are higher than changes in the last hundred years.

4.2.5.1.4 DEM Analysis

The location, shape and size of low-lying areas identify through DEM directly corresponds to paleo lagoons identified through early maps, which further confirms the extent and existence of paleo lagoons (ref. Figure 4.7). The flood plain of Thamirabarani separates both the paleo lagoons. Inundation model of 3m, 6m and 8m RSL rise is analysed using early maps and location of historical port site. A rise of 8 m RSL inundated the coastal plains and floodplains around Thamirabarani as far as 10 km inland, including the site of all the historic ports in the region (ref. Figure 4.7A). At 6 m rise, the Korkai port site and its immediate surroundings, a small patch near Palayakayal port, and a larger area of dune ridges of Kayalpatnam are seen above water level (ref. Figure 4.7B). On a rise of 3m, Korkai is found 3 km inland, Kayalpatnam is lying near the shore, Punnaikayal island is much smaller than it is now (ref. Figure 4.7C). In the absence of data on—terrain conditions in the Pleistocene epoch, tectonic movement, and the amount of siltation and aeolian deposition—the inferences from the inundation model were only used to understand the relative height of landforms. The model does not reflect the actual sea level values. DEM analysis helped in understanding the possible order of the geomorphic changes that occurred in the past. The analysis led to propose a theory on the evolution

[33] This measurement is based on the overlay of 1919 map on the base map and the strandline identified on that base map.

of Thamirabarani delta and the formation of Thootukudi tombolo, which is discussed later in Section 4.2.6.

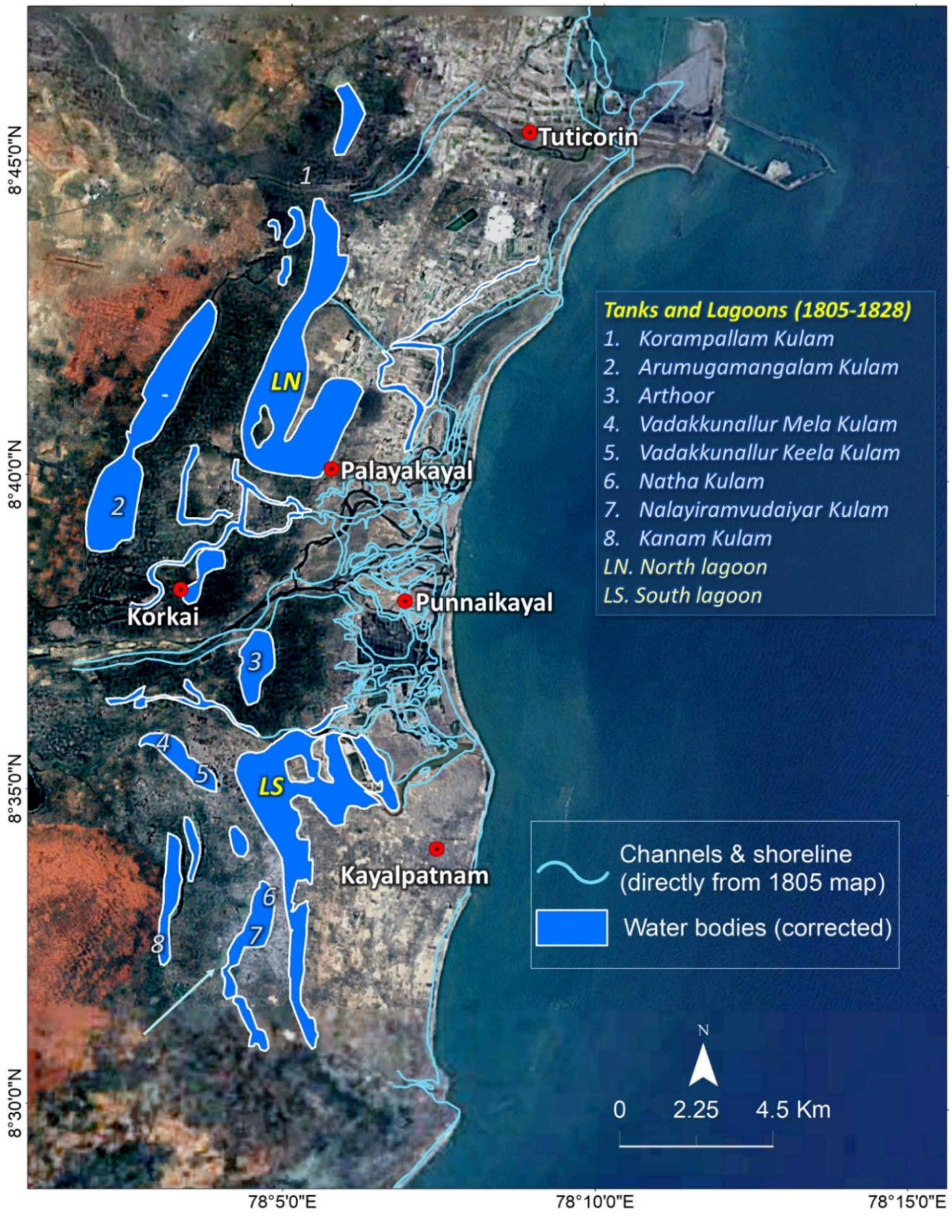

Figure 4.4. Extent of tanks and lagoons in the early 19th century (water bodies delineated using 1805 & 1828 maps and satellite images). Image data © Google Earth, Maxar Technology, 2020.

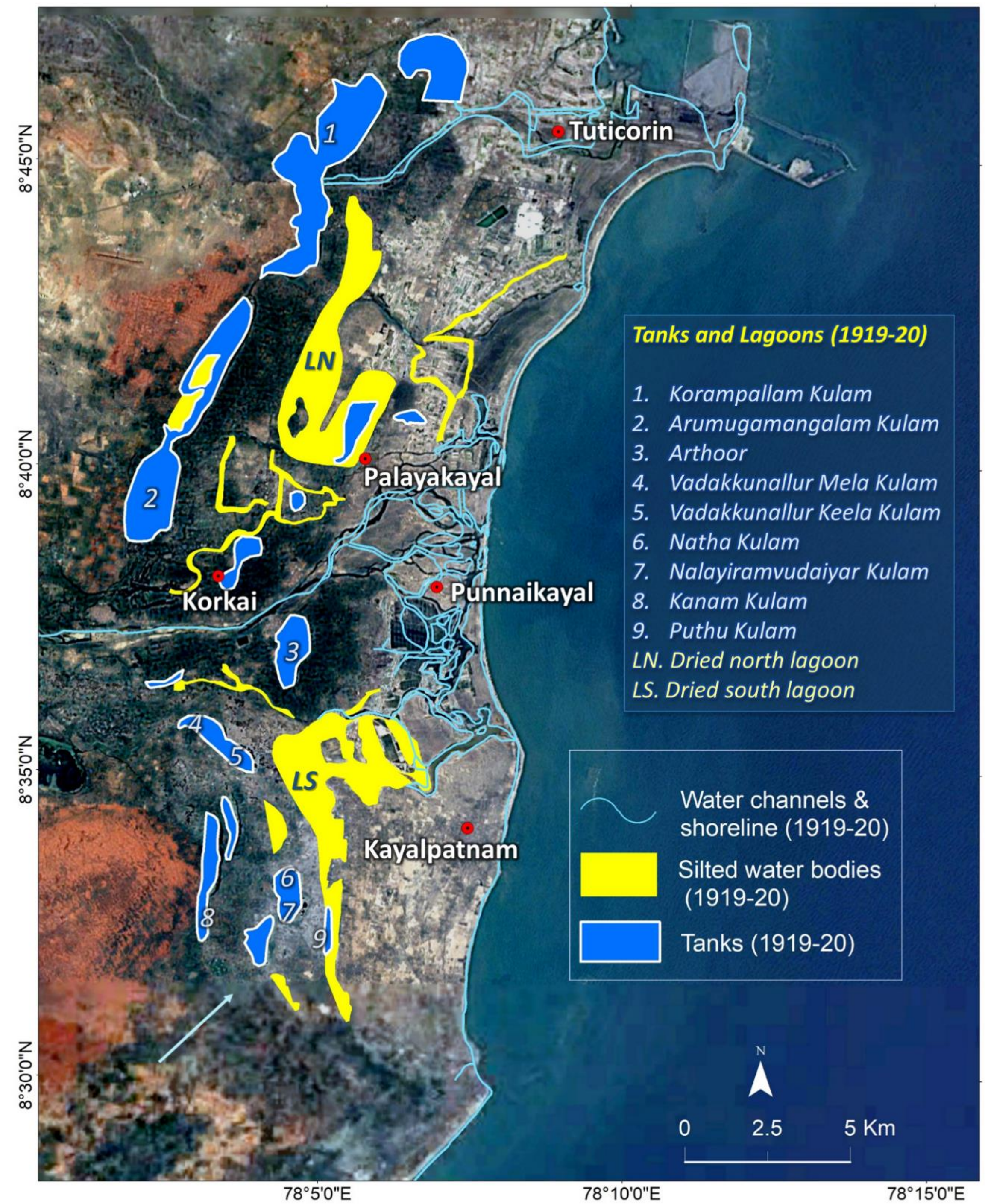

Figure 4.5. Extent of active (blue) and dried (yellow) tanks and lagoons in the early 20th century (based on 1919 map). Image data © Google Earth, Maxar Technology, 2020.

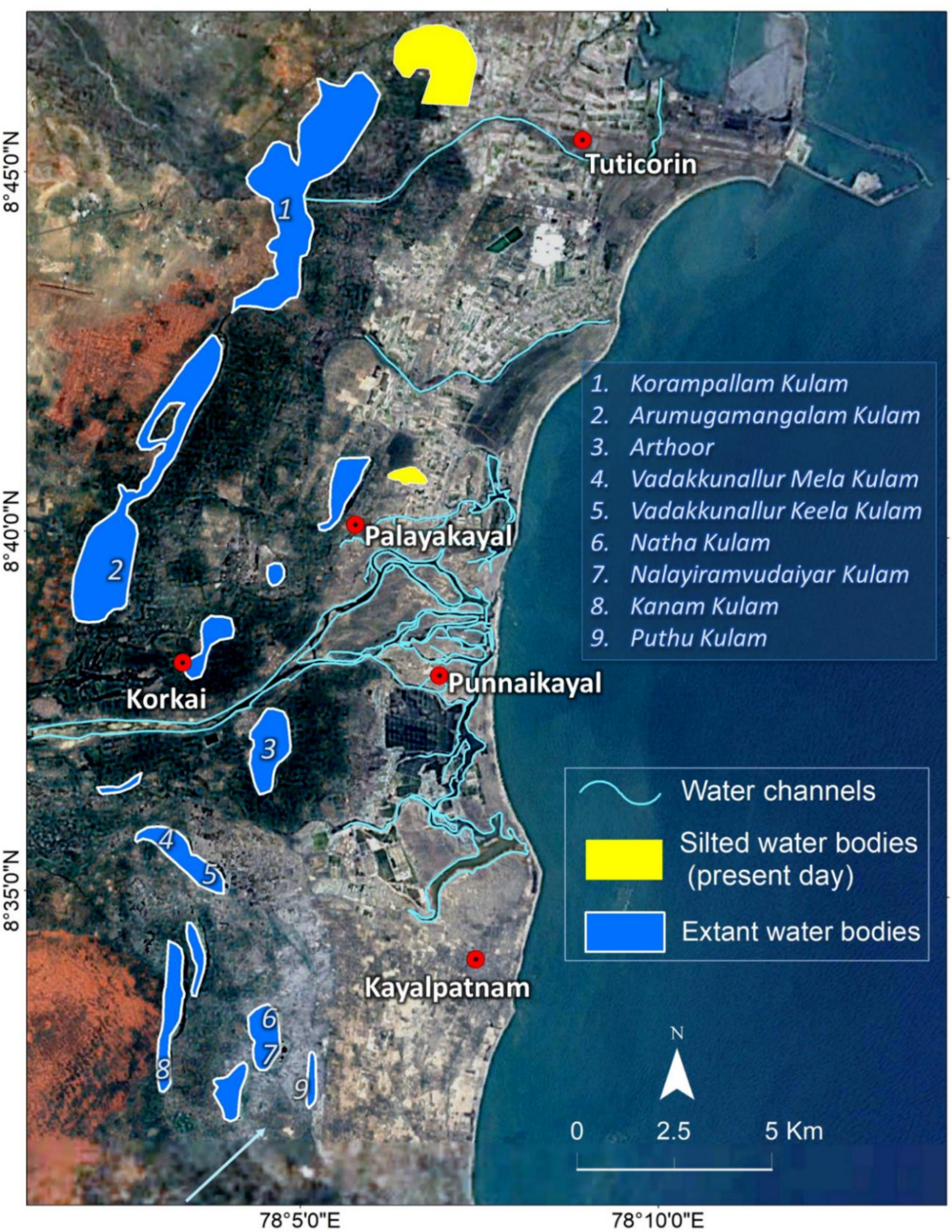

Figure 4.6 Extent of active (blue) and dried (yellow) tanks and lagoons at present (based on 2020 satellite image). Image data © Google Earth, Maxar Technology, 2020.

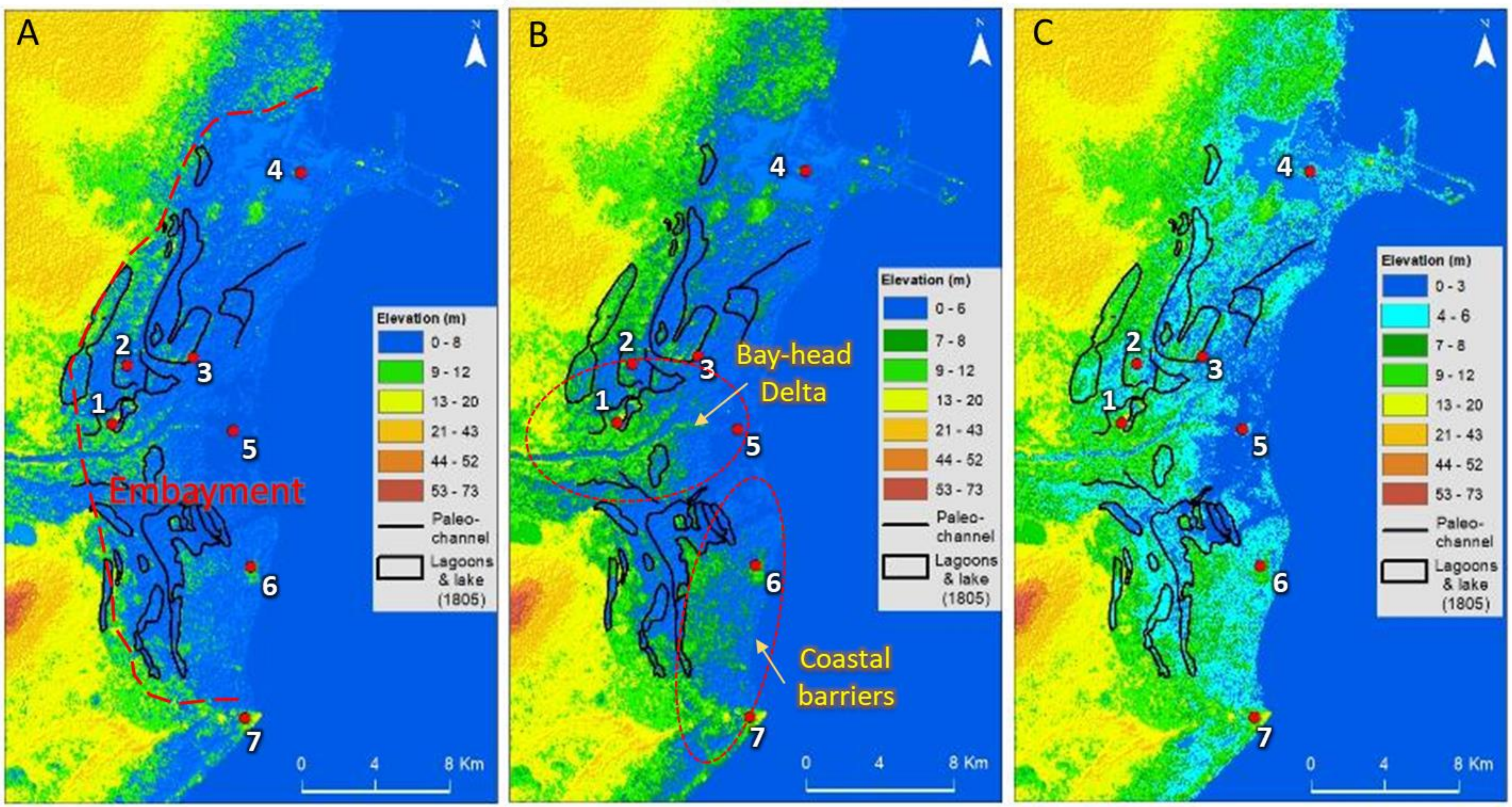

Figure 4.7 Visualization of transgression in Thamirabarani delta and later stages of successive regression using 'bathtub' inundation DEM model. Red dashed line in panel A marks the probable extent of the embayment. Red dashed circles in panel B highlights the raised coastal features (bay-head delta and coastal barriers). Emergence of land corresponds to the location of ancient ports in a chronological order. 1. Korkai Port, 2. Maramangalam, 3. Cail Port (Palayakayal), 4. Thoothukudi Port, 5. Punnaikayal Port, 6. Kayalpatnam Port, 7. Thiruchendur.

4.2.5.2 THOOTHUKUDI (TUTICORIN) TOMBOLO

Tombolos are wave-built depositional features that join the island or any other natural and man-made offshore obstruction to the mainland. The analysis of various kinds of maps, interpretation of satellite images, the juxtaposition of maps and images and their corroboration with other historical records suggest the following (ref. Figure 4.8 & Figure 4.9):

1) The Pandayan and Punnaiyadi islands were about 5 km away from the mainland in the late seventeenth and eighteenth centuries.

2) A spit seems to have grown from the extreme north of the Thamirabarani delta towards the islands, as can be observed in the early nineteenth century maps. The presence of this spit is also recorded by Cardwell in 1861. Foote in the 1870s also recorded the growth of the spit towards the islands.

3) By the end of the nineteenth century, the spit grew eastward and broadened to form a cape known as Devil's Point. The passage between Devil's Point and the islands was called Devil's Pass. The depth of the passage was marked as 16 ft. in a chart of 1879 (Pate, 1917, p. 20).

4) The transformation of the cape at Devil's Point to the tombolo occurred in the early twentieth century. From 1919, the coastal stretch, from the southern tip of the island towards further south for about 7km, has prograded seaward for around 450m.

According to Sudarsan (2007), multiple factors such as the combined effect of waves, abundant supply of sediments from Thamirabarani, longshore drift in the northerly direction, orientation of the islands parallel to the coast, cumulative length of islands and Muramshulli reef (> 6 km), the distance of islands from the mainland (~5.5 km) have been instrumental for the growth of this tombolo (Sudarsan, 2007). Though his understanding of the formation of the Tuticorin tombolo is very convincing, the representation of stages of its evolution is oversimplified. It underestimates the influence of longshore drift. Figure 4.10 illustrates the evolution of the Thoothukudi tombolo as understood from the present study and compares it with the diagram given by (Sudarsan 2007).

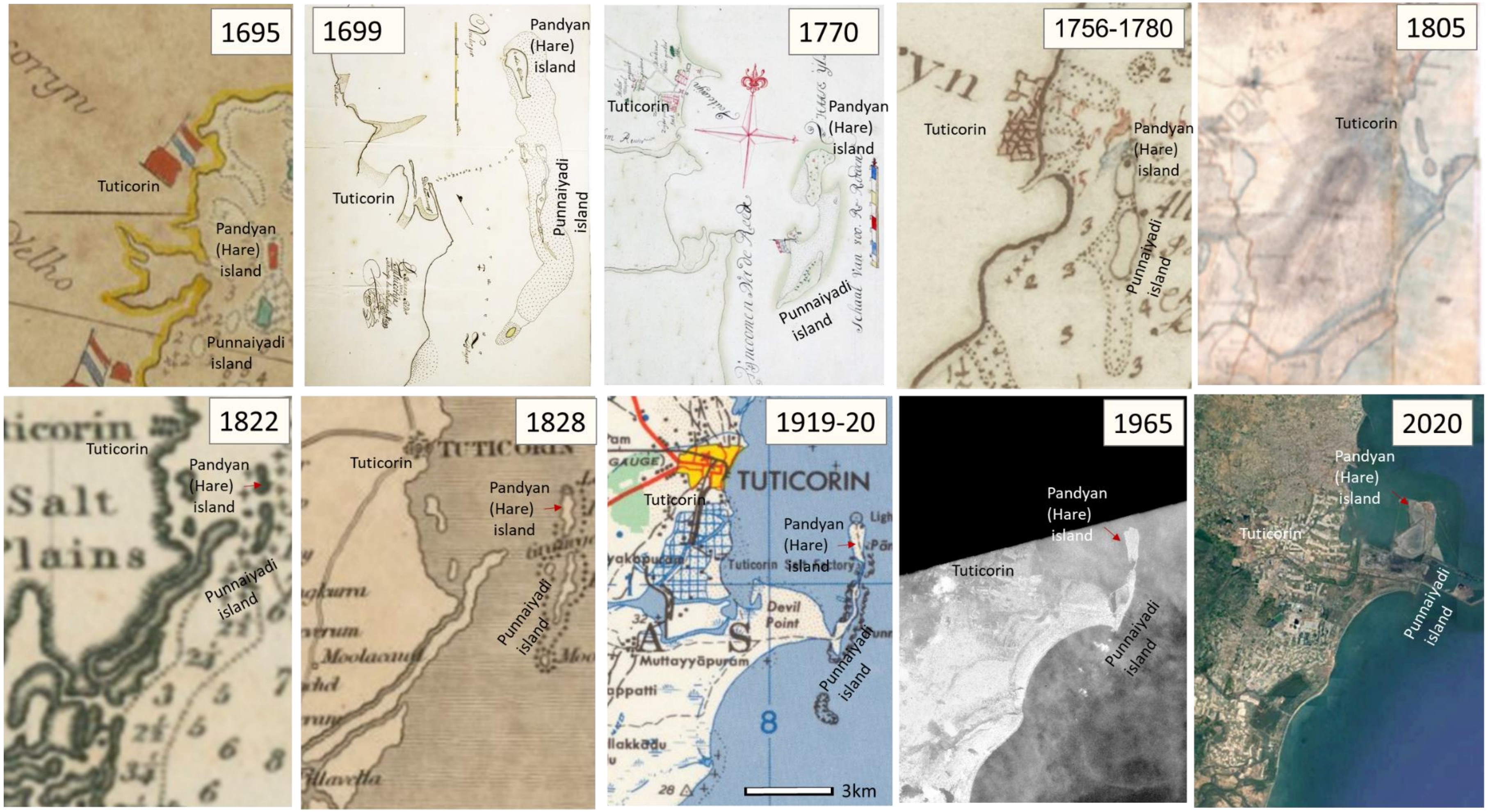

Figure 4.8 Depiction of the Thoothukudi mainland and the islands in the historical maps; wide gap between the mainland and islands in the 17th & 18th century; growth of spit in 1805, 1822 and 1828 map; and the tombolo formation by the 1919.

Figure 4.9. Shoreline digitised from georeferenced and non-georeferenced historical maps overlaid on a satellite image of 2020 showing the stages of tombolo formation. Image data © Google Earth, Maxar Technology, 2020.

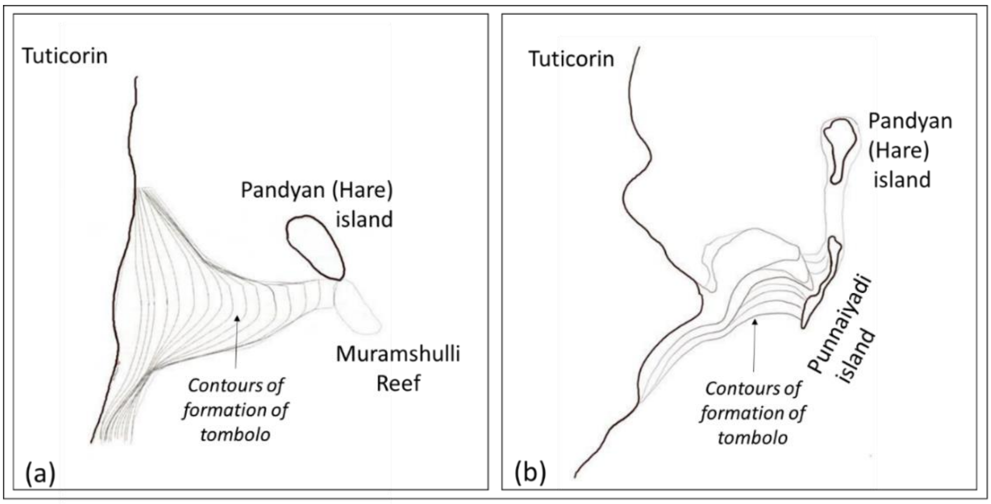

Figure 4.10 Comparison between (a) the existing theory of Thoothukudi (Tuticorin) tombolo formation from the salient (adapted from Sudarsan, 2007) and (b) the proposed theory deduced from map analysis.

4.2.6 EVOLUTION OF THAMIRABARANI DELTA: A DISCUSSION

The study finds the presence of two large choked-lagoon 3 km inland in the early nineteenth century. These paleo lagoons extend up to the south-eastern side of Korampallam Tank in the north and up to mid-way between Tiruchendur and Kayalpatnam in the south covering about 20 km north-south extent. They are found in low-lying areas. According to the description by Cardwell (1881, pp. 76, 284), seashells and deep-sea shells such as the *Chanks* were present in great abundance as far as Korampallam Tank and Maaramangalam. Some of the shells have been even found retaining a portion of their original colour. It suggests that the extent of the lagoon was even larger before the nineteenth century.

Previous studies suggest that coastal lagoons were formed around 6000 years ago on the valley mouths and low-lands submerged during the worldwide Holocene transgression (Bird, 2008). The morphology of lagoons broadly depends on geology, geomorphology, the sequence of changes in the RSL that have caused the coastal submergence, and the growth of coastal barriers that determine its interaction with the sea waves and tides (Bird, 2008). During the initial stages of progradation of beach ridges, sediments are supplied primarily from nearshore and in later stages, it is mostly supplied from the river (Anthony, 1995). The supply of sediments from various sources such as rivers, tidal currents, and wind gradually fills these lagoons and replace them with depositional coastal plains. Lagoons fed by rivers sometimes form delta of varied types (Bird, 2008).

A recent review article on Holocene sea-level change of the East coast of India is relatable to the worldwide transgression and indicated that the rising sea level reached the present level around 6800 years BP and a rise of ~4m was observed around 6050 years BP; since then sea-level fluctuation is found to be lesser in magnitude (Loveson & Nigam, 2019). Scott et al. (1989) also identify a sea transgression in this region after c. 6200 BP. A study of the Pulicat lagoon, which is about 580km north of the Thamirabarani delta, suggested that the sea level in that region was at maximum 6650 years BP (Farooqui & Vaz, 2000). This mid-Holocene transgression was followed by a phase of regression in the late Holocene (Vaz & Banerjee, 1997; Banerjee, 2000; Farooqui & Vaz, 2000; Alappat et al., 2015). During this phase of regression, Pulikat's extensive lagoon barrier system was formed (Vaz & Banerjee, 1997). Evidence of the sea-level rise of a few meters between

5200 and 4200 years BP was observed from Kanyakumari to Rameshwaram by Banerjee (2000).

The trunk portion of the Thamirabarani river has been found tectonically active with evidence of intense vertical uplift. Evidence indicative of tectonically induced subsidence and submergence of coastal region around the mouth of the river and later exposure of marine sediments to subaerial conditions due to tectonic uplift has also been noticed (Ramkumar et al., 2019).

Considering the data available on various published literature on past sea-level change, climate, geological and geomorphological processes in this region, the bay at the mouth of Thamirabarani seems to have formed during the transgression between 6000 and 4000 years BP. Evidence of sea transgression such as – occurrence of a few inches' thin layer of gritstone two feet below the surface of the town, underneath which lies sea-sand (larger grains above, the finer below); grit-stone formation all along the coast and half a mile further inland; occurrence of marine molluscs along the bank and floor of Korampallam tank; and scallops and oysters at 5 m above the sea level were observed by Cardwell in 1861. The abundance of seashells and chanks found in places that are 10 km inland and 11 feet high from the local sea level around the Tuticorin region suggest a large extent of the transgressive bay. Inundation model at 8m high sea level forms a large transgressive embayment which extends up to 10km inland and inundates places where Cardwell had found evidence (ref. Figure 4.7A).

During the mid-Holocene epoch (7-3 Ka BP), the climate was relatively wet and stable (Deo et al., 2011; Ramkumar et al., 2019). High precipitation, which results in high river discharge and more sediment yield, favours aggradation (Anthony, 1995). Bayhead deltas develop in diverse geologic settings, including flooded incised valleys and protected back-barrier environments (Simms et al., 2018). They are formed where the rate of sediment supply exceeds the transgression rate (Aschoff et al., 2016). Bayhead deltas recorded significant growth around 5000 years ago when there was a fall in the rate of sea-level rise (Simms et al., 2018). The last Glacier Maxima curve shows a decreasing trend around 6000 years ago (Loveson & Nigam, 2019). The bayhead delta was possibly formed in the incised drowned valley of the Thamirabarani river during this period (ref. Figure 4.7B).

A falling sea level is an important factor in forming successive beach ridges (Anthony, 1995). Regression of sea in the late Holocene and abundant supply of sediments (initially from nearshore, later from the river, and also from the erosion of Manapad and Tiruchendur headlands) had possibly resulted in the gradual development of barrier and beach ridges across the embayment (north of both Tiruchendur and Palayakayal) forming a big lagoon (ref. Figure 4.7B).

In this protected environment with an excess supply of sediments from the river Thamirabarani, the bayhead delta could have possibly grown seaward, dividing the lagoon into two halves and reached the present shoreline to form an open marine delta by the sixteenth century (ref. Figure 4.7B). The river also provided direct sediment supply to the lagoon and the coast, especially during the flood, and caused rapid siltation of the lagoon with fluvial deposits(Anthony, 1995) (ref. Figure 4.7C). The sequence of growth of the delta can be corroborated with the location of ancient ports that emerged and then declined in a span few centuries in the past (ref. Figure 4.7). The delta was extending up to the site of Korkai port by 800 BCE which is 7km inland now. The gradual siltation made the port defunct by 6 century CE and a new port Palayakayal (‘Cail’), about 3 km inland and around 6 km NE of Korkai, emerged as a major port. The delta prograded further seaward and made Palayakayal unsuitable for navigation by mid of sixteenth century. An accumulation of sediments of 2.5 m height occurred at Korkai since the beginning of the Christian era and 1 m at Palaiyakkayal since the 13th century (Deloche, 2012). In the context of ancient harbours in deltaic region, river mouths were preferred, though such locations were rarely sustainable due to continuous sediment supply and change in the course of river (Giaime et al., 2019).

The above description of the evolution of the Thamirabarani delta is based on the understanding gained from the analysis of historical maps, elevation models, satellite image analysis, and understanding obtained from various other literature. However, the effect of low magnitude transgression and regression that occurred between the mid-Holocene and present-day is not understood. The evolution of the Thamirabarani delta suggested by the present study certainly requires corroboration from the field and lab-based studies such as coring, dating, sedimentology and facies analysis to substantiate its findings.

4.3 KERALA COAST

4.3.1 SITE LOCATION AND HISTORICAL BACKGROUND

The area along the Kerala coast covered in the present study are the stretches of the coast along Chettuva (Chetwa or Chetway) estuary, Kodungallur-Azhikode Estuary (KAE), Vypin Island and Kochi estuary). These coastal stretches house four historically important town/port, *viz.* Chettuva, Kodungallur (Cranganore), Pallippuram (Palliport) and Kochi (ref. Figure 4.11). Some scholars believe that the present-day Kodungallur (5km inland) was the famous ancient port Muziris (mentioned in classical Tamil, Latin and Greek records) that flourished at the beginning of the Christian era (Bristow, 1959, 16). However, recent archaeological excavations have suggested Pattanam, a village 5km southwest of Cranganore fort, as a probable Muziris (Cherian et al., 2014). The waning importance of Muziris port in later centuries is attributed to its downfall and the consequent decline of trade with the Roman empire, and the geomorphic changes that took place at the mouth of the Periyar river, inducing unfavourable conditions for smooth navigation thereof (Bristow, 1959, 25).

An extreme flood event that occurred in river Periyar in 1341 CE caused heavy siltation of the ancient harbour of Cranganore, and the widening of a narrow channel along the Kochi resulted in the formation of an ideal natural harbour (Bartolomeo 1800, 126; Menon 1982, 163; Panikkar 1960, 8). Very soon, Kochi emerged as an important port that is still one of the major ports in the country.

At the beginning of the 16th century, the Portuguese, who first arrived in India in 1498, started looking for the strategic locations to establish their commercial and political bases in India. They built their first fortress in Kochi and Pallippuram in 1503 and Cranganore in 1523. Pallippuram, Cranaganore and Kochi remained in possession of the Portuguese till 1661, 1662 and 1663 respectively, after which it was taken over by Dutch (Menon 1982). Dutch took over Chettuva in 1717 and built a fort in 1718 and made it the capital of their Pupinivattam province (Rea, 1897, p. 46). The fort was named as Fort William.

4.3.2 PHYSIOGRAPHY

This region has a wet monsoon type climate with heavy rainfall during the southwest monsoon season (June-September) and northeast monsoon (October and November). March, April and May are the hottest months. The annual rainfall varies between 2500 to 3500 mm. It lies beyond the cyclone belt and, therefore, has a negligible risk of cyclones. In the 20th century, Kochi and its vicinity recorded four cyclones (in November 1912, 1935, 1959 and 1978). Out of these four, the storm in 1912 was severe (Kumar 2000, 66-7).

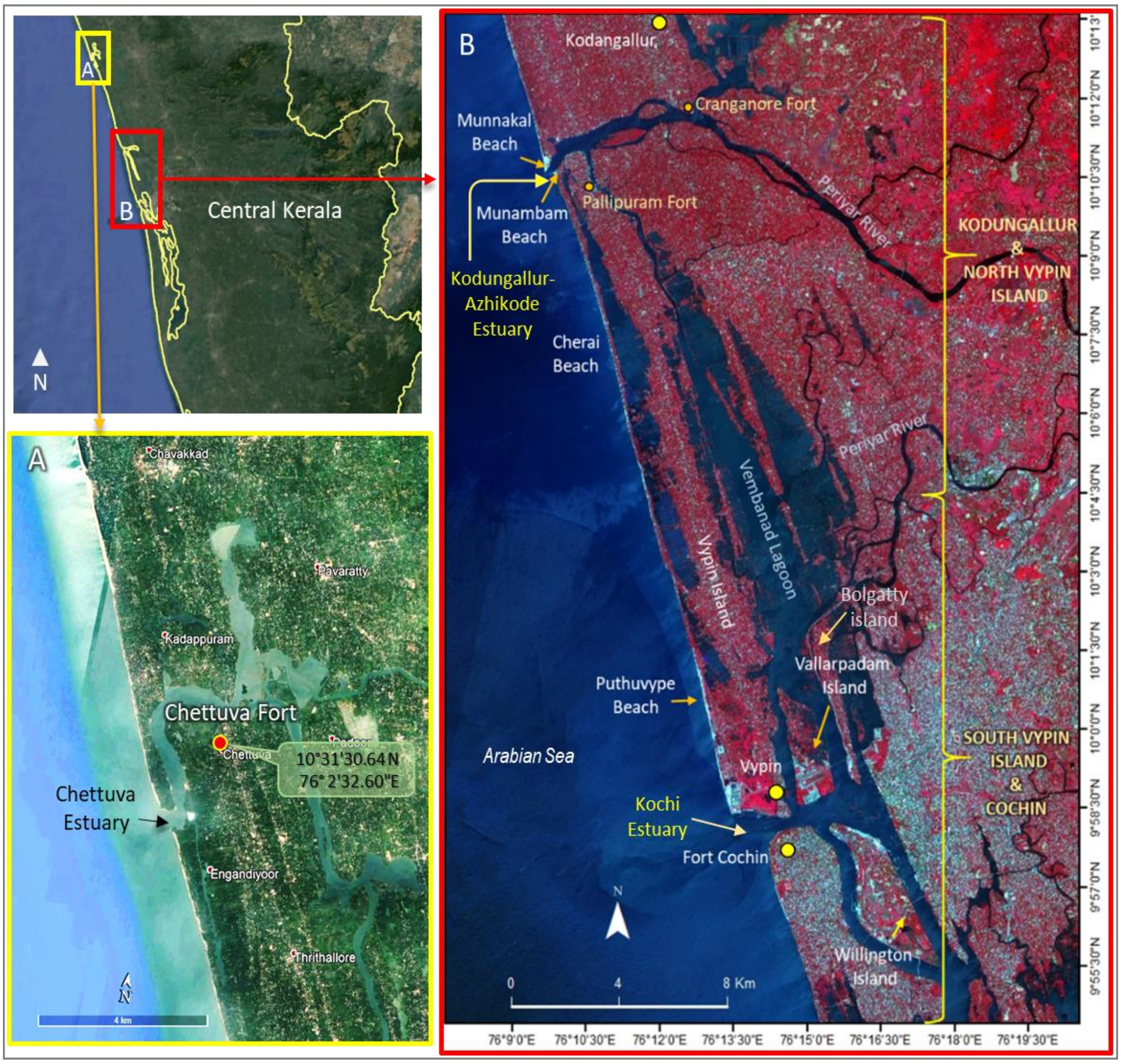

Figure 4.11 Study area in Kerala coast: Top left image shows location of the study area inside the box A & B; A) true color Google Earth Image of Chettuva coast; B) False Colour Composite (FCC) Sentinel 2A image (Band 5, 4, 3) of Kodungallur-Kochi coast. Image data © Google Earth, Maxar Technology, 2020 and USGS Earth Explorer

The coast experiences semi-diurnal tides and a micro-tidal regime with a mean highest high-water level of 1.20 m. The sea bed slopes gently in the offshore region with a gradient of about 1: 500-600. Littoral drift and the phenomenon of the formation of the mud banks (that tends to move along the coast) occur on this coast (*Cochin Port Trust*, 2020).

4.3.3 GEOMORPHOLOGY

The coastal landforms and associated sedimentary deposits in this region are beaches, barrier islands, strandlines, paleo delta, lagoon and flood plains (Narayana & Priju, 2006). This stretch of the coast forms a part of barrier island system which separates Lakshadweep Sea from a chain of elongated lagoons/estuaries parallel to the coast. It is an emerging coast started with a dominant fluvial process that shaped the coast till around 7000 years before present and later it went through fluvio-marine interaction processes around 2000 years before present and ended up as a dominant marine regime (Mathai & Nair, 1988).

The massive flood of the year 1341 brought down excess sediment at the interface of the sea and river, resulting in the formation of the Vypin island north of the present-day Kochi. A great flush of water widened the small *Cocci*[34] river to a very large river and formed a lake and a big spacious harbour on the northeast side of Kochi by violently sweeping away a village of the same name(Bartolomeo 1800, 126; Rajendran, 2019). The coast has formed a series of transgression and sea regression in the past (Kale & Rajaguru, 1985). It is largely shaped by both north-ward and south-ward longshore drift, which resulted in parallel coastal features and a straight and smooth shoreline in the recent past (Kunte, 1995).

4.3.4 MATERIAL USED

Being economically and politically important to the Portuguese, the Dutch and the British, this region was profusely mapped by them since the seventeenth century. The Appendix (Map-15 to Map-34) presents a list of maps used in this case study with its publication date or survey, publisher or map-maker and source.

Satellite data: Corona (31 January 1968) for all three sites and Sentinal-2a (11 February 2020 & 28 February 2020) have been downloaded from USGS EarthExplorer web portal.

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[34] The name Cochin in Malabar language is called as *Cocci named after a river of the same name.*

Google Earth Pro has been referred to analyse very high-resolution images (available from 2002) and Landsat images (available from 1985).

4.3.5 METHODOLOGY

Similar to the previous case study, all the maps of this region procured for the study were assembled in chronological order and then analysed as follows:

4.3.5.1 CONTENT AND CONTEXT OF THE MAPS

4.3.5.1.1 Temporal context

The oldest available maps of Kodungallur-Azhikode Estuary and Kochi estuary were published around the end of the seventeenth century by Isaac de Graaff and anonymous cartographers (ref. Appendix, Map-15, 16 & 17). Chettuva's maps are available from the year 1718 (Map-20). The Map-19 was made by Hans George Taarant in 1697, partly based on data from a survey conducted between 1666-1667 by map-maker and skipper Jan Tim (Schilder & et al., 2006, Vol VI). It is a large-scale map that represents the coast from Cranganore fort to Kollam fort. Johan Willem de Graaf, military engineer and surveyor, produced another largescale map of a larger extent, including the Chettuva between 1767 and 1800 (Map-23). The Map-24 (1767) is a copy of Graaf's map produced by H. A. Heidenreich around 1770 with some additional detail (Schilder & et al., 2006, Vol VI). All the maps of the seventeenth and eighteenth century, except Map-25 (British), were made by Dutch. Nineteenth-century maps were made by the British.

4.3.5.1.2 Scale

Maps from Map-15 to 21 except Map-19 are very large-scale maps. The geometry of Map-17, 18 and 21 is comparable to the shape of the coast. However, other maps among these are cartometrically very inaccurate. All maps (Map-15 to 21, except Map-16) mark a north arrow and a graphical scale. The large-scale map by Taarant and Graaf (Map-19) have rich content in terms of labelling and representation of the coastline, buildings and other landuses and is one of the most accurate large-scale maps of the time. Map-22, to 24 and 28 to 29 are medium scale maps. Map-31 is a detailed large-scale Kochi estuary with a graphical scale in furlongs and north arrow. Map-32 and 33 are 1: 250 000 scale and Map-34 is 1: 50 000.

4.3.5.2 SPATIAL ANALYSIS USING DIGITAL GRAPHICS

4.3.5.2.1 Tracing maps using graphics software

Due to the absence of well-defined stable features that can be used as control points and low cartometric accuracy, all seventeenth and eighteenth-century maps were traced manually on digital graphic software (Sketchbook) and saved with a transparent background. The British Hydrographic chart (Map-30) does not depict any well-defined stable features as these sea charts focus mostly on the coastline, navigable water channels and offshore areas. Therefore, despite good cartometric accuracy, the chart was digitised using a simple tracing method without georeferencing.

4.3.5.2.2 Grid analysis

A square grid of uniform scale of 500 X 500m (diagonal distance is ~700m) for Chettuva region and 1000 X 1000 m (diagonal distance is ~1400m) for Kodungallur-Azhikode-Vypin-Kochi regions are created (ref. Figure 4.14, 4.15 and 4.16). Coastline, lagoons, rivers and islands are digitised on a satellite image of the year 2020, and the digitised vector file is adjusted to a grid-sheet on a reduced scale. Digital outlines of other maps and images are brought to the same scale and orientation as the reference map and are arranged chronologically on the grid using these two reference lines. Due to ambiguity in the identification of common references and/or high anomaly in depiction and/or smaller area coverage, 1718, 1720 and 1750 maps of Chettuva and 1678 & 1680 maps of Kodungallur-Azhikode estuary region are placed with blank background on grid sheets (ref. Figure 4.14 and 4.15). The presence of these maps on the grid sheet made them available for comparative analysis. Recognisable sharp bends are identified as reference points in all the maps. These points are marked on the sheet, and lines from the 2020 map are highlighted for easy reference. An example of how these maps are interpreted logically is given in Figure 4.12 and discussed in Table 4.4. For more on Scaled Grid method ref. Chapter-3, Section 3.2.3.6.

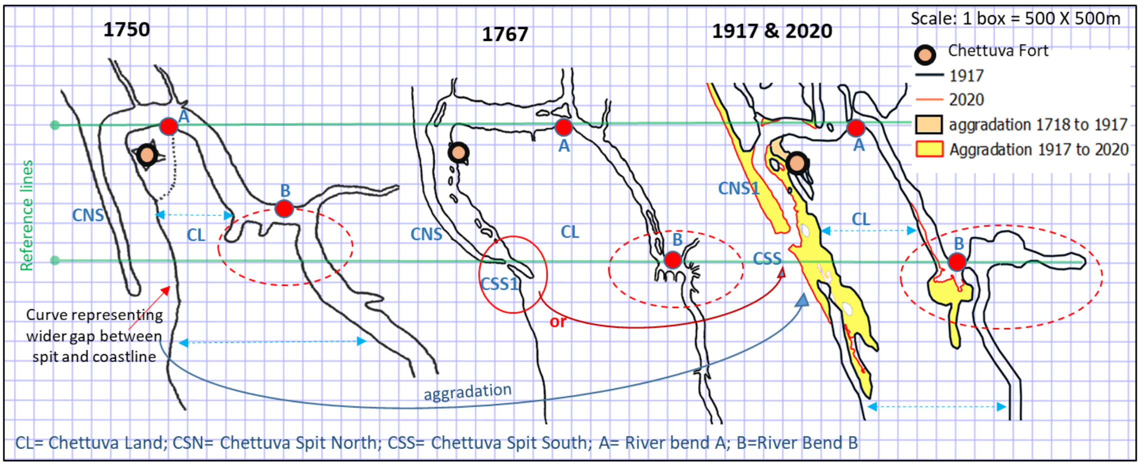

Figure 4.12 Logical interpretation of early maps of Chettuva (ref. Table 4.4)

4.3.5.3 GEOSPATIAL ANALYSIS

Remote sensing and GIS are widely used to study shoreline changes and understand coastal processes (Nayak, 2002). Strandlines on Corona and Google Earth images are identified and digitised. Selected maps and satellite images are integrated in a GIS platform, and shoreline change is determined for the study area as follows:

4.3.5.3.1 Identification of paleo features on satellite image

Features such as paleo backwater channels and lagoons, strandlines and beach ridges were traced from the satellite images, particularly Corona and Landsat images. Paleo features near Chettuva estuary were traced based on their shape, extent and relative distance identified on early maps and the presence of fieldmarks at their corresponding location on satellite images (ref. Figure 4.13). Strandlines and paleo recurved spits in Vypin Island was identified on Corona and Landsat images (ref. Figure 4.23).

4.3.5.3.2 Selection of the maps for quantitative analysis

Maps with a minimum of six well-distributed and well-defined stable features that can be located on the satellite image or any recent map are used for quantitative analysis. Among all the maps listed in Appendix, Map-29 (1840), Map-31 (1883), Map-32 (1917-18), Map-33 (1917) and Map-34 (1980) were used.

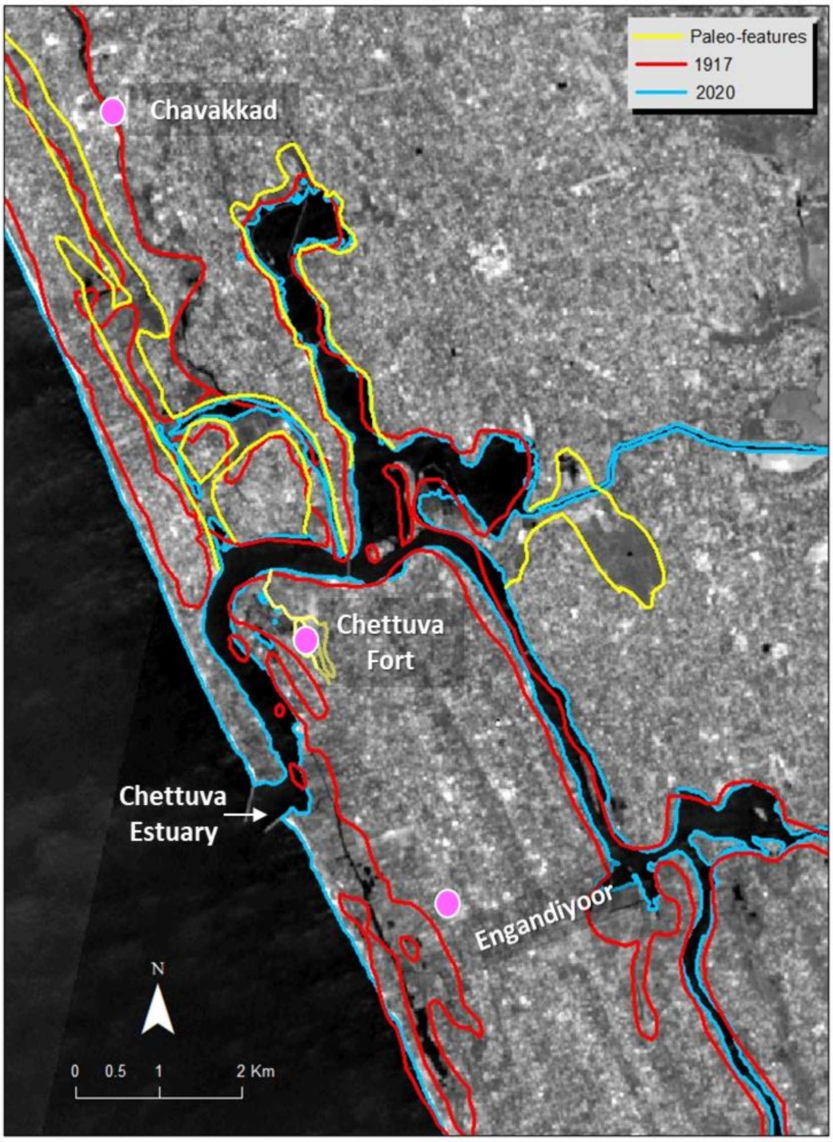

Figure 4.13 Identification of paleo water-features from historical maps and fieldmarks on satellite. image

4.3.5.3.3 Georeferencing

Selected historical map, Corona images of 1968 and high-resolution satellite image of 2020 (used as a base image) were georeferenced. The georeferenced maps were overlaid on the base image to check further the local accuracy of maps and the control points. Based on this assessment, necessary corrections were made on the location of identified control points, and the maps were georeferenced again. Information of total control points, transformation type and errors are given in Table 4.2. For the detailed discussion on georeferencing of old maps, refer Section 3.2.4.1 in Chapter-3.

Table 4.2 Georeferencing Parameters.

Map/image	Year	Transformation	Total CP	Errors (m)			Pixel size
				RMSE	Highest Residual	Lowest Residual	
Map-29 (ref. Appendix)	1840	P2	12	190	315	49	42
Map-31 (ref. Appendix)	1883	P2	11	18	31	3	10
Map-32 (ref. Appendix)	1917-18	P2	20	41	100	3	38
Map-33 (ref. Appendix)	1917	P2	10	47	92	3	38
Corona 62	31Jan68	PT	8	4	6.6	1.3	3
Corona68	31Jan68	PT	18	6	11	1	3
Corona41	31Jan68	PT	10	2.8	4	1	3

4.3.5.4 SHORELINE DETERMINATION AND DELINEATION

Map: the coastline marked in the old maps is taken as the shoreline for the shoreline change analysis. A common scale (1: 20,000) was adopted to make an equal generalisation of all the maps. The selection of the scale was made by optimising details of large and small-scale maps used in the study. However, it was found that digitisation of reduced large-scale maps is causing an error up to 20 m.

Satellite images: The ratio of band 2 and band 5 of Sentinal-2 satellite data has been used for automatic shoreline extraction of sentinel-2 images (for detail ref. Chapter 3, Section 3.2.4.5). Shoreline proxies in panchromatic Corona images are obtained based on the recommendation of ICMAM, INCOIS and NCESS; wet/dry line for sandy shore, land and sea boundary whenever the wet/dry line is not visible, and artificial structure such as sea wall was considered (Kankara et al., 2018).

Uncertainty in shoreline measurement

As discussed in Chapter 3, uncertainty in shoreline measurement can be due to positional errors and measurement errors. Sources of errors and their uncertainty value with the rationale are given in Table 3.3 in Chapter-3. Total uncertainty (Et) value is calculated for shorelines of each georeferenced map and satellite image using the equation given in Chapter 3, Section 3.2.5.6, and populated in Table 4.3.

Table 4.3 Uncertainty value of maps and images. (For details, ref. Table 3.3 in Chapter 3)

Maps	E_{px}	E_r	E_d	E_p	*Et (m)*
1883	10	18	10	10	***25***
1840	42	190	42	10	***199***
1917-18 (07)	38	41	38	10	***68***
1917 (11)	38	47	38	10	***72***
1968 (a)	3	4	6	10	***13***
1968 (d)	3	6	6	10	***13***
1968 (b)	3	2.8	6	10	***12***
2020	20	10	NA*	10	***24***

4.3.5.5 SHORELINE CHANGE ANALYSIS

Shoreline change analysis is carried out using Digital Shoreline Analysis System (DSAS) version 5.0 following the procedure explained in Section 3.2.5.7 in Chapter 3.

4.3.6 RESULT

4.3.6.1 INTERPRETATION OF GRID ANALYSIS

Grid analysis has been useful in placing the seemingly inaccurate historical map in the spatial context of the real world. Parallel comparison of maps on the scaled grid enabled evaluation of the accuracy of relative shape and dimension of the historical maps while keeping the geomorphic changes that occurred in time in the mind. Major observations and evaluation of map content of Chettuva, Kodungallur-Azhikode, Kochi Estuary and the surrounding area from the Scaled-Grid analysis method are summarised in Table 4.4, Table 4.5, Table 4.6 respectively. Synthesis of the observations obtained through this analysis is discussed as follows:

4.3.6.1.1 Chettuva estuary and its adjacent coast

This coastal stretch includes the area from Chavakkad in the north to Vadanappally in the south of the estuary. From Figure 4.14 and Table 4.4 it is understood that the northern spit that is running towards the south is almost of the same length between 1718 and 1840. The reduced length is noticed by 1851-53, which, as shown in the 1917 map, further drastically reduced along with the southern spit; after which, within 50 years, grew about 2.5 km long and 500m wide. Since 1965 the coast has become more or less stable.

The presence of two spits south of the Chettuva estuary is noticed in the 1718 and 1720 maps. From 1765 onwards, the southern spit looks more or less stable, except for the 1917 map where we notice remarkable erosion. Backwater channels and lagoons are found to be gradually silting from the mid-nineteenth century to the mid-twentieth century. The silted water features are highlighted in Figure 4.13. Slight erosion is noticed after 1980. Recently, the construction of Chettuva harbour has enhanced erosion on both sides of the estuary (Noujas & Thomas, 2015).

4.3.6.1.2 Kodungallur- Azhikode Estuary and North Vypin

This coastal stretch includes the area from Azhikode in the north to Edavanakkad (northern part of Vypin island). The analysis suggests that there was no spit on the northern side of the estuary between 1678 and 1750 Figure 4.1 and Table 4.3. It started forming in the southerly direction to a length of nearly a kilometre by 1767. A narrow island of around a kilometre long is observed near the distal end of the spit, which seems to have detached from the flow of the water across the estuary or due to interrupted supply of sediments or both (Héquette & Ruz, 1991). With a continued supply of sediments, the spit grew for about 5km southward by 1840. The 1840 map also shows another island of about 1 km near the end of the spit. In the 1851 map, the detachment of the north spit from its proximal end and southward formation of a spit from the north tip of the Vypin Island, running for around 1.5 km, is noticed. The presence of a chain of narrow elongated barrier islands, offshore Vypin, is also observed. These offshore barrier islands seem to have primarily formed by segmentation of the spit due to inlet channel formation (Dillenburg & Hesp, 2009; Gilbert, 1885).

Interestingly, the Vypin Island in this map is depicted as very narrow, possibly due to continuous erosion. Like Chettuva, the 1917 map of Vypin Island also shows almost complete erosion of the chain of offshore barrier islands. However, deposition is also noticed on the east and southeast side of offshore barrier islands. From 1968 onwards, this stretched is more or less stable.

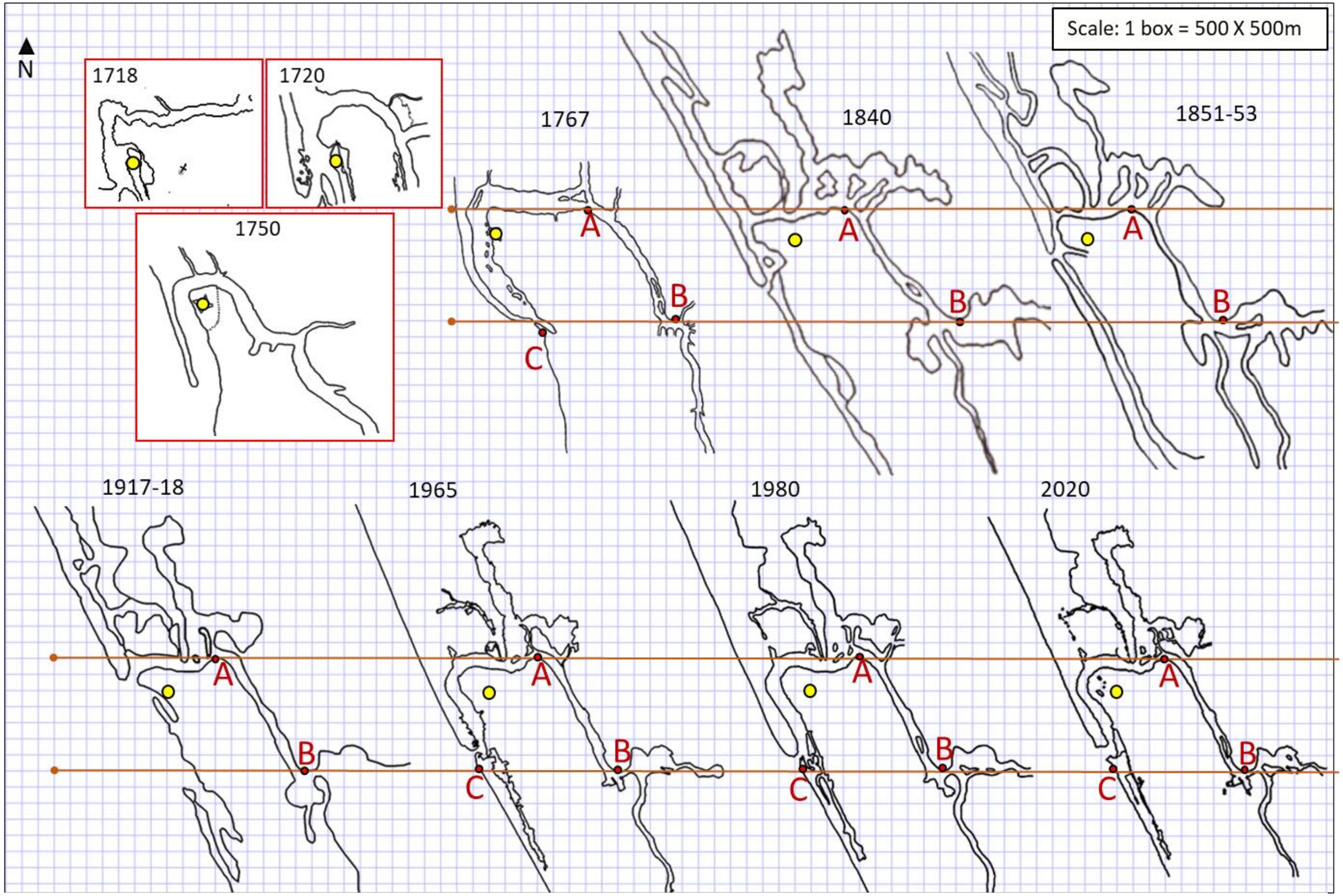

Figure 4.14. Scaled-Grid analysis of digitized historical maps and satellite images of coast along Chettuva estuary; A,B, & C are corresponding common reference points. Grid scale is determined using a 2020 satellite image. (To identify land and sea, refer Figure 4.11)

Table 4.4. Summary of interpretation of Scaled-Grid analysis of the coast along Chettuva. (ref. Figure 4.14)
Y=Yes; N= No; EW=East West; NS=North South; NM= Not measured; CNS= Chettuva North Spit

SITE	***Maps*** (numbers based on Appendix)	***Interpretation based on***			***Evaluation of map content based on***			***Spit length***				***Remark***
		Shape	***Relative distance***	***Presence of Paleo feature***	***Shape of shoreline & water features***	***EW extent of features***	***NS Extent of features***	***Northern Spit***		***Southern spit****		
								Relative length	***Measured Length***	***Relative length***	***Measured length***	
CHETTUVA	Map-20 (1718)	Y	Y	Y	Comparable to 1720 map and identified paleo features on the satellite images & recognised in 1917 map	Not enough relative references to comment	Not enough relative references to comment	Extend upto the south of the latitude of Chettuva fort	NM	See the column 'Remark '	NM	Two spits on the southern side of the estuary are depicted. Chettuva fort is situated on one of the spits which extend a bit north of the fort; and the other spit is at the southwestern side of the fort just below the north spit. The former has been identified as paleo feature on satellite images, the latter noticed in 1720 and 1917 map
	Map-21 (1720)	Y	Y	y	Shape of spits identified as paleo features & recognised in 1917 map	Not enough relative references to comment	Not enough features to comment	Extend further south of the above mentioned extent	NM	See the column 'Remark	NM	Same as previous
	Map-22 (1750)	Y	Y	Y	Comparable with 1765 and 1917 map but displays large distortion	not proportionate to ground distance; Error >Map-23 (1767)	-not proportionate to ground distance; -error >Map-23 (1767)	CNS is extending beyond its present day length and	NM	Feature not found	NM	Useful only for qualitative interpretation in relative terms

								the latitude of Point B				
	Map-23 (1767)	Y	Y	N	Less distortion than 1750 map, but straight features are represented in curves	-Error >1840 map but less than 1750 map -Map distance not proportionate to ground distance	-error >1840 map but less than 1750 -Map distance not proportionate to ground distance	CNS is extending beyond its present length	~4000m (if it is CSS3 of 1917 map) or ~6500m (if it is CSS1 of 2020 map)	Much smaller than CNS	~700m	-Two different interpretation for the south spit (CSS1). -Useful for both qualitative and quasi- quantitative interpretation depending on features
	Map-29 (1840)	Y	Y	Y	High degree of correspondence with present day map and identified paleofeatures	Error <250m near river mouth & increases away from the coast up to 1km;	Error <250m near river mouth & increases away from the coast up to 700m;	CNS is ~700m shorter than its present length	~2200m,	Longer than present day	~1500m (from the latitude of Point B)	-east-west error is more than southwest error; -Useful for both qualitative and quantitative interpretation keeping the errors in mind. It's a hydrographic chart which explains less error along the coast
	Map-30 1851-53	Y	Y	Y	Almost same, however, more generalised than 1840, lines and curves are smoother	-Error <250m near river mouth & increases away from the coast up to 1km; -More cartometric accuracy than 1840	Error <250m near river mouth & in some places such as non-extant channel or lagoon up to 1km;	CNS is ~800m shorter than 1840 map and 1500m shorter than its present length	~1400m	Longer than 1840 map & its present length	~2200m (from the latitude of Point B)	-difference of east-west and southwest error is not noticed -Useful for both qualitative and quantitative interpretation keeping the errors in mind.

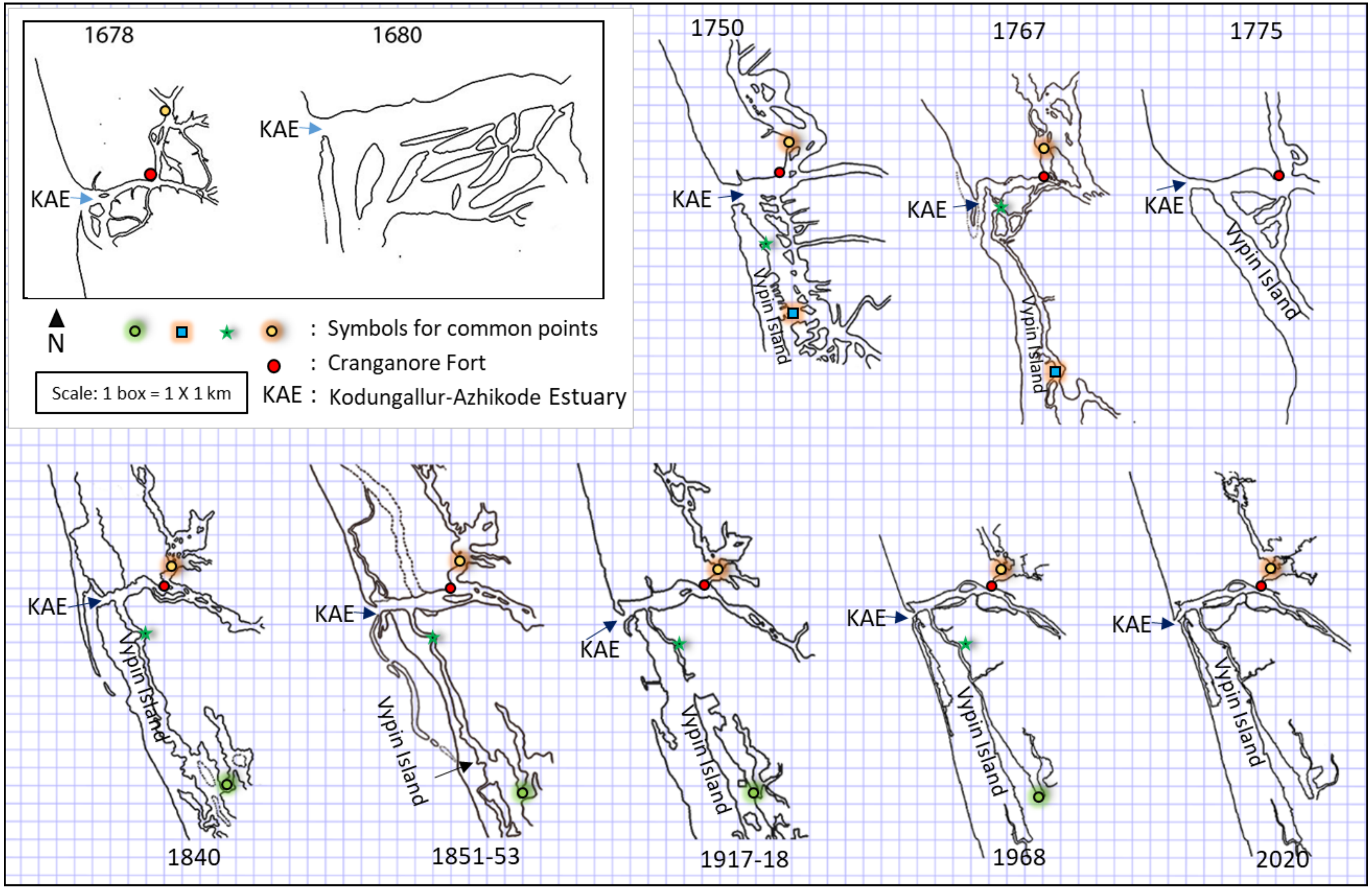

Figure 4.15. Scaled-Grid analysis of digitized historical maps and satellite images of coast along Kodungallur-Azhikode Estuary (KAE). Grid scale is determined using the scale of 2020 satellite image. (To identify land and sea, refer Figure 4.11)

Table 4.5 Summary of interpretation of Scaled-Grid analysis of the coast along Kodungallur- Azhikode Estuary. (ref. Figure 4.15)
Y=Yes; N= No; NA= Not Applicable; E=East; W= West; N=North; S= South; NM= Not measured; **Kodungallur-Azhikode = KA;**

Site	***Maps*** (numbers based on Appendix)	***Interpretation based on***			***Map Content evaluation***			***Spit length***				***Remark***
		Shape	***Relative distance***	***Paleo feature***	***Shape of shoreline & water features***	***EW extent of features***	***NS Extent of features***	***North Spit***		***South Spit***		
								Relative length	***Measured Length***	***Relative length***	***Measured length***	
KODUNGALLUR & AZHIKODE ESTUARY	Map-15 (1678) (analysed without grid)	Y	Y	N	KA land and N & S arms of estuary: comparable; -North of Vypin island (NVI) is represented as a spit and its shape is comparable to 1767 map	KA land better represented than north part of NVI	Similar to 1767 map	Not present	NM	Absent, (though the north head of the NVI is shown very narrow)	NM	Can be useful to extract information regarding the spits and to relate with other early maps
	Map-16 (1680)	Y	Y	N	Number of islands are exaggerated and their shape is not conformal	Relative distance of the land north and south of the estuary is comparable	Not enough references to comment on that	Not present	NM	Absent, (though the north head of the NVI is shown very narrow)	NM	useful to extract information regarding the spits and to relate with other early maps
	Map-22 (1750)	Y	Y	N	-NVI: better than other previous maps; -Backwater channels: exaggerated	Scale is not uniform; KA: compressed	Scale is not uniform;	Not present	NM	Not present	NM	useful to extract information regarding the spits and to relate with other early maps

					-KA land: very generalised	NVI: comparable	NVI: compressed; KA: Stretched					
	Map-23 (1767)	Y	Y	N	-Better than 1750 map in overall representation; -North head of NVI: bent towards the estuary as in 1678 map; Northern arm of backwater: exaggerated	KA: comparable NVI: comparable	KA: not clear NVI: Stretched	Around 1km, followed by an elongated island of about same length near its end, oriented towards SW	~1km	Not present	NM	Important observation: -presence of a narrow island at the end of North spit; -presence of islands south of the estuary as also noticed in all the previous maps.
	Map-25 (1775)	Y	Y	N	Very generalized; Islands: not conformal	Scale and orientation of features are not uniform;	Scale and orientation of features are not uniform;	Not present	NM	Not present	NM	useful to extract information regarding the spits and to relate with other early maps
	Map-29 (1840)	Y	Y	N	Much better than previous maps; shapes of major curves, bends and features is almost matching correctly with slight distortion and generalisation	Overall very good correspondence; difference of half of the grid size is noticed at comparable locations	Same as its EW extent	Presence of a long spit that runs up to present-day Cherai beach, elongated island is present at its end	>5km, Island: ~1km	Not present	NM	Shape of the NVI is broader and different from other maps, possibly due to the changes in the geomorphology as noticed in the following images.

	Map-30 (1851-53)	Y	Y	Y	Similar to the previous maps; shapes of major curves, bends and features is almost matching correctly with slightly more distortion and generalisation than 1840 map	Overall good correspond ence; difference of less than grid size is noticed at comparable locations	Same as its EW extent	Much smaller than what was measured in the previous map	A few hundred meters	Long, narrow and broken strip of land offshore Vypin island stretching from Munamba m to Edavanakk ad	8km (cumulati ve of all the pieces of land strips)	Very short length of north spit and presence of long narrow stretches of spit and islands southward of Manambam suggest a breach of spit after 1840 and relocation and realignment of sediments offshore Vypin island; Shape of the Vypin island narrower than 1840 map and subsequent maps;

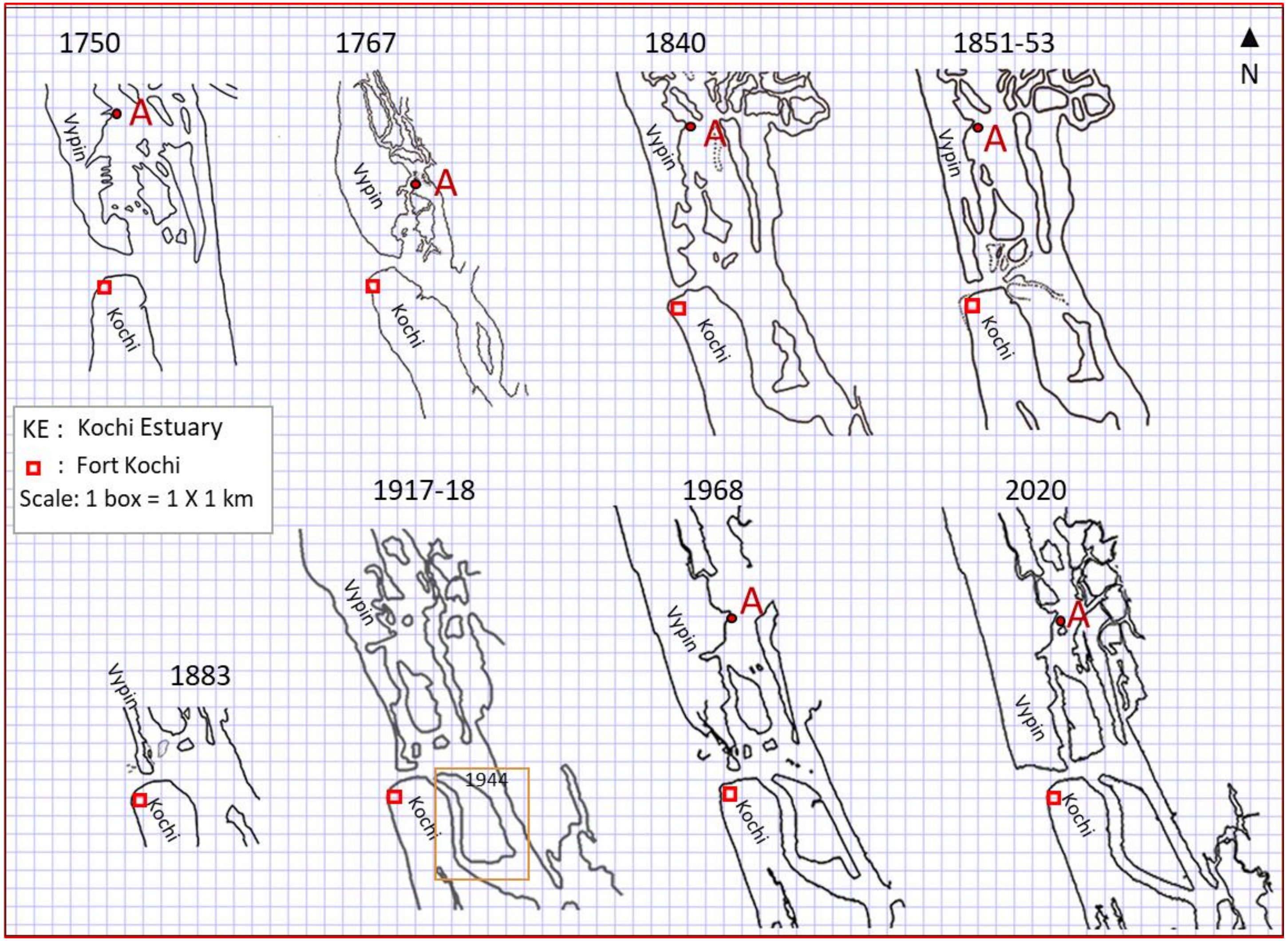

Figure 4.16 Scaled-Grid analysis of digitized historical maps and satellite images of coast along Kochi estuary; 'A' is corresponding common reference point. Grid scale is determined using the scale of 2020 satellite image. (To identify land and sea, refer Figure 4.11)

Table 4.6 Summary of interpretation of Scaled-Grid analysis of the coast along Kochi Estuary. (ref. Figure 4.16)

SITE	***Maps***	***Interpretation based on***			***Map Content evaluation***			***Backwater islands***			***Remark***
		Shape	***Relative distance***	***Paleo feature***	***Shape of shoreline & water features***	***EW extent of features***	***NS Extent of features***	***Vallarpadam***	***Bolgatty or Mulavukad***	***Willingdon***	
KOCHI ESTUARY	Map-22 (1750)	Y	Y	N	Overall more generalised than other maps; South Vypin Island (SVI): *Comparable* with 1840 map; Kochi land (KL): comparable to 1851 map;	Bolgatty island is stretched	Not enough references to comment on that,	Wider than 1767 & 1840; Two small islands on its south and one on its NE side	Wider than 1767 & 1840	Not present	Prominent bends are exaggerated; inward curves are deeper, outwards are more protruding.
	Map-23 (1767)	Y	Y	N	KL: distorted; SVI: wider and convex on the sea side, shape of eastern part of SVI is comparable in relative terms	Backwater area is compressed; SVI: stretched, may be an error or due to significant changes in shoreline	SVI: shape of eastern part of SVI is compressed	Narrower than 1750, northern part is broader than 1840`; Two small islands on its south and one on its NE side	Only half portion (western side) is represented	Present in a very small size and eye like shape; extend NS for ~3km and EW for ~1km	We find exaggeration in NVI in the previous table, it is highly possible EW exaggeration is an error
	Map-29 (1840)	Y	Y	N	Much better than previous maps; KL: very much comparable with recent maps;	Overall very good correspondence; difference of < half of the grid size is noticed at	Same as its EW extent;	maximum EW extent is ~1.5km; NS is ~2.5km; Two small islands on its south and one on its NE side	Similar to 1917 and 1968, except its extension towards NE side	Broader than previous map; maximum EW extent is ~2km; NS is >3km	Useful for qualitative as well quantitative analysis

					SVI: on the seaward side slightly concaved from the latitude of the Bolgatty island to its south	comparable locations					
	Map-30 (1851-53)	Y	Y	N	Almost same, however, more generalised than 1840, shows two strips of land on the SVI	Same as above	Same as above	A little wider than in 1840 map	Same as above	Same as above	Useful for qualitative as well quantitative analysis

4.3.6.1.3 South Vypin and Kochi estuary

This region covers the coastal stretch from Nayarambalam (middle of the Vypin Island) to Mundamveli. For the interpretation of maps, refer to Figure 4.16 and Table 4.6. The early maps do not show any spit in this stretch. However, it is interesting to observe the chronological order of aggradation on Vypin Island, Vallarpadam, Bolgatty and Willingdon islands (ref. Figure 4.11 for the location of these islands). The amalgamation of four islands forms the present-day Vallarpadam Island. Bolgatty Island is noticed to be extended north-eastward. The Willingdon Island is grown from one small island of less than 3sqkm or 740 acres to its present form around 14sqkm or 3460 acres. However, the expansion mainly occurred during the construction of the modern port from the soil dredged out from the Vembanad Lake to make room for the new port in the 1920s[35]. Even in the expansion of the other two islands, human activities have been the catalyst. Another remarkable observation is the progradation of the southern part of Vypin Island for up to 2km.

4.3.6.2 SHORELINE CHANGE

4.3.6.2.1 Changes with reference to archaeological sites and remote sensing analysis

Fort Kochi and its beach: The four maps from the top left in Figure 4.17 are plan maps of fort Kochi. Therefore, the depiction of the beach with respect to the fort is considered correct, assuming that the relative context of the fort and the beach is truly mapped, which is highly possible in such large-scale maps. The 1840 and 1851-53 maps (from the Scaled-Grid analysis) and the rest of the following maps (from GIS overlay) correctly depict this relationship and, hence, are used for the shoreline change analysis in a relative context. Figure 4.17 shows a cyclic pattern of erosion and deposition. The changes are not occurring in one direction (positive or negative[36]).

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[35] https://cochinport.gov.in/index.php/history (accessed on 5th september 2021)

[36] The term positive is used for deposition and negative is used for erosion.

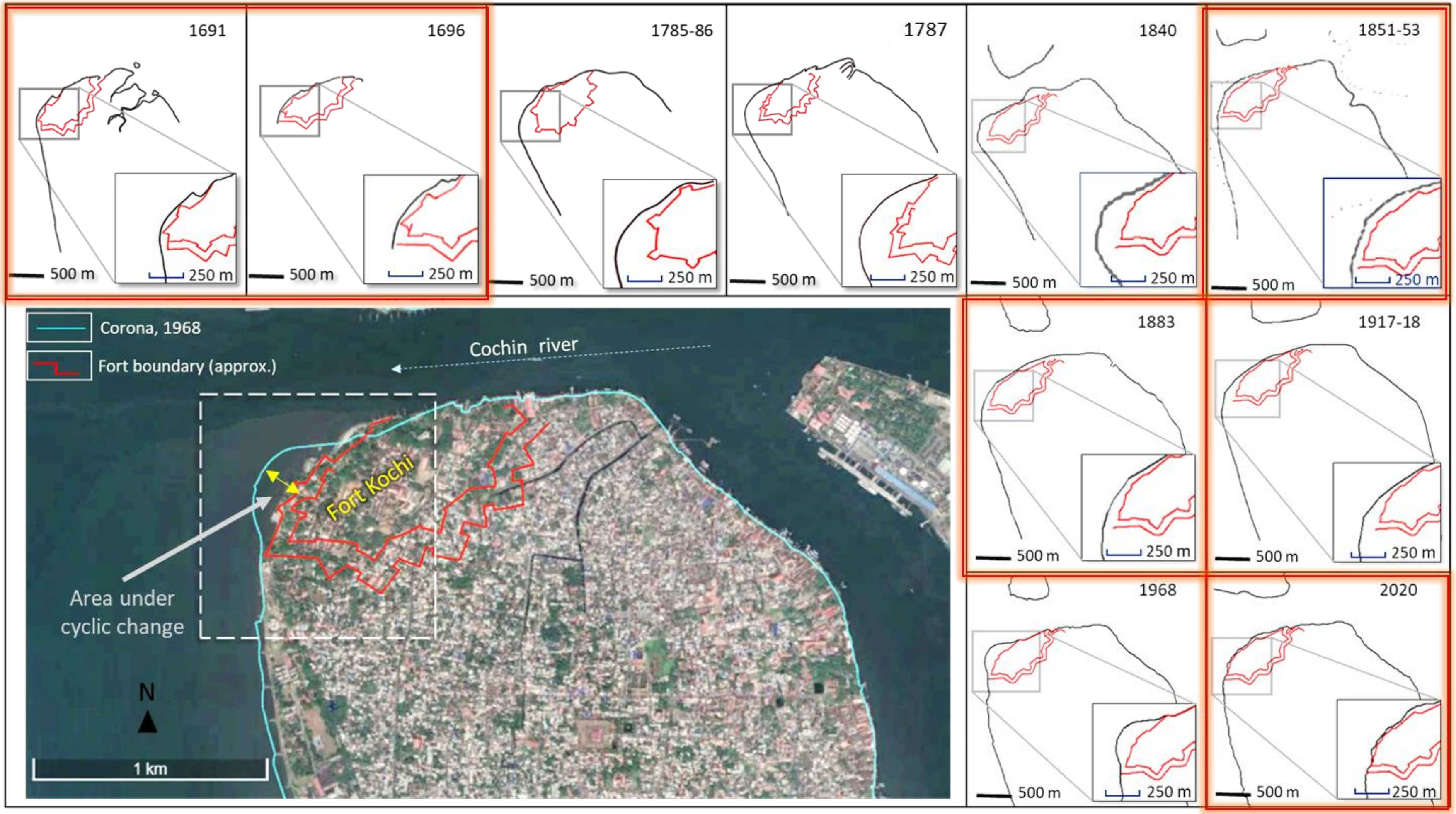

Figure 4.17 Cyclic pattern of erosion and deposition along Fort Kochi. The maps inside red boxes show erosion and without boxes show deposition.

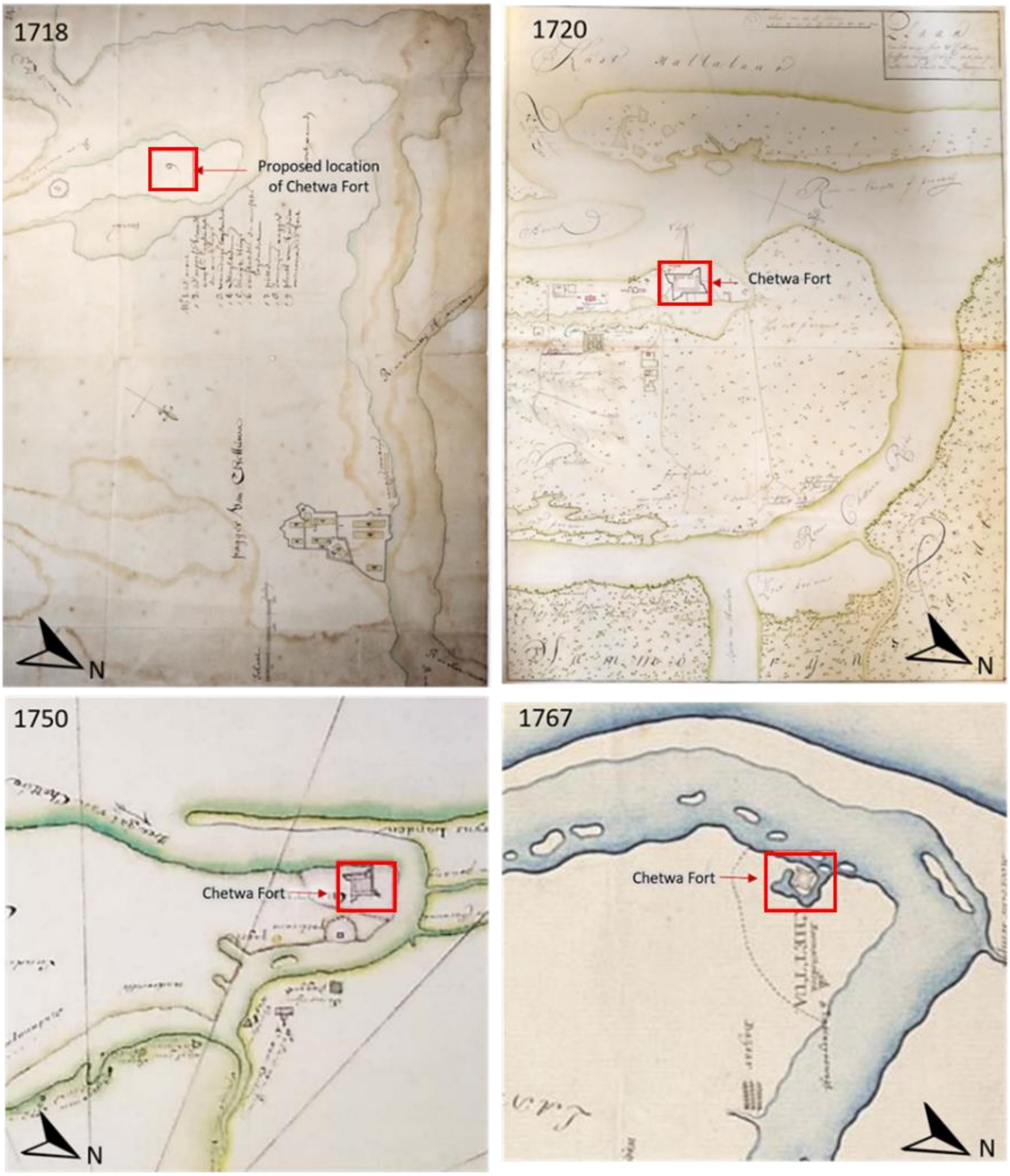

Figure 4.18. Location of Chettuva Fort and its surrounding in early maps (refer Appendix, Map-20 to 23).

Fort William or Chettuva fort and its surroundings: The early maps in Figure 4.18 depict the Chettuva fort situating on a narrow land strip surrounded by water from its three sides. The 1718 map is before the construction of the fort showing its proposed location. 1720 map shows general architectural details of the fort and its surrounding landforms quite accurately, particularly near the fort. The continuity in the depiction of the fort as surrounded by water from three sides is observed in the 1767 map as well. The juxtaposition of these early maps with satellite images revealed fieldmarks corresponding to the land strip of Chettuva fort (ref. Figure 4.19). The above analysis confirms that the coast has prograded up to around 800 m in the past 300 years. Though the early maps used here may have planimetric inaccuracies, nonetheless, due to the identification of paleo land-strip high accuracy in measurement of shoreline change could be achieved. Shoreline change between 1718 and 1917 and between 1917 and 2020 is also measured by overlaying digital shorelines extracted from the identified paleo feature (i.e., the fieldmark), 1917 map and 2020 satellite image. By combining the observations from GIS analysis with Scaled-Grid analysis, it is noticed that there was a continuous land progradation from 1718 to 1851-53. A period of erosion is observed between 1851 and

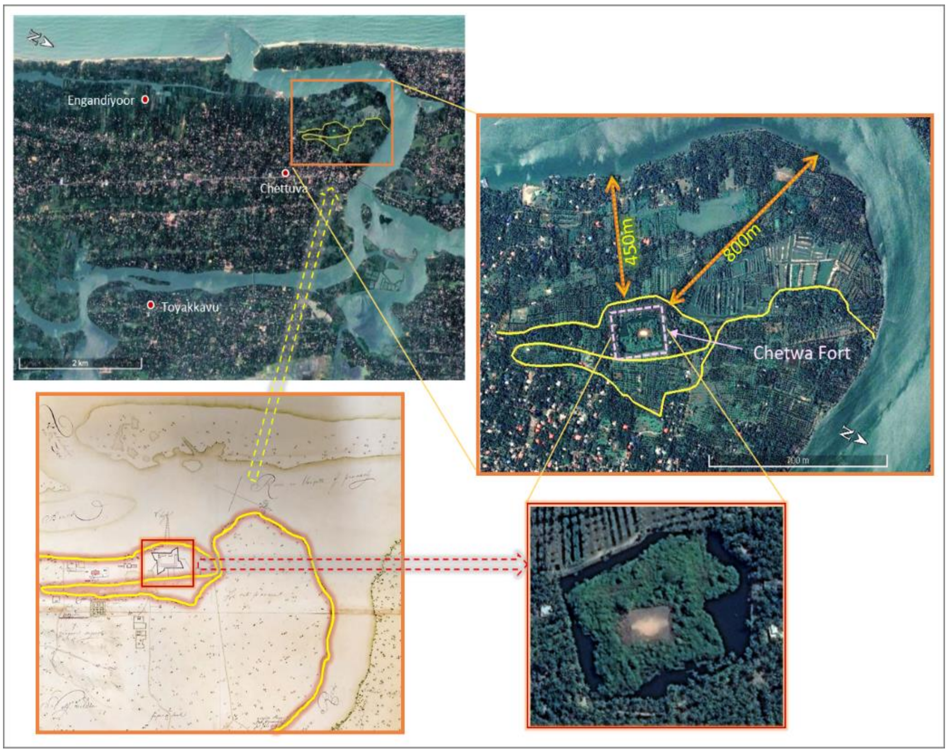

Figure 4.19. Identification of paleo-shoreline on the satellite image based on fieldmark that follows the shape of the shoreline depicted in an old map of 1720 (ref. Appendix, Map-21). Image data © Google Earth, Maxar Technology, 2020.

1917 (ref. Figure 4.20). The process of progradation was resumed after 1917, and by 1965 the coast extended up to about 800m seaward, and subsequently, it became more or less stable.

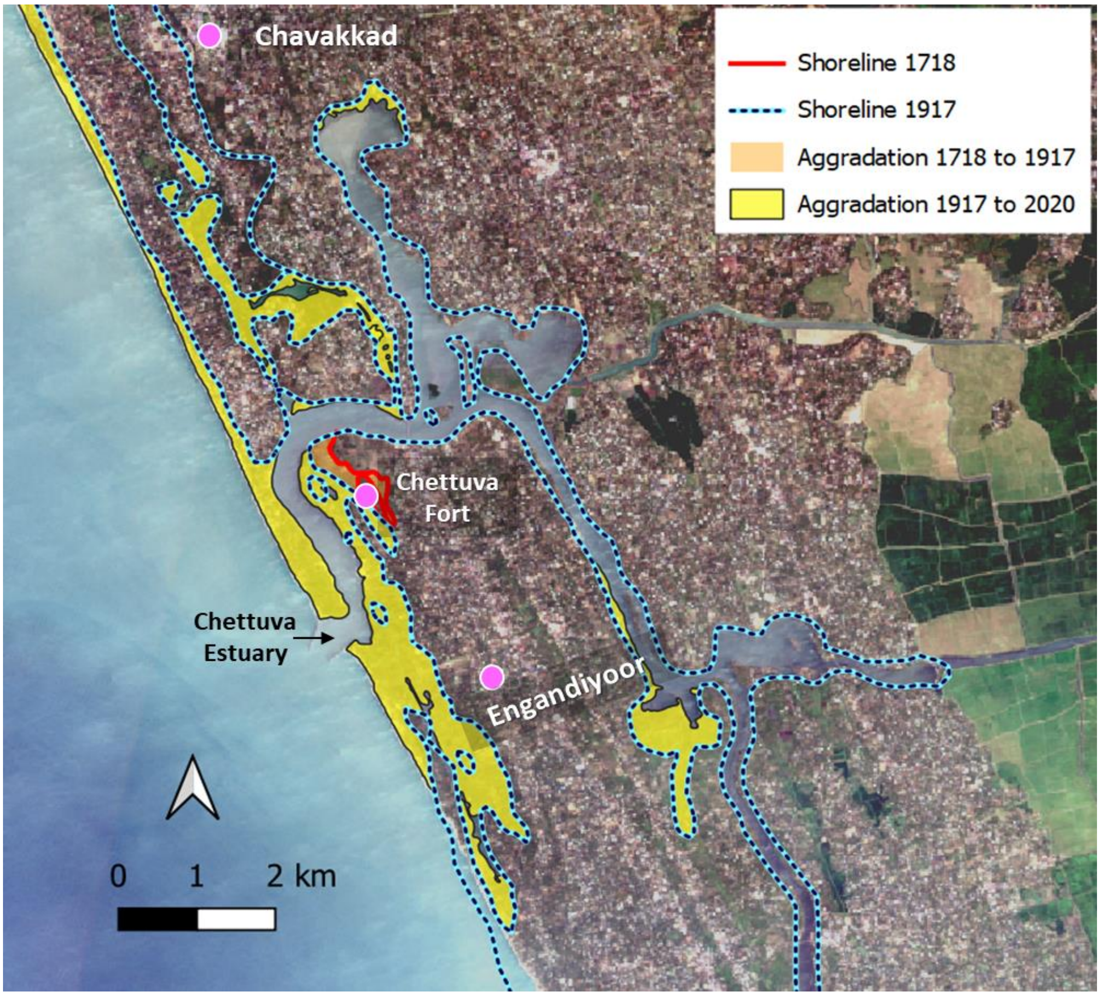

Figure 4.20 Shoreline change based on 1718 map (Map-20), 1917 map (Map-32) and 2020 satellite image. [Note: This GIS analysis of early maps doesn't include non-georeferenceable maps of mid-nineteenth century in which the coast looks similar to the present day. Hence, the apparent LINEAR positive change on the coast is delusive.] Image data © Google Earth, Maxar Technology, 2020

4.3.6.2.2 Changes measured through transects on overlaid georeferenced maps in GIS software

This analysis is performed for a coastal strip stretching from Azhikode in the north to Mundamveli in Kochin in the south. The result of this analysis is presented in Figure 4.21 and Figure 4.22, the former displays transect from 1 to 35 (from Nayarambalam to Mundamveli) and the latter from 36 to 70 (from Azhikode in the north to Edavanakkad). Result of the analysis can be synthesised as follow and theorised in Section 4.3.7.

Changes from 1840 to 1883: The map of 1883 used in this analysis covers a very small stretch from the southern tip of the Vypin Island to a little south of Fort Kochi. This entire stretch shows positive changes ranging from a minimum of 400 to about 700m. Even if we consider the estimated uncertainty, i.e., $\pm$224 (199+25), ref. Table 4.3. There is still a positive change in all transects.

Changes from 1840 to 1917: Both the maps (1840 & 1917) cover the entire stretch. The uncertainty value for both the map is$\pm\ 267\ (199 + 68)$ (ref. Table 4.3). There is overall dominance of erosional processes. North Vypin (transects from 48 to 61) experienced severe erosion from a minimum of 375m to as high as 1100m. There was a positive change along the coast of Edavankkad and a little north of it and Nayarambalam (from transects 30 to 47), though the changes were much lesser than the positive changes to its north. From the south of Nayarambalam to the southern tip of Vypin island, the coast experienced erosion from 100m to about 800m, of which 75% of transects are more than 300m in length, surpassing the uncertainty value. Further, south of Kochi estuary, slight deposition is noticed, lesser than the uncertainty estimation of both the maps.

Changes from 1917 to 1968: The estimated uncertainty value for both the map is ± 81 (68+13) (ref. Table 4.3). Slight erosion (~200 to 400) is observed north of Kodungallur-Azhikode Estuary (KAE), showing the increased value from north to south. Transects from 48 to 60, immediately south of KAE, are excluded here as this stretch has developed a narrow barrier strip of about 150 to 250m width parallel to the coast. However, that stretch is considered to have a positive change. South of that was the protruding mass of sandy land in 1917 map extending up to 600m seaward, got eroded by 1968 making the coast straighter. Tremendous deposition occurred in the southern part of Vypin Island. About 5km of coastal stretch in the area has gained land more than 1km. The remaining stretch shows minimal changes.

Changes from 1968 to 2020: Very little change of any kind is observed between these two maps except for the southernmost part of Vypin Island, where land has advanced up to 2 km seaward and slight deposition north of KAE due to the construction of a jetty. Otherwise, the coast is more or less stable.

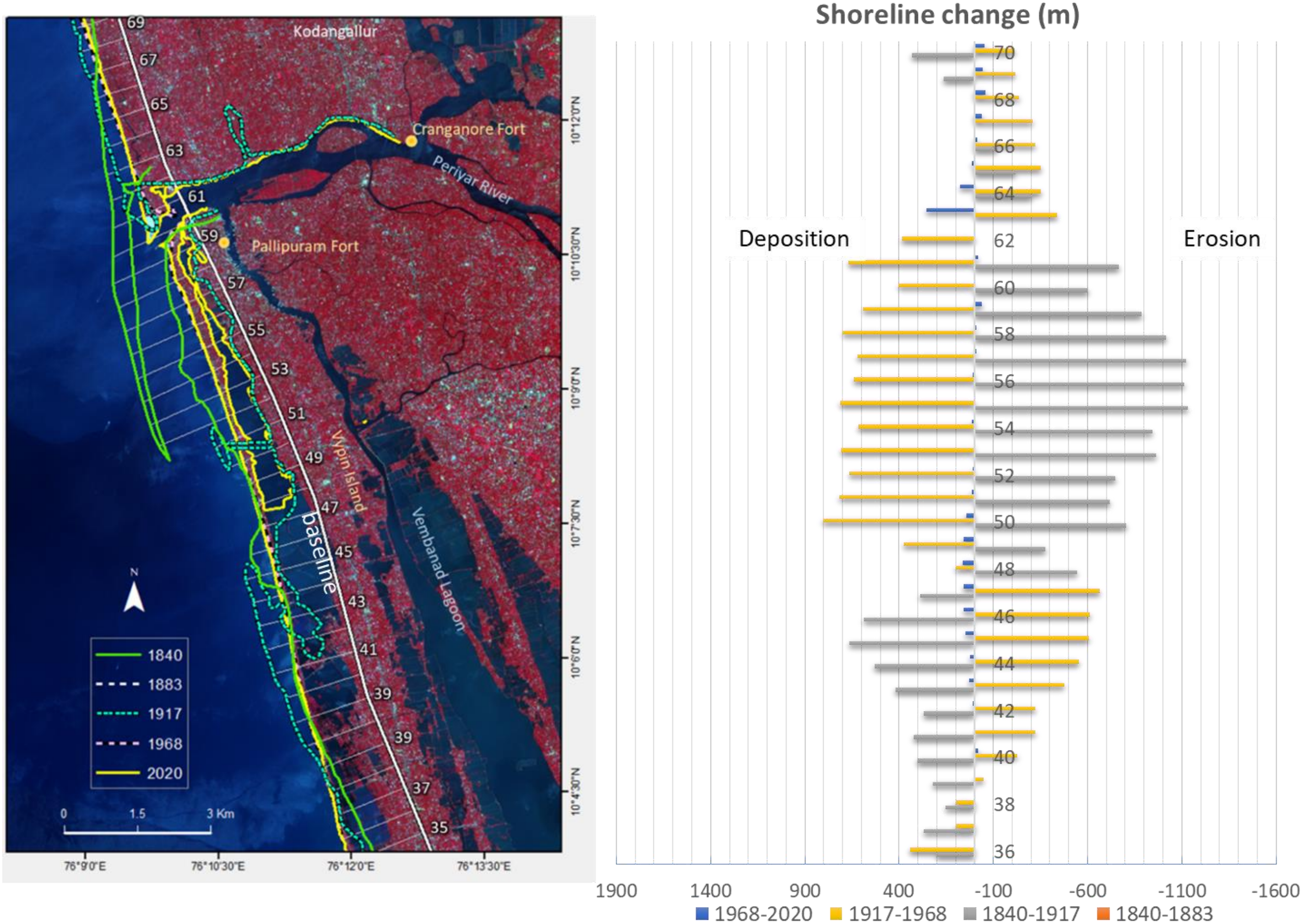

Figure 4.21 Shoreline change along Kodungallur-Azhikode Estuary (KAE) from 1840 to 2020; Left - FCC Sentinel2A image of the coast along KAE with transects perpendicular to its baseline and shoreline extracted from early maps and satellite images; Right – bar graph of changes occurred at each transect. Image data © USGS Earth Explorer

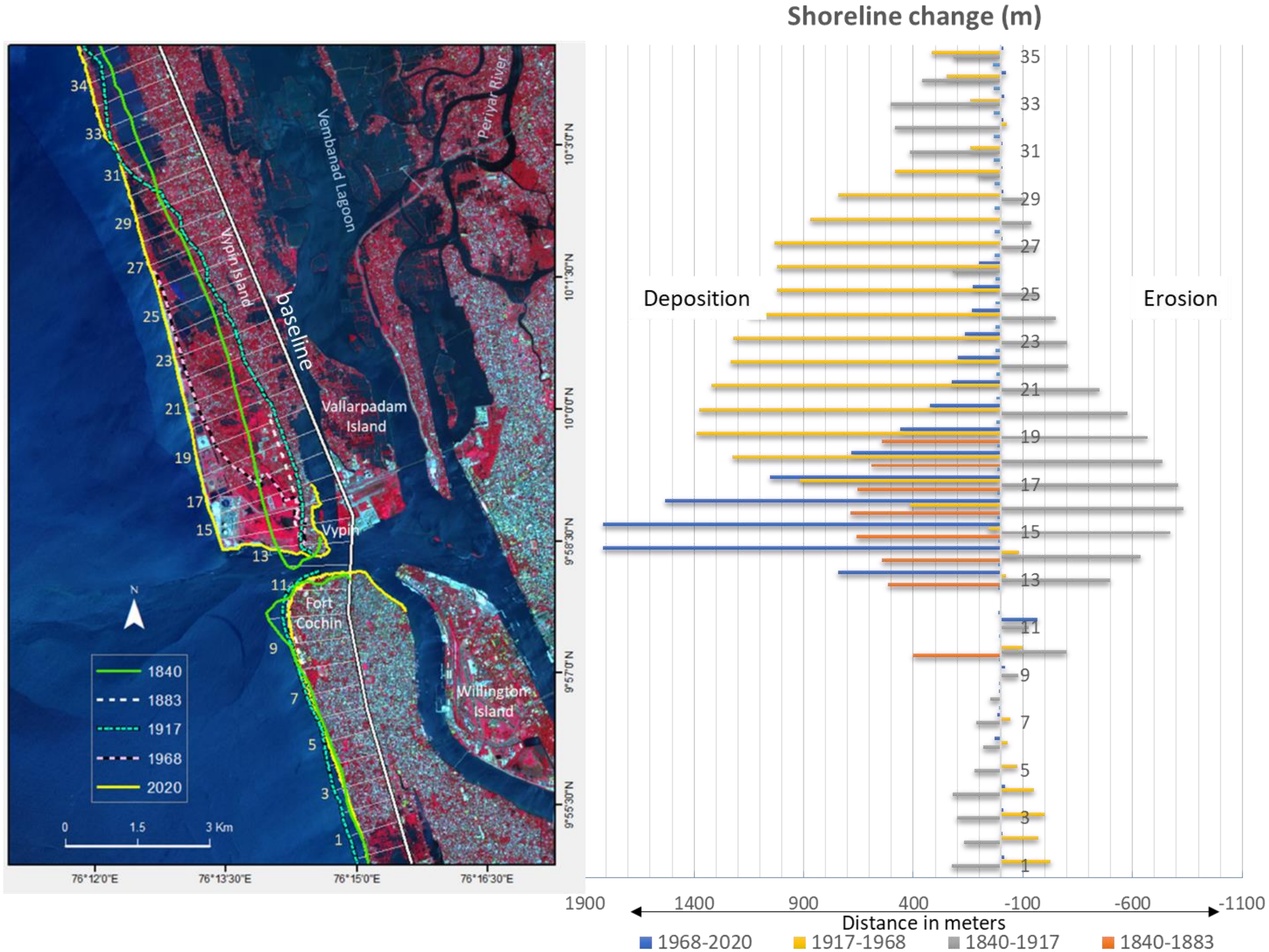

Figure 4.22 Shoreline change along Kochi Estuary (KE) from 1840 to 2020; Left - FCC Sentinel2A image of the coast along KE with transects perpendicular to its baseline and shoreline extracted from early maps and satellite images; Right – bar graph of changes occurred at each transect. Image data © USGS Earth Explorer

4.3.7 EVOLUTION OF SAND SPITS IN THE STUDY AREA: A DISCUSSION

General understanding of sand spits: The sand spit is a dynamic and complicated depositional feature parallel to the coast. The formation of a spit depends on number of factors such as complex interplay of the orientation of the coast, wind and wave climate, sediment availability, longshore sediment transportation, presence of submerged bar, tidal exchange, nearshore bathymetry, sea-level change, tectonic activities and adjacent morphological features (Kumar et al., 1983; Bird, 2008; Davidson-Arnott, 2009; Venkatraman Hegde et al., 2012; VS Hegde & Nayak, 2015; Duc Anh et al., 2020; Gilbert, 1885; Putro & Lee, 2020).

Spits are considered a reliable indicator of net shore drift and sediment transportation (Gilbert, 1885; Taggart & Schuwartz, 1988; Kunte & Wagle, 1993; VS Hegde & Nayak, 2015). Sometimes spits get detached from their proximal end due to various factors such as a change in littoral transport gradient, lack of sediment supply, severe storm, flood and sea-level rise. This detached spit forms barrier Islands and, in some cases, paired spits (Héquette & Ruz, 1991; Davidson-Arnott, 2009; Dan et al., 2011; Duy et al., 2018; Duc Anh et al., 2020). Spits, detached spits and barrier islands migrate laterally towards the land due to overwashing during the storms and realign and refill the breached gaps during the calmer periods (Kunte & Wagle, 1993; Dan et al., 2011; Baztan et al., 2015). Elongation of spit causes erosion of sandy shore on downdrift side, and the removed sediments get transported with the alongshore currents and deposits further down (VS Hegde & Nayak, 2015; Duy et al., 2018). Because of such dynamic processes, the shoreline keeps changing its shape and orientation at a local level. Even slight curvatures on an almost straight coastline can cause erosion on a convex seaward shore and deposition on a concave seaward shore (Baztan et al., 2015).

Spits along Chettuva and North of Kodungallur-Azhikode Estuary (KAE): Chettuva and KAE, at present, is flanked by paired spits. It is found that spits on the north side of both the estuaries are predominantly formed by southerly longshore drift. Map analysis suggests the dominance of southerly longshore drift for the last 300 years in the study area. Noujas & Thomas (2015) also observe net southerly transport around Chettuva and north of KAE; however, he noted a reversal of direction of net longshore drift north of KAE after the construction of breakwater, which now transports sediments northward.

Kumar et al. (1983) had also found a net southerly transport from Azhikode to Kochi estuary. The explanation of the formation of spits north of the estuaries is rather simple as both the net direction of longshore drift and spit growth are in the same direction. However, despite net southerly longshore drift, the spits south of both the estuaries developed towards the north.

Analysis of early maps of Chettuva estuary shows narrow strips of land, elongated shoals or submerged islands, and a chain of islands between the spit and the mainland parallel to the coast present at a different point of time in the eighteenth and early nineteenth century. These features, at present, have become a contiguous part of the mainland, contributing to the advancement of the alternate beach ridge and swale topography of the coast towards the sea. The sequence of parallel beach ridges is extended up to 6km inland and are visible in the Corona image. Availability of fluvial discharge in large quantity due to heavy discharge in the mid-Holocene contributed to the formation of beach ridges in the region (Alappat et al., 2015; Narayana et al., 2017). These are created by fair-weather waves and tidal fluctuation (Alappat et al., 2015). Studies also suggest higher sea levels during the early and mid-Holocene, followed by a phase of marine regression (Alappat et al., 2015; Narayana et al., 2017). The region shows evidence of coastal emergence due to neotectonic activities (Narayana et al., 2001; Alappat et al., 2015; Narayana et al., 2017). There is an overall progression of the land from a land strip surrounded by water from the three sides (the place where Chettuva Fort is situated) to the formation of another strip parallel to it at a distance of fewer than 100m its west by 1917 to the present-day coastline. As mentioned above, these features form parallel beach ridges. The massive erosion observed in the 1917 map had occurred between 1912 (see above) and 1917, possibly due to some extreme flood or storm. This event seems to have caused flooding of the low-lying areas and detachment and fragmentation of the ridges. The constructive marine, fluvial and tidal forces replenished these ridges by 1968. It could also be much earlier than this. It is important to note that no major catastrophic event has been recorded between 1910 and 1917. One major flood in Kerala was recorded in 1924, and the next with similar severity recorded recently on 16 August 2018. Analysis of Sentinal2A images of the region dated to 20 August 2018 does not show any destruction of the coast of that kind (1917); the ridges and spits are intact, only inundation of low-lying areas in the north can be observed.

Evolution of Spits of Vypin islands: The chronological study of early maps and satellite images provided some data points to explain the evolution of these spits. Vypin Barrier Island, which is between KAE and Kochi estuary, forms diverging spits. The analysis suggests that the spit south of the KAE, originating from the north of Vypin Island, is formed due to the following factors that occurred simultaneously or subsequently: a) breaching and fragmentation of the ~7 km long northern spit that resulted in the formation of a chain of narrow barrier islands (ref. map 1851 in Figure 4.1); b) erosion of the land on the downdrift side opposite to the barriers (from transect 47-60) forming a concave seaward shape, c) subsequent landward movement of the barrier islands due to overwashing; d) interim formation of the southern spit from the straightening and lengthening of barrier islands under the influence of longshore drift and cross-shore waves[37] which between 1912 and 1917 got eroded leaving only two small islands and caused deposition on the downdrift side (ref. map 1917 in Figure 4.1); e) the deposition on the southern side formed a convex shape which possibly acted as a sediment divider. On either side of this protrusion, the shoreline forms a seaward concave shape with a sheltered effect. The bell shape of the shore, the orientation of the shoreline of the Vypin Island at that time and the supply of offshore sediment have been instrumental in the formation of diverging spits. Other major factors are seasonal variation in the direction of wind and wave, cyclic fluctuation in sediment and water influx and periodic reversal in the alongshore current (VS Hegde & Nayak, 2015). The interpretation of the shape of the depositional patterns of Corona image and Landsat image confirms that the spit north of the Vypin Island (south of KAE) is developed from south to north while the spit on its southern end developed towards the south.

[37] Information obtained from an outline of the 1910-12 map given in Mathai & Nair (1988)

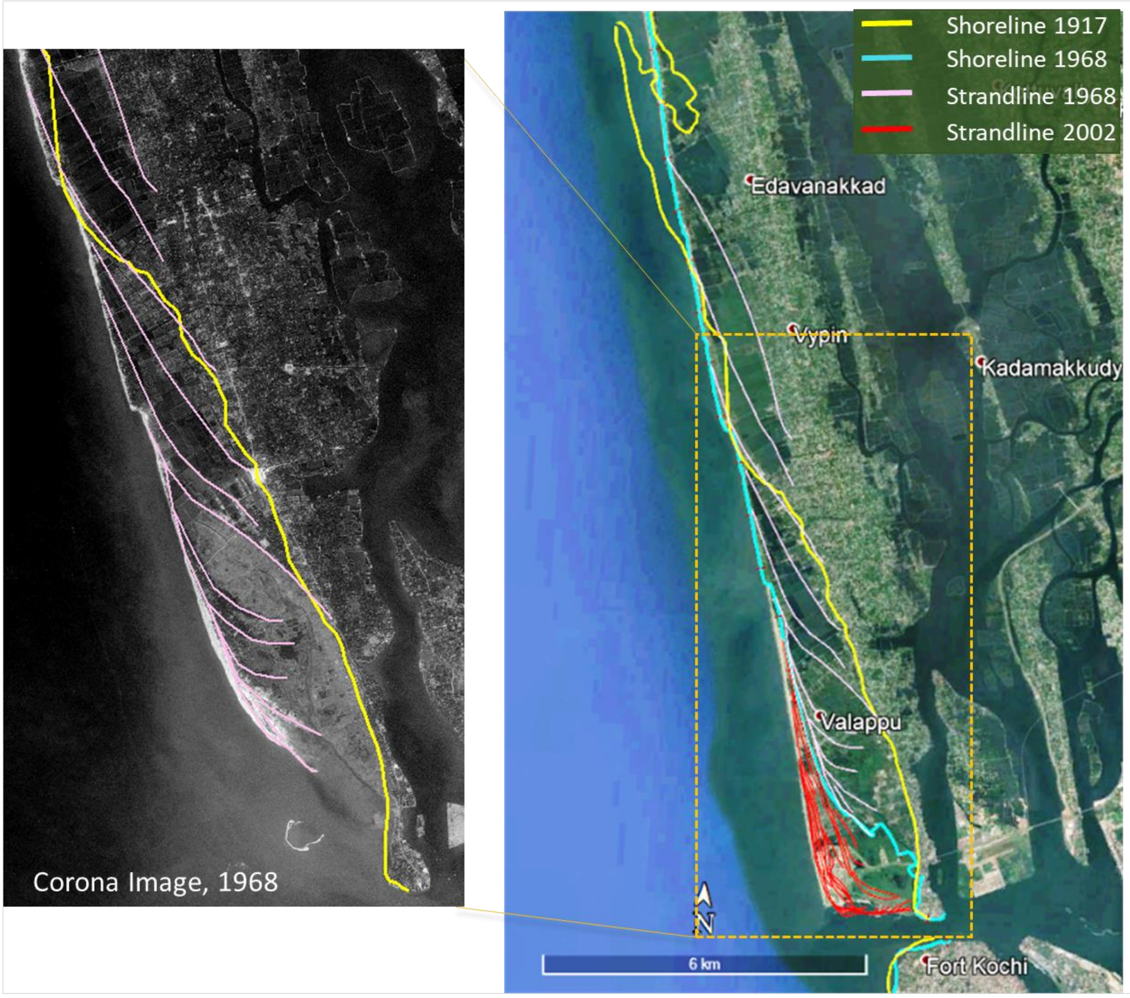

Figure 4. 23. Left- Corona image (1968) with highlighted strandlines; Right- Shoreline and strandline as identified from 1917 map, Corona image and Landsat image (2002) overlaid on a base map (2020). Image data © USGS Earth Explorer (Left) and © Google Earth, Maxar Technology, 2020 (Right).

The spit on the southern side of Vypin Island is a sequence of successive recurved spits with pronounced curvature formed due to the divergence of waves around its distal end close to the narrow strip of Vypin Island and Kochi inlet. The recurve spits mark the stages of growth (ref. Figure 4.23) and can be traced in Corona image of 1968. Between the recurves and the sheltered landward side of the spit, lagoon, salt marsh and mangroves are developed. By 1968, the northern and central part of Vypin Island became nearly straight; only the southern part was deeply curved inland, providing a low energy space for further spit growth in the next few decades and caused progradation of shoreline for about 1 to 2 km. The abundant supply of sediments from the dredged material and river discharge that gets carried offshore during monsoon flood and brought back to the shore by swells during the non-monsoon season and further distributed by longshore currents deliver the required material for the growth of the spit (Narayana & Priju, 2006). An accelerated rate of erosion in the catchment areas also contributes to sediment supply to this region (Narayana & Priju, 2006). The detailed investigation of bathymetric charts by Kumar et al. (1983) shows flat inshore bottom contours along the southern end of Vypin Island that provided spits with a ready platform for its growth caused a rapid progradation. Once the distal end of the spit reached close to the Kochi inlet, the curvature approached a 90-degree angle towards the inlet under the influence of tidal current (Figure 4.23). The beach ridge and swale formation in the Vypin Island between 1917 and 2020 is due to successive addition of spits parallel to the coast. However, the maps before 1917 suggest erosion of the island sea shore from 1840 to 1917 and aggradation of islands on its lee side. Process of erosion is difficult to trace without the presence of any noticeable stable features on the satellite images.

Though no major breaching or erosion is observed in the entire stretch studied here in the recent decades, however, historical manual of 1911 suggests that erosion of the sea-shore was a frequent phenomenon in that region between the late nineteenth and early twentieth century (Menon, 1911). According to this manual, the north spit of Vypin Island (which also got washed away between 1912 and 1917) was experiencing continuous erosion, which had made the spit so thin that it could be easily washed away by sea at any time (Menon, 1911). Map analysis also suggests the dominance of erosion of shore between 1840 and 1917, after which progradation and stability of the coast are noticed.

4.4 CRITICAL UNDERSTANDING OF HISTORICAL MAPS IN GEOMORPHOLOGICAL STUDIES

This section summarises the critical aspects of historical maps that were dealt with in the chapter.

4.4.1 AVAILABILITY OF MAPS

The more the number of maps of different time points, the better and more reliable the understanding of the geomorphic changes. Big temporal gaps such as 50 year's intervals of maps are insufficient to understand the processes that occur in a shorter time, with high certainty. For example, if the map of 1851-53 was not found, the nature of the breach of spit and erosion that occurred between 1840 and 1851 couldn't have been understood. Efforts should be made to find as many maps as possible for a given study area.

4.4.2 ORIGINALITY AND TEMPORAL CONTEXT OF MAPS

Mapmaking involves several processes such as ground survey, drafting, engraving, printing and publishing. Generally, maps were surveyed and drafted usually around the same time, but often they are found to be published later, in some cases multiple times with some updates or as a copy as late as 50 to 100 years. Considerable coastal geomorphic changes can occur in years or even less. Hence, information about the surveying date becomes critical. In some maps, survey dates are given, while in others, they are not. In the absence of survey dates, comparison of maps, survey history, and knowledge of cartographer or publisher helps get an approximate understanding of surveying dates. For instance, the map of the Thamirabarani delta found in Yule Cordier's book published in 1929 and the topographical details used by Robert Bruce Foote in his geology map published in 1883 seem to have been traced from the India Atlas sheet-81 published in 1828. This judgment was based on the content of the map as well as comparison with other contemporary maps.

4.4.3 ACCURACY AND ERRORS

Cartometric accuracy of maps may not be that important for archaeological investigation, but it is important for coastal geomorphology. It is very difficult to judge if a noticed change on the shore depicted in a map is due to cartographic error or a true representation of a modified shoreline when the accuracy of the map is not known. Accuracy also varies with scale (for detail ref. Section 3.2.3 in Chapter-3). However, to a large extent, these issues can be overcome by the use of satellite images and relative reference of landmarks or features with a distinct shape. Satellite images were found extremely useful in validating the accuracy and correcting the content of maps by identifying the strandlines, vegetation marks or fieldmarks that corresponds to shorelines or other features marked on maps. For example, accurate demarcation of shoreline around Chettuva fort on the satellite image from a cartometrically inaccurate map of the early eighteenth century.

4.4.4 IDENTIFICATION OF CONTROL POINTS

Another critical aspect of historical maps of the coast, especially maps before the eighteenth century, is the unavailability of enough stable and reliable control points. Georeferencing is not possible in the absence of control points, and hence, those maps cannot be brought into the GIS platform for further analysis. However, the Scaled-method demonstrated in the present study offers a logical way to chronologically study the maps and make a rational comparison based on shape, pattern and position of features relative to each other.

4.5 CONCLUSION

The study carried out in this chapter has made two main contributions.

First, it demonstrates how to study maps of different scales, time and types more logically and systematically using the methods proposed in the third chapter. However, the study does not propose a fixed methodology that can be used as a template for all the sites. Selection of method depends on the presence of landmarks, types of maps available, visibility of paleo features on satellite images, the nature of landscape and magnitude of change. The understanding obtained from the analysis of the historical maps does require corroboration with field and lab-based studies.

Remote sensing images and DEM have been found instrumental in validating the information and the quality of the historical maps. Not only that, the identified paleo water-features can be demarcated with high accuracy even if the historical map that shows them is less accurate. Whenever validation of a map is not possible, the interpretation of the map depends on the subjective inferences of the individuals studying them. In such cases, more the knowledge of origin, content and context of the map, the better would be the judgement and deduction.

Second, this study has proposed a novel understanding of the evolution of the Thamirabarani delta and the spits of central Kerala (Chettuva estuary and region between Kodungallur and Fort Kochi), particularly in the past 300 years. The study observes an overall dominance of constructive forces on both the east and west coastal sites. Both the sites are gaining land. Maximum progradation (~2 km) has occurred in the southwestern part of Vypin Island. Nevertheless, episodes of destructive force are discerned around Vypin Island between 1840 and 1851, and in central Kerala between 1910 and 1917. The reason for the remarkable erosion of the coast between 1910 and 1917 is not known yet, further research needs to be carried out to probe into that. After 1967, the coast seems to have become more stable and straight compared to the coast before that.

The study clearly shows the immense potential of historical maps in understanding the past geomorphic processes and evolution of landforms. These maps are vital source of temporal information and present the most convenient way to date significant geomorphic changes that occurred in recent centuries. On the other hand, paleo features identified from the satellite data alone would not provide any temporal context unless the paleo feature had formed within the temporal range of the availability of satellite data. For example, the present study informed about the siltation of two large lagoons at the mouth of river Thamirabarani and dated the occurrence of these changes, which was much before the launch of first earth observation satellite; and could be dated using early maps. Besides, other dating methods such as radiometric dating provide only point information while maps give the date for the entire feature and thus are better in perceiving the spatio-temporal context of that time period than any other method.

There are thousands of early coastal maps of different parts of India and other places in the world that are available in various digital archives and libraries worldwide. With the methods suggested in the present study, these under utilised historical cartographic documents can be studied to understand better the coastal geomorphic processes that occurred in the past few centuries at a regional and global level.

CHAPTER 5

HISTORICAL COASTAL MAPS AS A SOURCE OF ARCHAEOLOGICAL INFORMATION

"...we must scavenge for traces of past human activity that have survived in material form and develop expertise in interrogating these materials before their secrets fade into oblivion."

-Rajani M B (2021)

5.1. INTRODUCTION

Colonial powers, when establishing themselves in India, recorded the geographical information of important port towns and cities on maps of different scales. They prepared small-scale maps to visualise the larger picture of the region and planned their long-distance sailing routes. They made medium to large-scale maps for safe landing and comprehensive plan map of forts for military purpose.

These maps are a unique and rich source of archaeological information for two main reasons- 1) they are the factual statement of geographic reality (both human and physical) available from as early as the 16^{th} century in different scale, form and style as discussed in Chapter-2; and 2) they depict historical buildings on the coast (visible from offshore) in small and medium scale navigation charts as landmarks, which is a reliable source of the past built structures and can be studied with reference to the surrounding geomorphic features. Integration of these historical maps and views of varied dimensions and types has the potential to provide a palimpsest of historical activities that can be read through lens of remote sensing data and geospatial tools.

The present chapter attempts to harness the above-mentioned potential of historical cartographic maps. It demonstrates the value of these multifarious historical cartographic documents in advancing archaeological and historical understanding of the Indian coast using the case study method. It also brings out the critical aspects and challenges in the methodology and discusses the significance of such studies. The important role that archaeological sites play as a geographical reference to understand the geomorphological changes has been discussed in Chapter-4.

This chapter presents the following four case studies (ref. Figure 5.1): Case study - 1) Panchagangavalli cluster: Cambolim (Gangolli), Barcelore (Kundapur) and Basrur; Case Study - 2) Onor (Honnavar); Case Study-3) Old Goa; and Case Study - 4) Kollam, in Kerala coast.

The sites selected for Case Study-1 and 2, *viz.* Cambolim (Gangolli), Barcelore (Basrur/ Kundapur) and Onor (Honnavar), are historical ports. Portuguese strategically selected and built their fortress at these sites as they were situated close to their capital Old Goa and far from the constant conflict occurring on the Malabar coast. Later, these sites emerged as important trade centres for the Portuguese in the late 16^{th} and early 17^{th} centuries. These sites at Canara (Karnataka coast) had been a theatre of wars and conflicts, which resulted in the construction and destruction of several fortresses.

Cambolim (Gangolli) and Barcelore (Basrur/ Kundapur) are situated along the estuary of Panchgagavalli river and studded with many fortresses. As per the historical records, there were two fortresses in Cambolim island (now known as Gangolli and at present is not an island), two in Kundapur, one in Basrur. However, there were doubts and debates on the identification and location of the respective forts. The great availability of old maps (mostly Portuguese) of this region and the current debates on the identification of the fortresses motivated the selection of this region as the second case for the study.

Honnavar, the second case study site, was another important port. It had a Hindu fort that the Portuguese acquired, then burnt and constructed a new fort at the same place later. The location of this fort was not known and has not found or discussed in any academic work. Only the original historical records and travel accounts have some textual description of its location but not enough to locate it on the ground. The early maps (all

Portuguese) of Honnavar inform us about the shape, size and location of the fort with respect to the topography, making the site interesting and valuable for further investigations.

The third case study investigates the vestiges and extent of the forgotten fortified Portuguese city of Goa as the preliminary analysis of some of the old maps and views instigated an interest to probe into this overlooked part of Goa heritage.

Kollam is selected as a principal site to lay the foundation for a broader understanding of the methodology through an in-depth analysis, interpretation and discussions, and thus, covers a substantial portion of the chapter. The selection of Kollam as a principal site is made for the following reasons: 1) the archaeological site of Kollam is largely unexplored; 2) it has a large number of historical cartographic documents made by Portuguese, Dutch, English and French, which includes large-scale sea chart, medium-scale map, plan map, bird's eye view and paintings from the early 16th to 19th century; 3) it presents an interesting example of palimpsest of Portuguese, Dutch and British construction activity on the same location; and 4) being situated on a coastal promontory, it forms an interesting geomorphological setting and may inform us about the geomorphological changes at that location.

The understanding of the location and structure of the forts in the above mentions sites is conjectural or unknown. The early maps of these sites inform us about the shape, size and situation of the fort with respect to the topography. Hence, these sites have been taken up to address the existing uncertainties and debates on the extent and location of the fortresses they have.

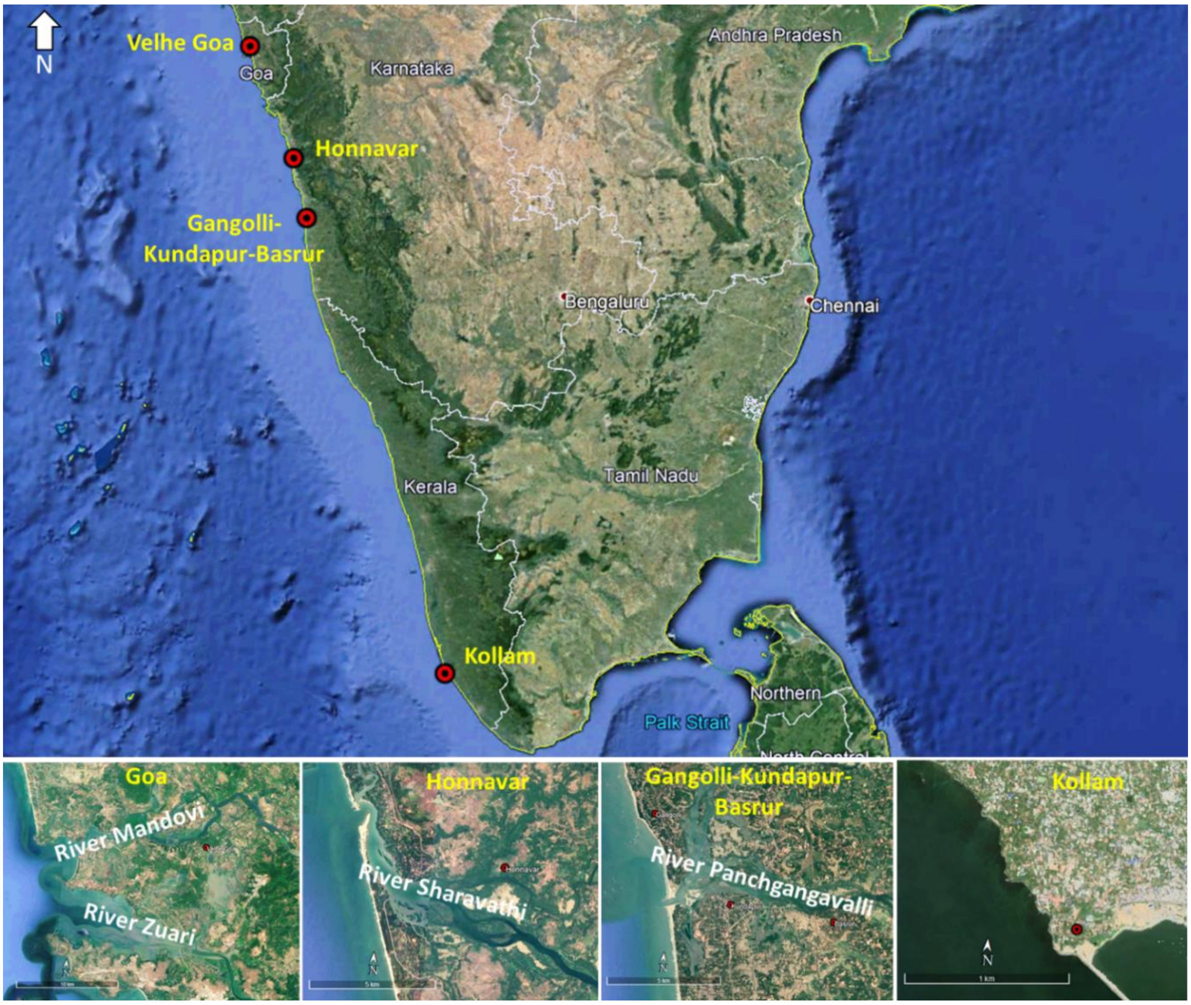

Figure 5.1 Location of sites selected for the case studies.

5.2. PANCHGANGAVALLI: CAMBOLIM (GANGOLLI), BARCELORE (KUNDAPUR) AND BASRUR

Along the mouth of river Panchagangavalli there is a cluster of several forts (viz. Fort Cambolim, Fort Barcelore, The Old fort, Moors Fort, Fort of King of Basrur, Tipu Sultan's Fort and Fort of Virabhadra Nayaka) that are featured in colonial maps and historical records. Identification of forts and their location have been discussed in the literature with ambiguity. This case study attempts to identify and locate these forts using historical maps, satellite images and GIS.

5.2.1. HISTORICAL BACKGROUND

The conquest of Portuguese with the native rulers of Basrur and Gangolli started with the arrival of Viceroy Pedro da Silva e Menezes with his army in 1569. Being eager to acquire the Basrur fortress that belongs to the ruler of Tolar, the Portuguese rushed to the town to attack the fortress, kill, and capture its inhabitants. The ruler of Tolar, with the help of his neighbouring king of Cambolim advanced to counter the attack but the Portuguese easily repulsed them. The following night, both the kings reappeared with great strength and gave a tough fight to the Portuguese that made the latter to conclude that the 'fortress was untenable' (Danvers 1894, 545; Heras 1927, 296–97). With the zeal to capture the fort, the Portuguese made another attack a few months later, which was concluded with a peace treaty. Soon after this event, the Portuguese constructed a new fortress on a site between the city and the mouth of the river (located in present-day Kundapur) in two months (Heras 1927, 297; 1930). At the beginning of the 17th century, the ports of 'Barcelore', Bhatkal and Onor (Honnavar) came under the control of Nayakas of Ikkeri. In a treaty of peace in 1631 with Virappa Nayaka, the Portuguese were given possession of the island of Cambolim and permission to build a fortress therein. After few years, Virabhadra Nayaka constructed a fort opposite to it (Udaya 2004). In 1652, the fort of Cambolim was attacked by the Shivappa Nayaka, and in the next year, it was entirely dismantled (Danvers 1992, 303). In the 1660s, when the Portuguese got a nominal success in taking up the possession of 'Barcelore' and Mangalore, they found their fort in a dilapidated condition and could not repair them for defence. Vasco Fernandes Cesar de Menezes dismantled the fort of 'Barcelore' in 1712.

The prolonged conquest and unrest in the region and constructions and destructions of the fortress have left room for confusion and debates on identifying the respective forts and their true geographic location. The present case study attempts to identify remains of forts in the region and clarify existing doubts about the location by studying early cartographic records of this region using historical text, remote sensing images and GIS.

5.2.2. CARTOGRAPHIC SOURCES

The maps of Kundapur, Basrur and the surrounding area made by Portuguese, Dutch and the British are acquired from different sources. The maps with their sources and other information is given in the Appendix (Map-35 to 40). The content and the context of the maps are discussed in the following section.

5.2.3. UNDERSTANDING THE CONTENT AND THE CONTEXT OF MAPS

5.2.3.1. PORTUGUESE MAPS

All the available Portuguese maps of this region are the combination of bird's eye view and planimetric map. The orientation of the features (both manmade and natural) in the old Portuguese maps is not conformal, and they represent the exaggerated size of the forts (ref. Figure 5.2 A, B and C). Cambolim fort, constructed in 1631 and dismantled in 1652, is depicted in the 1639 map and absent in the 1630 map (Figure 5.2). Though published in 1674, the map (ref. Figure 5.2 C) was made before 1649 as the maker of the map (Manuel de Faria e Sousa) died in that year and the absence of Cambolim fort in this map suggests that the map was made before the construction of the fort in 1631. The 1639 map also marks a rectangular fort-like feature at the location of an 'old fallen fort' shown in a Dutch map (for the Dutch map ref. Figure 5.3).

5.2.3.2. DUTCH MAPS

Only one Dutch map of this region was found. This map represents the situation of the sites in 1678. It is a medium scale planimetric map more accurate than the Portuguese maps. However, the features are marked more symbolically. It marks three forts: 1) Moors Fort, 2) *T' Groote* Fort (The Great Fort), and 3) *Oudver rallen* Fort (Old Fallen Fort). Moors Fort in the map is probably referred to the fort which is at present known as Tipu Sultan's fort lies close to the light-house at Gangolli (ref Fort number 5 in Figure 5.6). The Great Fort is referred to the Portuguese's Barcelor fort, and the Old Fallen Fort refers to the old mud fort depicted in the Portuguese map of 1639 (ref. Figure 5.2 B and F). The map, however, does not mark any fort in Basrur, which is found in a British map published two centuries later.

Figure 5.2. Representation of Barcelore Fort and Cambolim Fort in old Portuguese maps; A) Map-35; B) Map-36; and C) Map-38 (ref. Appendix); D) Satellite image marking the identified extent (in yellow line) and possible extent (in red line); (E) Remains of Barcelore Fort; and (F) Remains of the old mud fort marked in (B).

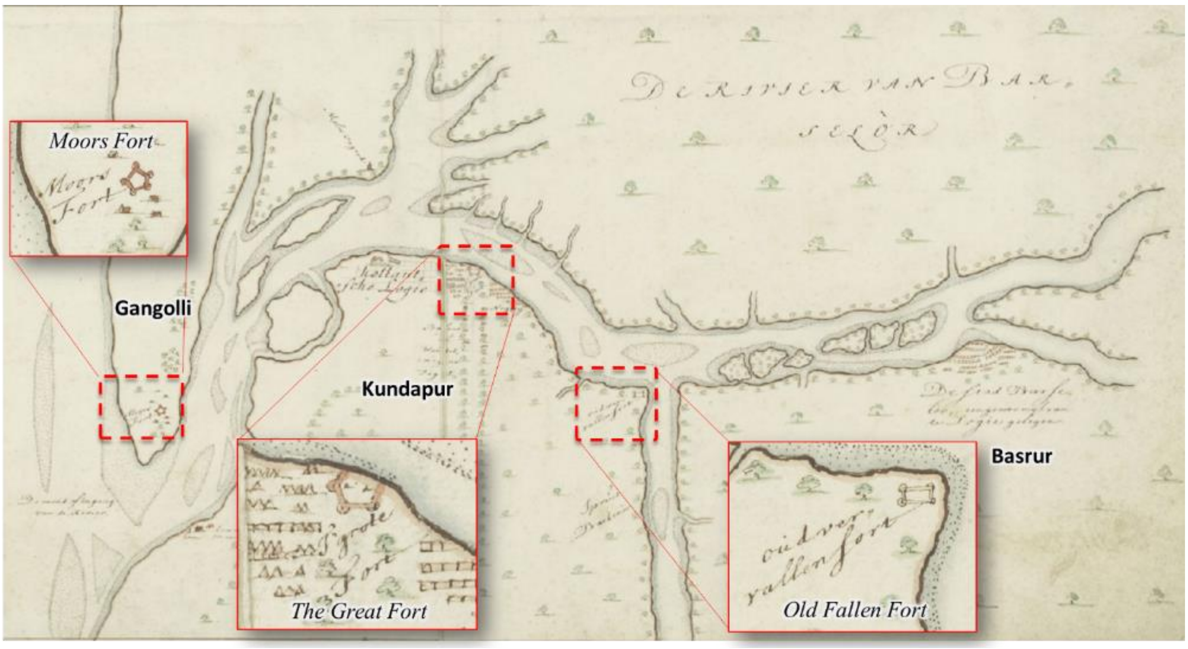

Figure 5.3. An old Dutch map of the situation in 1678 representing the location of forts. (ref. Appendix, Map-39)

5.2.3.3. BRITISH MAP

The available old British map is a small-scale admiralty chart surveyed in 1856 (ref. Figure 5.4). Being a small-scale map, it does not show the study area in detail. Interestingly, it shows only the Basrur fort. Apart from the Portuguese maps that show a walled town at Basrur, this admiralty chart is the only historical map found that shows a fort at Basrur. However, the depiction of a fort-wall forming an oval shape covering almost the entire town is found in a map published in a Kannada book titled as "Hesarāda pattana Basarūr; Ondu adhyayana[38]" (Renowned town Basarur: A study).

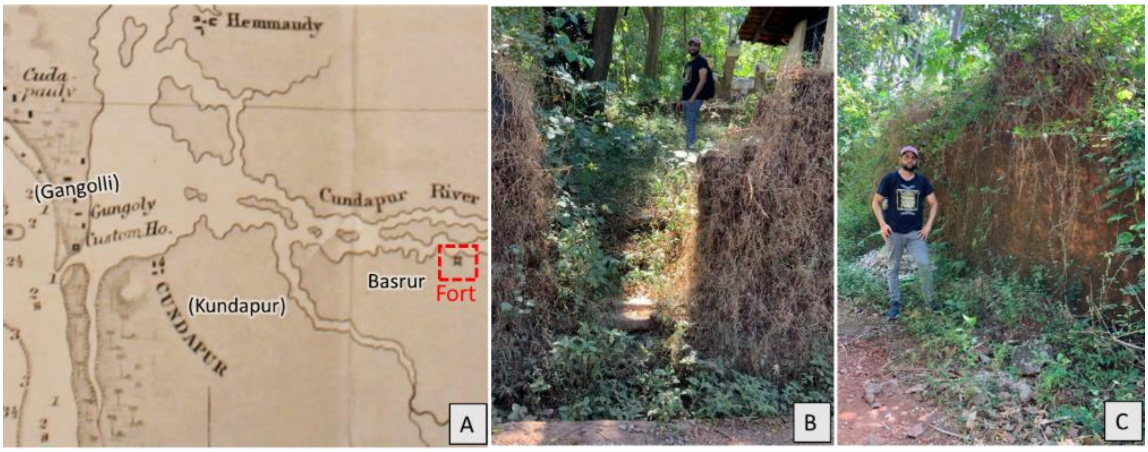

Figure 5.4. A) An old British map (Map-40) dated to 1856 representing only a fort at Basrur; B) & C) are ground photographs of a huge structure at the same location in Basrur

[38] "Hesarāda pattana Basarūr; Ondu adhyayana" (Renowned town Basarur: A study) - [in Kannada], Compiled and Published by Sharada College Trust, Basarur-576211,Udupi District, 1997.

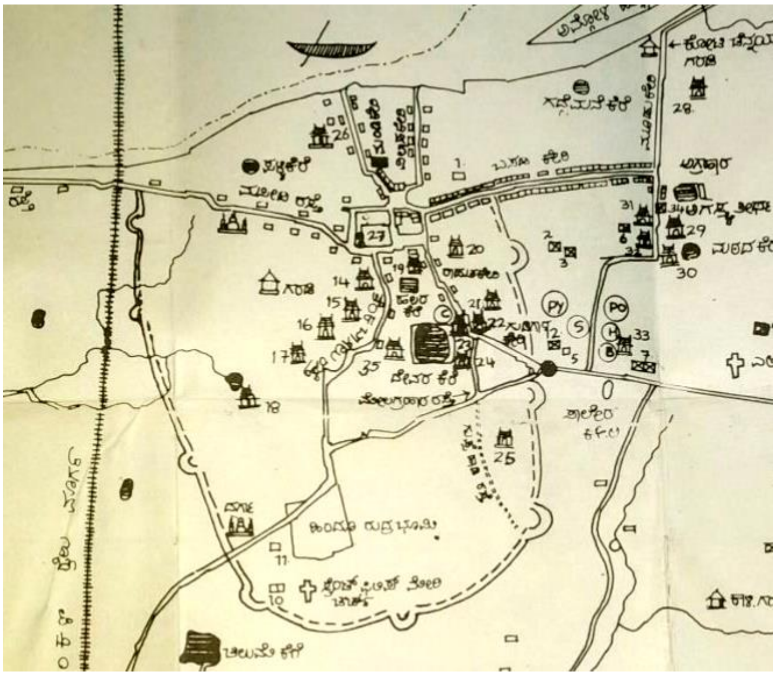

Figure 5.5. A subset of a Basrur map showing the fortification of the town (source: *Hesarāda pattana Basarūr; Ondu adhyayana)*

5.2.4. GEOSPATIAL ANALYSIS

The content and spatial context of the available historical maps is assessed by analysing the relative position of natural and manmade features depicted on maps. Unfortunately, no visual traces except for the cropmark around the 'old fort' have been found on satellite images. However, through the analysis of Portuguese maps, the probable location of the 'Barcelor' fort, the 'old fort' and Cambolim fort was identified, and a field visit was planned. Remains of the northern and eastern part of the 'Barcelor' fort were observed during the fieldwork carried out in January 2020 (ref. Figure 5.2E). Some ruins on an elevated ground were also observed at the location of the 'old fort' (Figure 5.2F). The presence of fragments of a huge structure in the town of Basrur was also noticed, however, a detailed study of architectural aspects and the construction material can be undertaken in future to understand the entire structure. No remains were found at the location of Cambolim fort.

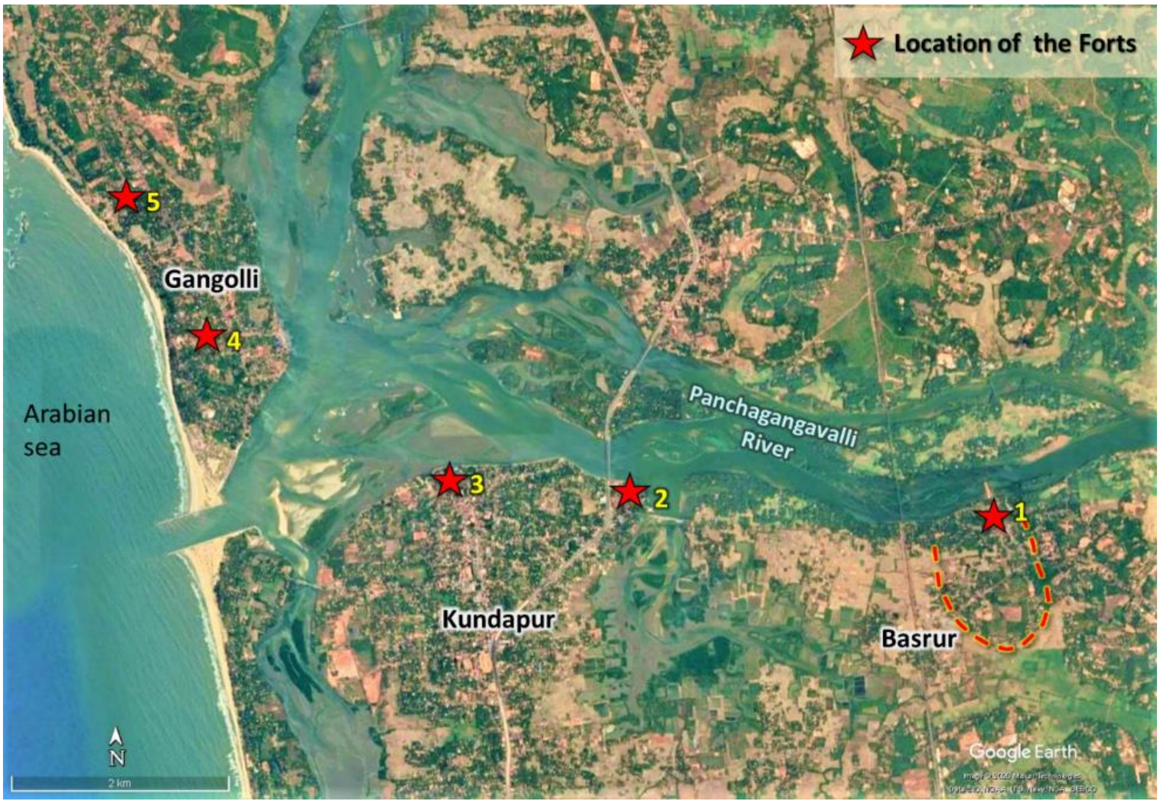

Figure 5.6. Location of forts identified through the analysis.

5.2.5. DOUBTS, DEBATES AND DISCUSSION

Historical literature suggests the presence of five different forts, though it has been challenging to identify their location.

5.2.5.1. FORT OF BARCELORE

Portuguese fort of Barcelore was thought to be situated in the town of Basrur, considering the similarity in names. By referring to an old engraving published by Faria y Sousa, Father Heras identifies the location of the Barcelore fort at the town of Kundapur and '*Barcalor de Sima'* or 'Upper Barcalor' as the town of Basrur (Heras 1930, 182). By observing the presence of the large number of Hindu temples and inscriptions in Basrur, and remains of the fort at Kundapur, he further substantiates his interpretation of the map. On inquiry with the local, he was told that Kundapur had an almost square shape fort commonly known as *Kotte-Baghil* very close *to* the river that runs on its north covering approximately an area of 130 ft. by 100 ft. (~40 X 30m) with its north and east side elevated much higher than its other sides (Heras 1930, 183). According to Shejwalkar (1942), Heras's note on *Kotte Baghil* applies to the 'old fort', which seems untrue for two reasons: 1) the location of the Barcelore Fort identified in the spatial analysis and the field observation is at present known as *Kotte-baghil*; and 2) Heras does not say anything about the fort being situated at the corner side of the entrance of the arm of a creek which lies on the east side of the fort. The location, shape and description of the fort mentioned by Heras corresponds with the Barcelore fort. However, Heras gave an underestimated dimension of the fort. The approximate extent identified through the analysis and ground survey is 650 ft. by 550 ft (~200 X 170m).

5.2.5.2. FORT OF KING OF BASRUR AND/OR THE 'OLD FORT'

In 1569, Portuguese attacked and attempted to acquire the Basrur fortress, which they found 'untenable'. Shejwalkar (1942) identified this fort with the 'old fort' and believed that there is no fort in Basrur but a walled town. The British admiralty chart of 1856 and ground observation reveal promising evidence of a fort in Basrur towards the north near the river (probably a citadel) and a fort wall with bastions around the town (Figure 5.4 and Figure 5.5). This invites a question: Did the Portuguese attack this fort in Basrur or the 'old fort' at the corner? Since the earliest Portuguese maps do not depict this 'old fort' but a map published later in 1639 represent that, there is a possibility that the 'old fort' did not exist when the Portuguese attacked the region for the first time; this leads to another question: did the 'old fort' exist at the time of their arrival or not? If we trust the map and believe that the cartographer did not miss or deliberately omit the 'old fort' then the answer to the second question is 'no' and, therefore, answers the first question as well, that is, 'the fort at Basrur'. In that case, it opens another question of when was the 'old fort' built and who made it? The historical text referred to by Shejwalkar (1942) provides ambiguous spatial description; hence, it cannot be used as concrete evidence. To address these questions, a more detailed archival work and ground investigation are required.

5.2.5.3. CAMBOLIM FORT

Tentative Location of Cambolim fort is identified based on the location of Immaculate Conception of Blessed Virgin Mary Church at Gangolli, which is believed to be built on the location of a non-extant church (ref. Figure 5.2 A). The latter was built inside the fort at the time of its construction. The church can be noticed in the historical maps made during that time (Figure 5.7). In the absence of any remains of the fort and unavailability of planimetrically accurate maps, it is difficult to ascertain its extent.

According to the historical records, the Portuguese were given possession of the 'Island of Cambolim' (Udaya 2004). At present, Cambolim (Gangolli) is not an island. It is connected to the mainland from its north, which suggest aggradation between the north of the island and the mainland.

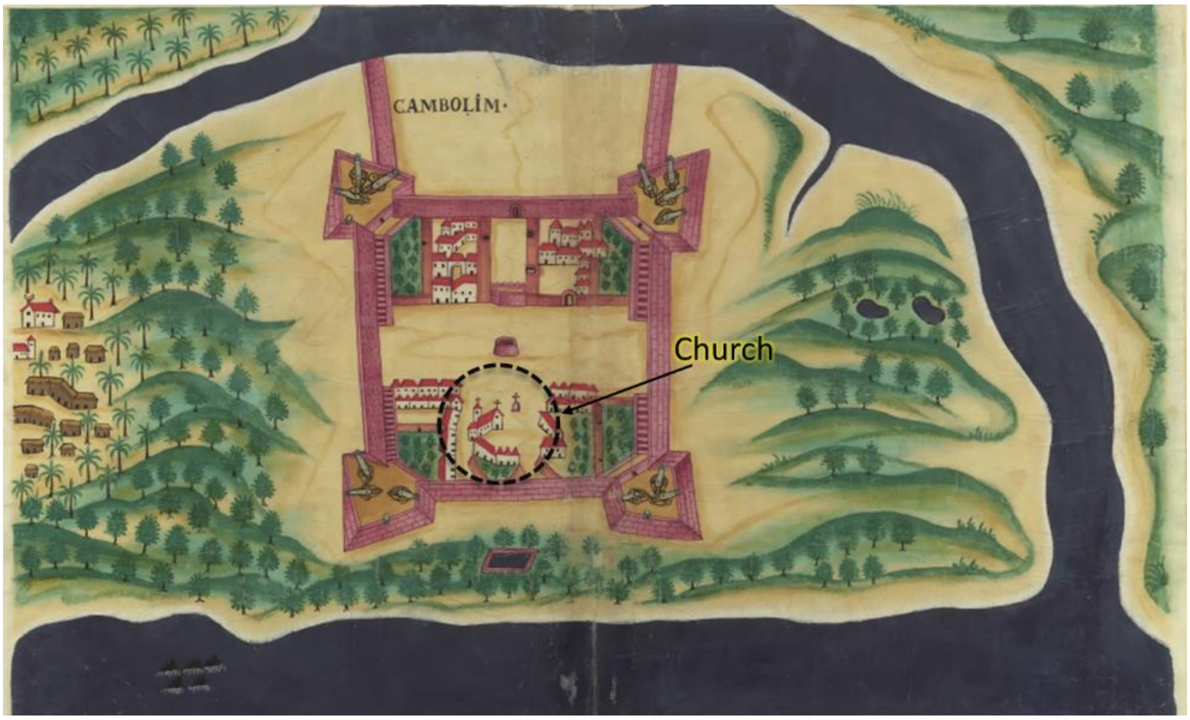

Figure 5.7. Portuguese map of Cambolim fort. (ref. Map-40) (Courtesy: Biblioteca Nacional Digital)

5.2.5.4. TIPU SULTAN'S FORT OR THE FORT OF VIRABHADRA NAYAKA

After realising the increase in the power of the Portuguese by their construction of a new fort at Cambolim, Virabhadra Nayaka erected a fort opposite to it. Its location has not been found discussed in any literature or historical text. Remote sensing analysis did not show any promising observation. However, inquiry from the locals of that area led us to visit what is presently known as Tipu Sultan's fort. It is located at 1.5km north-north-west to the Cambolim fort (Immaculate Conception) at Gangolli. In the second half of the 18th century, this region was under the control of Tipu Sultan, and he took over many forts in that region, some he strengthened and some he destroyed (Buchanan 1807). In Gangolli, Tipu seems to have taken over Virabhadra's fort. People now only remember its possession by Tipu. Interestingly, a Dutch map of 1678 (ref. Figure 5.3) marks a Moors Fort at that location. During that time, moor merchants were powerful in that region. However, no account of occupancy or construction of a fort by them in that region is recorded.

5.3. HONNAVAR (ONOR)

5.3.1. HISTORICAL BACKGROUND

When the Portuguese attacked Honnavar (1569), it was 'by nature very strong' and well-fortified. The fort was located on the north bank of the mouth of river Sharavathi (Srivastava 2018, 187). After a few days of bombardment, the Portuguese occupied the 'small fort' and re-named it 'Santa Catherina' (Danvers 1894, 547; Subrahmanyam 1984, 445). After that, Honnavar became their principal port for the export of Kanara pepper (Udaya 2004). The Portuguese burnt the original Hindu fort and constructed a new fort on the same site. In 1654, Sivappa Nayak took over Honnavar from the Portuguese (Shejwalkar 1942). The old fort was standing on a hill (Danvers 1894, 547; Silveira 1957, 396). However, the exact location of the fort is not known, and nobody seems to have inquired about the presence of the fort in recent times. Texts also do not provide exact location or description to find this fort. The existence of this fort has also faded from living memory of the local population.

5.3.2. CARTOGRAPHIC SOURCES

The most reliable source of spatial information of the fort has been the historical cartographic document. However, Onor (Honnavar) fort is found only in the Portuguese maps. A Portuguese atlas titled- "*Ensaio de iconografia das cidades portuguesas do ultramar*" by Luis Silveira[39]) has a collection of six historical maps of Onor fort, published in the 17th and the first half of the 18th century (Figure 5.8). João Teixeira's atlas, published in 1630, also has one map of Onor fort (Figure 5.9).

[39] Document accessed from the 'Directorate of Archives & Archaeology' in Panjim, Goa on March, 2017.

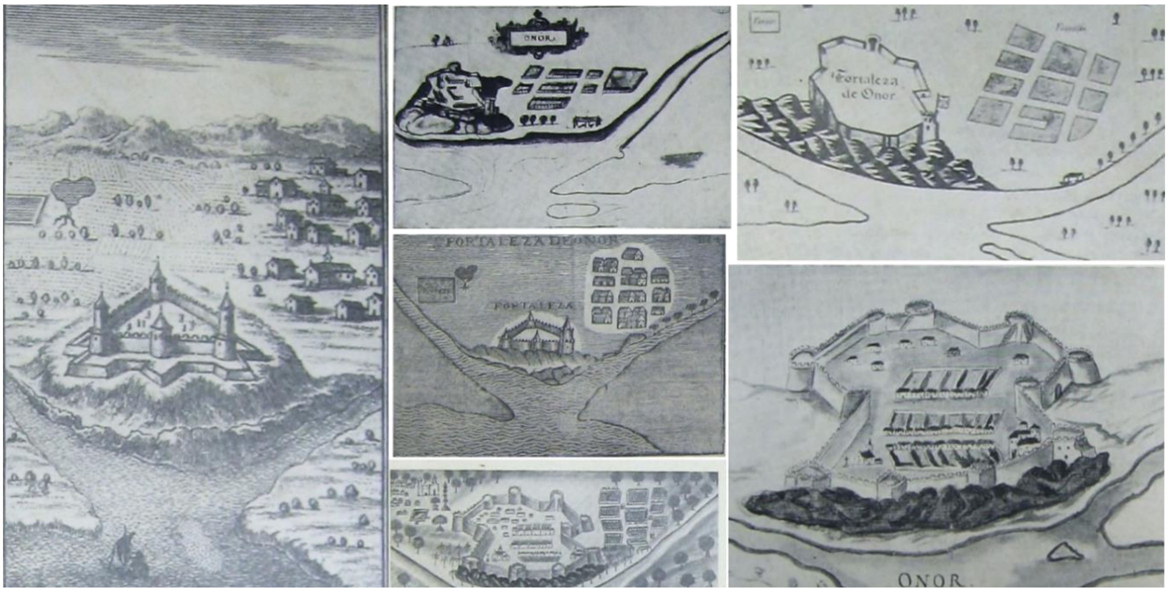

Figure 5.8 Depiction of Onor Fort in the 17th century Portuguese maps. (ref. Appendix, Map-41, and from 43 to 47) (source: *Ensaio de iconografia das cidades portuguesas do ultramar)*

5.3.3. SPATIAL CONTEXT OF MAPS

Figure 5.9 The map of Onor Fort with a north arrow. (ref. Map-42) (Source: João Teixeira's atlas, published in 1630)

The spatial context of the fort is assessed by analysing the relative position of natural and manmade features depicted on maps, and the textual description of its situation. None of the maps acquired by the time of the present analysis (maps provided in Figure 5.8) had information on orientation. Therefore, for the identification of the orientation of the maps and features depicted in the maps, the protruding hilly landmass (Tanmadgi village, in Honnavar Taluk) at the nose of confluence of two rivers flowing along the forts' two sides has been identified on the satellite image. The visual analysis suggests that the maps are oriented to the west-north-west direction. Later, a map published in João Teixeira's atlas in 1630 was found. This map has a compass rose to mark the north whose orientation matches the direction identified through previous analysis. This instance further substantiates that geomorphic features on these maps play an important role in studying cultural features. Although Onor's map in Teixeira's atlas marks direction, the shape of the fort is not properly depicted (in Figure 5.9). This further highlights the need for mining information from multiple maps.

5.3.4. GEOSPATIAL ANALYSIS

Geospatial analysis of historical maps and satellite images helped in finding the remains of the fort as follows:

5.3.4.1. IDENTIFICATION OF THE FORT IN THE SATELLITE IMAGES

Identified physical features (especially the protruding hilly landmass) were further investigated on the satellite image to find any cropmark or pattern. The satellite image analysis revealed a promising positive cropmark of the shape of Onor fort as depicted in a few of the maps (ref. Figure 5.10). These marks were found on a hill.

5.3.4.2. GROUND VALIDATION

The location of identified cropmark was saved in a handheld GPS device, and a field trip to that location was carried out. On field, an old stone wall and foundation of a broader structure (most likely a bastion of the fort) were observed on the site (ref. Figure 5.10). A resident of that place, during an informal interview, stated that the place was his ancestral property which was around 300 years old.

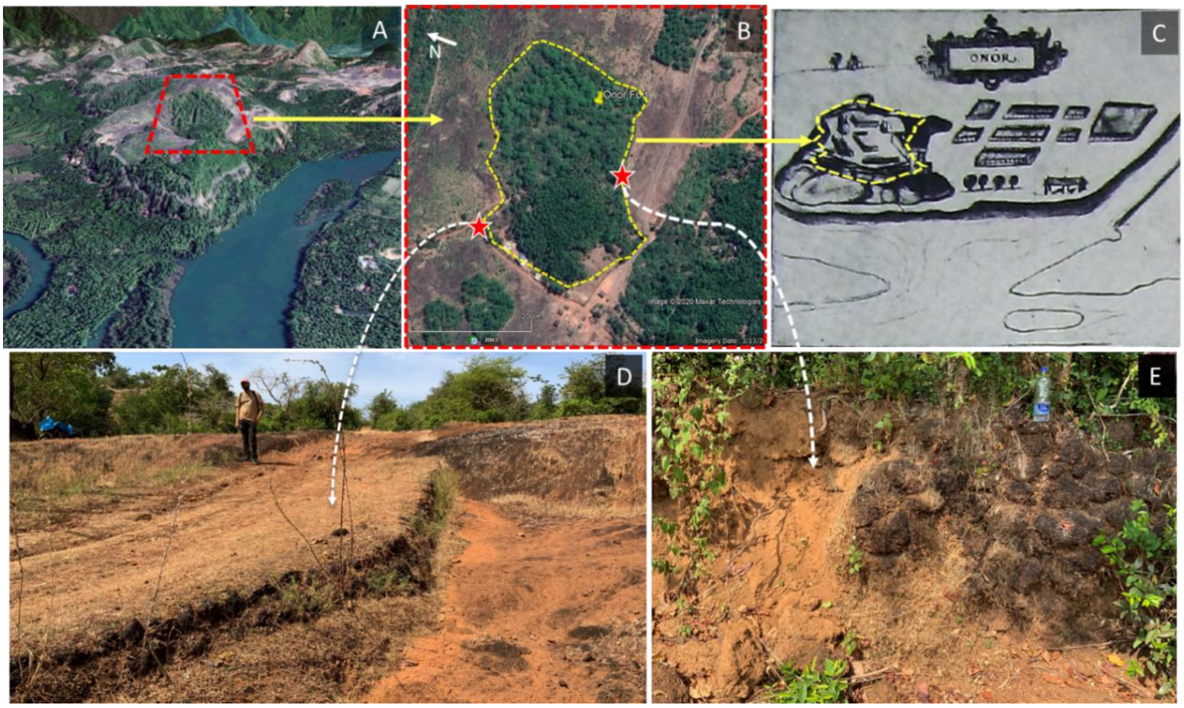

Figure 5.10. Vestiges of Onor fort. A) Google earth 3D view of the fort; B) Satellite view (from Google Earth) of cropmarks of the fort; C) Portuguese map (1610) (Map-41); D) & E) field photographs.

5.3.5. FINDINGS

Integration of spatial information from old maps, historical texts and ground observations suggest that Onor fort was situated on a hill at 14°17'1.41"N latitude and 74°28'37.62"E longitude. The approximate area of the fort estimated using shape, pattern, and cropmark is 20 acres. There are no remains of any superstructure of the fort; only its foundation can be seen in some parts. To better understand the layout of the fort, excavation at the site and a detailed study of architecture and construction material can be carried out in the future.

5.4. VELHA GOA/ OLD GOA

5.4.1. HISTORICAL BACKGROUND

Goa was captured from the sultanate of Bijapur by the Portuguese in 1510 (Pearson 1987, 88). The area taken over by Affonso de Albuquerque, the then Governor of Portuguese India, consisted of islands (called simply Ilhas). Goa, at that time, had a new town built by the Moors or Muslims on the north shore to Divar island[40] with a fort and a wall, massive religious buildings, bazaars and narrow streets (Pearson 1987, 94; Linschoten [1598] 1997). According to Denis L. Cottineau de Kloguen (1831), the ancient town wall (the inner fortification) was about a kilometre in length (extending from the old custom house near St. Cajetan Church to College of St. Bonaventure near Rosary hill) and about 400 meters broad (extending from the shore up to the rising ground at the backside of the convent of Bom-Jesus) (ref. Figure 5.11). After acquiring Goa, Albuquerque gave an order to repair and strengthen the fortifications. He did not destroy the Palace of 'Sabaio'[41] because it was a great building (the palace was later called the Palace of the fortress or Fortress of the Viceroys) (Fonseca 1986, 194–95). The palace was enclosed within the new fortification of the city (Danvers 1894, 212). The city's population and hence, the size of the city grew much larger during the century. The number of Portuguese households increased from 450 in 1524 to 1800 in 1540. By the 1630s, the total population (including Ilhas, Bardes and Salcette) was a little more than a quarter of a million (Pearson 1987, 92–93). The Viceroy Antonio de Noronha, who administered Portuguese India from 1567 to 1571, had built an outer fortification of the town (Kloguen 1831) that can be seen in many 17th century maps of the Old Goa (ref. Figure 5.11). With a rich heritage in Goa, remains of this old town fortification have slipped into oblivion, and we do not find mention of this fort in the list of archaeological sites. Moreover, the investigation of the remains of this fort-wall does not seem to have caught attention of Indian researchers.

In this case study, historical cartographic records, text, and remote sensing data have been analysed to identify the remains of the least known old Goa town fortification and measure its dimensions.

5.4.2. CARTOGRAPHIC SOURCES

The Portuguese atlas "Ensaio de iconografia das cidades portuguesas do ultramar" by Luis Silveira (1955?[42]) has a large number of 16th and 17th century maps and views of Goa.

[40] Referred from the introduction of 'The Commentaries of Afonso de Albuquerque', London, 1875—84, vol. ii, p. c)

[41] 'Sabaio' is a term used by the Portuguese to refer to Adil Shah of Bijapur

[42] Exact date of publication is not known.

Some of these maps are also available online. For the present study, four distinct maps from reliable and known sources are selected. One is the bird's eye view (Figure 5.11A) from the first volume of the *Civitates Orbis Terrarum* published in 1572. This atlas is edited by Georg Braun (1541-1622) and largely engraved by Franz Hogenberg (1535-1590). The second map (Figure 5.11B) is from of John Huyghen Van Linschoten's 1596 '*Itinerario*', who travelled to Goa in 1583. The third map (Figure 5.11C) is from João Teixeira's atlas (1630), and the atlas has also been referred to in the previous case studies. The fourth map (Figure 5.11D) is by António de Mariz Carneiro from his Atlas *Descripçam da fortaleza de Sofala, e das mais da India com huma rellaçam das religiões todas q[ue] há no mesmo Estado* published in 1639. However, other maps were also referred for visual analysis.

5.4.3. GEOSPATIAL ANALYSIS

Geospatial analysis of historical maps and satellite images was carried out to find out the traces of the Adil Shah's fortress (situated in the present days Velha Goa), which Albuquerque strengthened in 1510.

5.4.3.1. THE SPATIAL CONTEXT OF MAPS

Spatial information present in the three maps mentioned above is integrated and studied. João Teixeira's map has the main elements of a map, such as labels, symbols, and orientation. It accurately represents the profile of the coast and the landscape, which made it very convenient to place the site into the real geographic space. These three maps are South-up maps (south at the top of the map and north at the bottom) with a 180-degree rotation of the map from the standard convention of North-up. Such maps are also called upside-down maps. The spatial objects of the maps and their spatial relation with each other have been studied by referring to textual records. For example, Kloguen (1831) describes the fortification of the 'Goa city' opposite the Divar island that helped situate the fortification of Old Goa in the present landscape while referring to the old maps. Analysing such spatial association from maps and text remote sensing analysis of other remains has been carried out.

5.4.3.2. IDENTIFICATION OF THE FORT IN THE SATELLITE IMAGES

Very high-resolution images and 3D view of the terrain from Google Earth Pro are investigated by referring to the old maps to find any visual traces of the remains of this fort. Cropmark defining the presence of fragments of the fort wall of Velha Goa, corresponding to the shape and size of the fort wall depicted in old maps, has been found on the satellite image, which was subsequently investigated on the field (Figure 5.12). The shape of the outer wall depicted in Carneiro's map has better correspondence with the cropmarks identified on satellite images than any other contemporary and older maps.

5.4.3.3. GROUND VALIDATION

Cropmarks of the fort-wall found in the satellite image are not present in a continuous form. Rather, it is in fragments due to the subsequent destructions (Linschoten [1598] 1997), negligence and encroachments of parts of the wall. Therefore, the space between the identified parts of the fort wall was interpolated using the landscape features and topography with reference to the shape of fort in old maps. In Figure 5.12, the yellow line (marked by the presence of cropmarks and ground-based observation) shows the stretches of the fort where remains of walls are present on the ground and has been referred in the figure with numbers. At locations 1, 3, and 4, the remains of the wall are more conspicuous, while at location 2, it was strewn with thick vegetation. Ruin of one of the gates of the fort was found at location 4. The wall is made of laterite and plastered in lime and mortar.

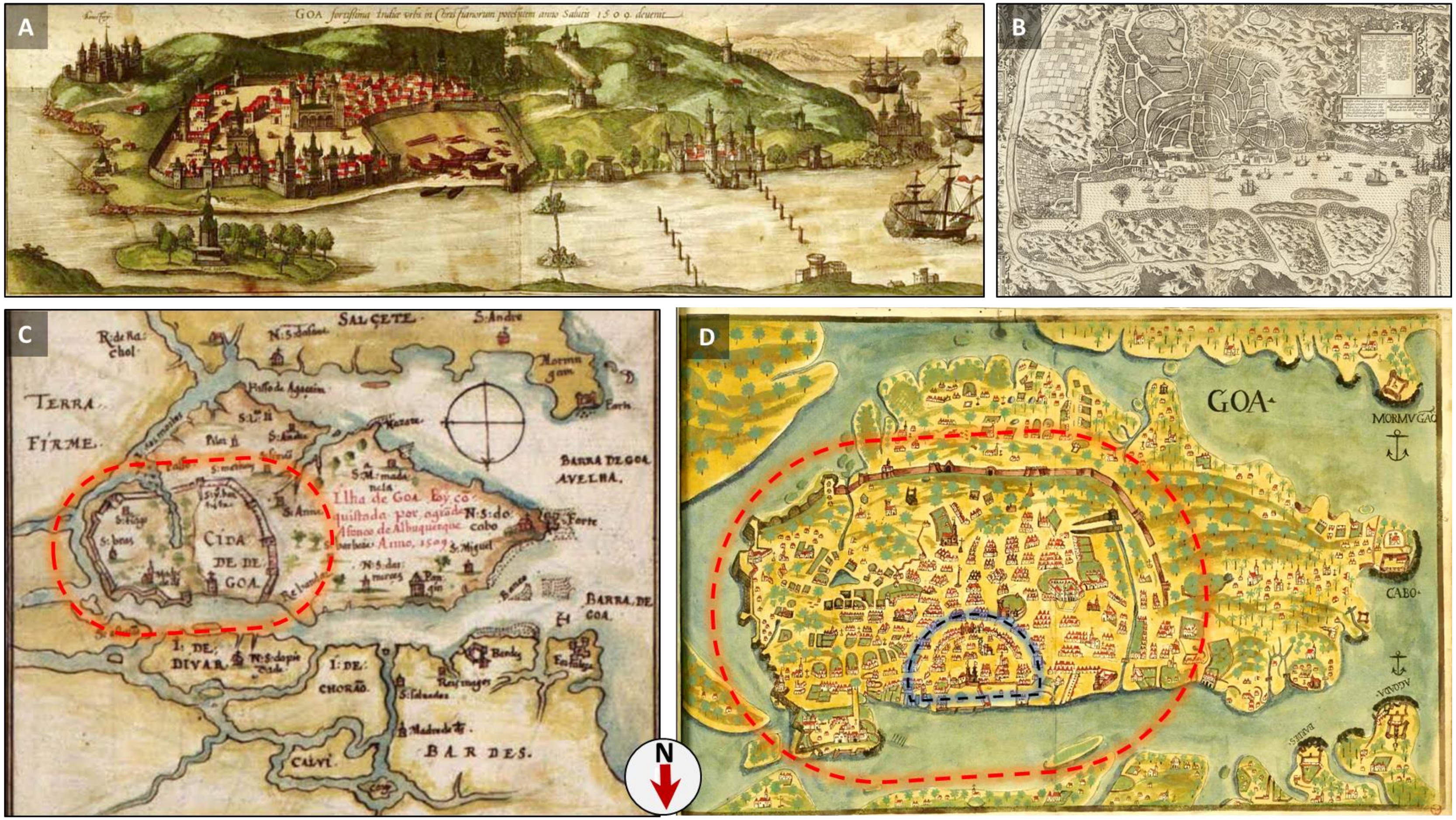

Figure 5.11. Early maps of Old Goa. A) Bird's eye view of Goa island from the Atlas Civitates Orbis Terrarum, 1572 (ref. Appendix, Map-48); B) Map of Goa from the account of John Huyghen Van Linschoten, 1596 (Map-51), C) map of island of Old Goa from Albernaz, João Teixeira' s Atlas, 1630 (Map-49), and D) map of island of Old Goa from Antonio de Maris Carneiro's atlas, 1639 (Map-50)

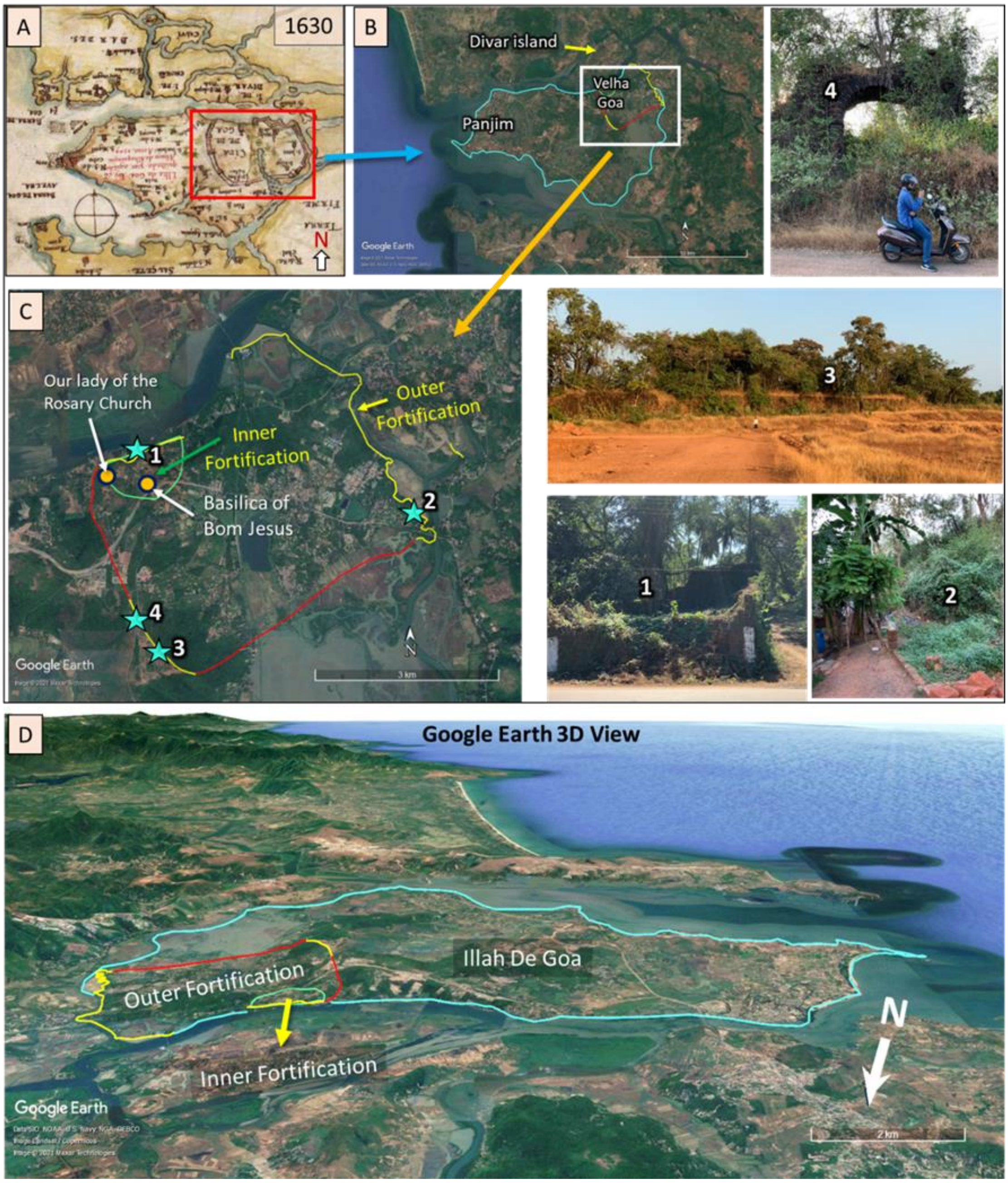

Figure 5.12. Inner and outer fortification of *Illah De* Goa (Island of Goa). A) 1630 map from Teixeira's atlas showing the large fortified town (Map-49); B) Satelite view of Island of Goa and its surroundings; C) Zoomed-in satellite view of inner and outer fortification of Old Goa city- yellow line shows the remains of fort wall traced on satellite image and observed on the ground; numbers from 1 to 4 shows the location of the field photographs on the image C, and their field photos are given with their respective numbers; D) Google Earth Pro 3D-view of the Goa Island corresponding the bird's eye view of Goa island from the Atlas Civitates Orbis Terrarum, 1572 (see Figure 5.11).

5.4.4. FINDINGS

From the analysis of old maps and views, satellite images and ground observations, extant remains of the fort wall of the old city of Goa has been identified, and the extent of the fort wall as depicted in the maps has been measured. The east-west and north-south extent of the fort city was around 3.5 km and 4 km, covering around 4000 acres of land. The extant remains of the wall are more than five kilometres in length.

The map published in *Civitates Orbis Terrarum* (1572) presents the features and details of the terrain disproportionately large and depicts only the inner fortification. Linschoten's map shows a detailed layout of roads but has inconsistency in scale and incorrect shape of islands. Though it omits the principal cartographic elements such as scale and north arrow, Carneiro's map represents the details of the town and the fortification better than other contemporary and older maps. However, Teixeira's map represents the overall profile and proportion of the coast more accurate.

Further investigations with detailed fieldwork, material analysis and literature review of original historical texts might provide a clear picture of this fort. These vegetation strewn and desolated walls have withstood the vagaries of weather and time. However, the strength of the wall that lasted for more than four centuries may not survive for long due to massive construction activities in the region. Therefore, these remains should be given attention by the concerned authorities.

5.5. KOLLAM FORT[43]

5.5.1. HISTORICAL BACKGROUND

Kollam in Kerala, India, has historically been an important trading port. The port was confined to the promontory, now called Thangassery, 3 km west of Kollam Junction railway station. This port was frequently visited by Chinese and Arabic as early as the 7th and 8th centuries ("Imperial Gazetteer of India, Volume 14" 1908). It had also been of great interest to Portuguese, Dutch, British[44] and local neighbouring rulers during the colonial period (Aiya 1906), which in India spanned from 16th to twentieth centuries. Portuguese established a factory[45] in Kollam in 1503 (Mathew 2017). Francisco de Almeida, the first Portuguese viceroy to India, had conquered this place in 1505 and built

[43] This section has been published in Gupta & Rajani (2020b)

[44] Portuguese, Dutch and British spelt Kollam as Covlao/Covlam, Coylan/Coylang and Quilon, respectively

[45]Factory is a colonial term for entrepot.

the Fortaleza (a fortress) called Fort St. Thomas in 1519 (Diffie 1977; Mathew 2017), which was later expanded to a larger fort (for detail ref. section 5.5.4.1 and 5.5.4.2). In December 1658, the fort was captured by the Dutch United East India Company and then was re-occupied by the Portuguese in April 1659. In December 1661, Dutch finally took control of Kollam (Schilder et al. 2006), which they held for over a century. In 1795, the English East India Company took over Dutch factories and possessions (Aiya 1906). The port and the surrounding coastal stretch have been frequently mapped by Portuguese (16th and 17th century), Dutch (17^{th} and 18^{th} century) and British (18^{th} and 19^{th} century) at different scales and for various purposes.

5.5.2. PHYSICAL DESCRIPTION OF KOLLAM

The study area includes a small coastal stretch in the Kollam District of Kerala State, India. The Kollam fort is situated on Thangassery Point (a promontory of laterite rock abutting the sea). The extent of the fort for the present study is determined by using colonial maps, which depicts the fort extending from the shore of Thangassery promontory to around 800 m inland (ref. Figure 5.13). A small portion of the Portuguese fortress, known as Thangassery Fort or Fort St Thomas, was declared a Protected Monument by the Archaeological Survey of India (ASI) in the 1980s. These remains lie at 8°52'53.95"N and 76°34'6.40"E and occupy an area of ~ 0.1 acre, which is a very small fraction of its original area (ref. the sections 5.2.3.1 and 5.2.3.2). During the field visit, laterite deposits exposed to the seawater are observed in pockets along the Thangassery promontory.

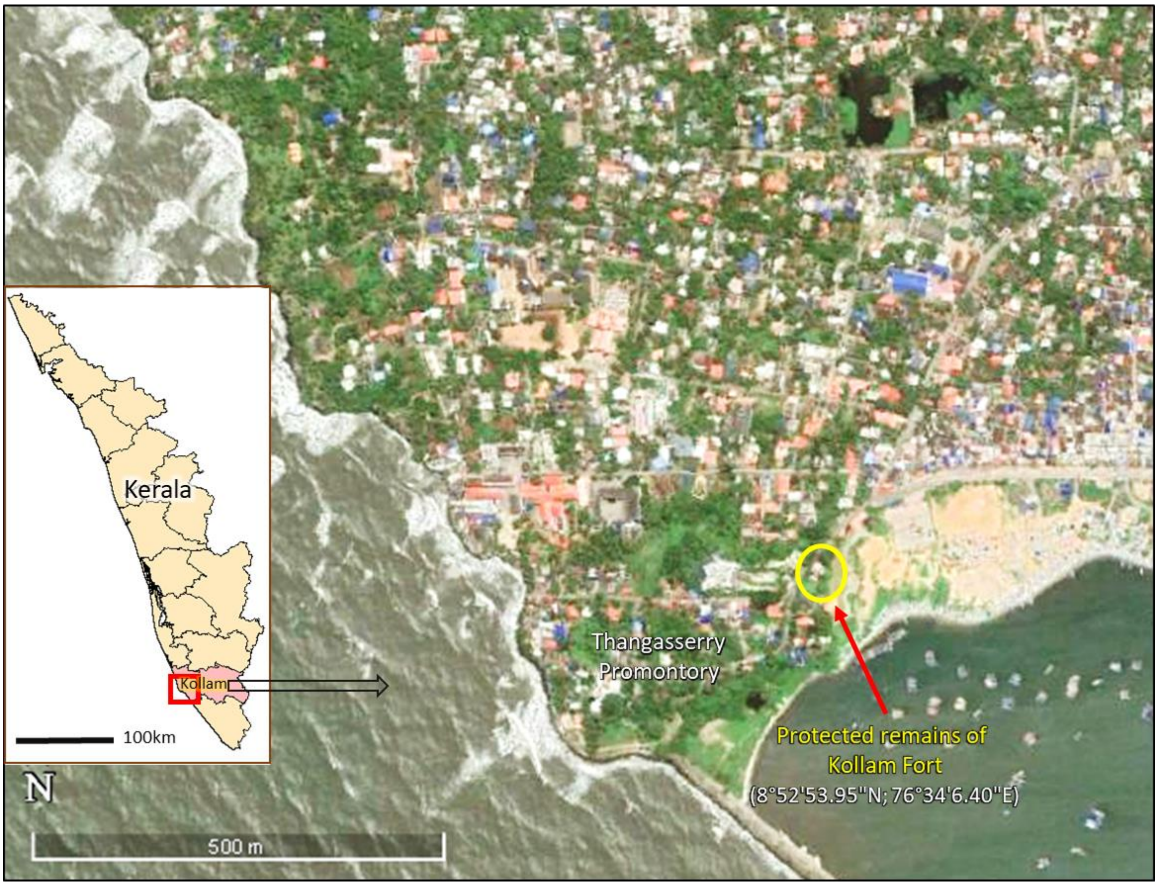

Figure 5.13.Kollam fort and its situation.

5.5.3. METHODOLOGY

An integrated methodology is adopted that involves three steps: (1) data collection and acquisition, (2) understanding the content and context of old maps, (3) geospatial analysis. Following are details of each step:

5.5.3.1. DATA COLLECTION AND ACQUISITION

The data used in this study are historical maps, paintings, views and very high-resolution (VHR) satellite images. Historical maps have been gathered from various places and sources, and are of different scales and of various types. This study has included maps only showing the fort area in full or part and excluded small-scale maps that mark Kollam only as a point feature. The dates of maps (used in the present study) range from the mid-16th century to the late 19th century. For the remote sensing analysis, historical satellite images available in Google Earth Pro (from January 2003 to February 2019) have been used.

5.5.3.2. UNDERSTANDING CONTENT AND THE CONTEXT OF OLD MAPS

During the colonial period, Kollam was largely mapped by Portuguese, Dutch and British. French also produced a few copies of the maps. Content of the maps (such as orientation, annotation, toponymy, scale, and the context of the history of the time they were made), their mapping style and the purpose they served, have been examined so that information can be derived meaningfully. They have been categorised based on who made them (Portuguese, Dutch, French and British) that has also conveniently put them into chronological order.

5.5.3.2.1. Portuguese maps

The earliest map of colonial Kollam is a Portuguese handmade bird's-eye view dated 1515 ('Appendix', Map-52; Correia 1858; Algeria et al. 2007). Another map made by Joao Teixeira (Map-53), published in 1630, has characteristics of both bird's-eye view and plan map. A fortress (a fortified palace of a citadel) and a fort (a fortified defensive structure stationed with troops) wall with bastions are depicted in a perspective view, while the other features are represented in a plan map style. Antonio Bocarro's map (Map-54) of 1635 is similar to Teixeira's map, looks like an artistic copy (with intricate architectural details), but does not depict map elements such as title, north arrow and labels, which is present in Map-53. In Maps 52, 53 and 54, Kollam is variedly spelt as Coullam, Covlam and Covlao, respectively. We have not found any Portuguese map of Kollam made after these. Portuguese maps do not have planimetric accuracy and therefore, cannot be georeferenced. However, they are rich with spatial information such as the depiction of manmade structures (architectural details of buildings, fort and layout of roads) and their relative positions with respect to the shape of the coastline consisting of a rocky promontory with a bay to its east. Thus, found very useful visual analysis.

5.5.3.2.2. Dutch maps

Map-55, dated 1672, is the first available Dutch bird's eye view of Kollam (Baldaeus 1672). This is the only Dutch map that shows the Portuguese fort wall (the wall is henceforth referred to as PF) and the plan of a revised fortification (consisting of two demi and one complete triangular bastion) that the Dutch later built; the Dutch Fortification is referred to as DF. Map-57, dated 1687, is the earliest available planimetric map of Kollam with all the main elements of a map (like title, scale, north arrow, label and legend). It has a graphical scale of fifty *rijnlandse roeden* equivalent to 188 m on the ground (one *rijnlandse roeden* = 3.767 m). The georeferencing accuracy (described in 5.5.3.3.3) of the map indicates that it was made with the planimetric survey technique. Some of the maps dating from the mid-18th century (Map-60 to Map-66) seem to be copies of Map-57 with new annotation as they have very little new content. Copying of maps was a regular practice for producing copies when opportunities for collecting new data were few and far between. There are three other medium and small-scale maps of the Dutch fort—Map-58 by Hans Georg in 1697, Map-68 by Graaf, Joh. Wilh. De in 1767 and Map-59 by an anonymous cartographer in ca.1703. These maps depict prominently the typical triangular shape bastion of the DF, showing the importance of the fort at that time. In most Dutch maps, Kollam is spelt as Coylan except few where it is referred to as Koylang.

5.5.3.2.3. French Maps

The only French map we found of this area is made by Jacques Nicolas Bellin in 1747 (Map-61), was, in fact, the first historical map of Kollam that we examined in the present study and only after initial interrogation we realised that it was a mirror-reversal copy (similar maps made by Bellin were also published in 1750, 1755, 1756 and 1764 [ref. Map-60 to 65]). Recognising 'original' versus a mirror-reversal is of significance particularly to the present study (Figure 5.14). Initially, the shape of the coast and the fort as depicted in Map-61 was searched on satellite images as that was the first map collected. Since, the map was a reverse copy, the patterns did not match, and we first mistakenly assumed that the landscape had changed beyond recognition. Later, through further archival exploration, we found maps with correct orientation made by other Dutch cartographers (mentioned in the previous section). This interesting observation also emphasizes that some of the historical maps can have such big errors and, thus, should be used with utmost care.

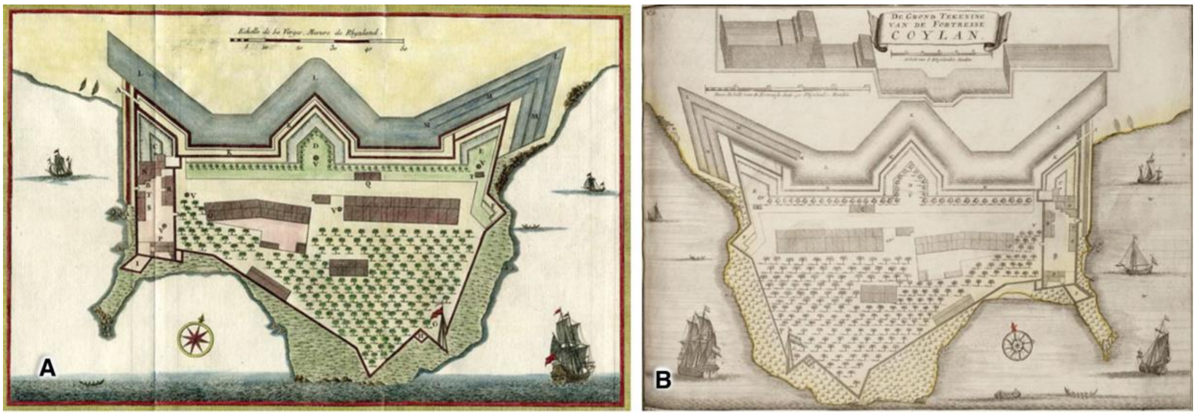

Figure 5.14. A) Kollam fort an Erroneous mirror reversal map made by Jacques Nicolas Bellin in 1745 (Map-61); B) a proper copy made by Francois Valentyn, 1724 (Map-60)

5.5.3.2.4. British Maps

We did not find any British map of Kollam fort except the small-scale map of 1829 (Map-70) where the triangular bastioned fort is only symbolically represented but with the name Tungumshery (also spelt as Tangacheri or Tangachery elsewhere). In this map, the name Quilon is attributed to the then small settlement 2 km east of DF, and it forms the core of what is the present-day city of Kollam. Map-73, dated 1883, is an admiralty chart that, apart from land features (like streets, canal, settlement and trees), gives soundings and contours of underwater topography in the sea and inland lakes. This map does not mark DF; instead, it has a fresh layout of five parallel roads running west–east (as though striking out the old and replacing a new floor plan) with the area annotated as Tangacheri and a road (Tangacheri Road) connecting it to the town of Quilon. The map also marks a dotted boundary that coincides with PF's layout; hence, it has been considered for the present analysis. The map's scale is in English miles (1 English mile equivalent to 2.1 km) and sea miles (1 sea mile equivalent to 1.8 km). The absence of the DF in British map may indicate a lack of importance during that time. Since the remains of DF are visible on recent satellite imagery and ground even now (ref. section 5.5.3.3.1 and 5.5.3.3.2) they would have been only more conspicuous in 1883 when Map-73 was made. However, Suganya and Rajani (2020) have reported that the British map dating from 1878 of Agra had deliberately omitted marking old city-wall when there is other evidence of the wall's existence at the time, which suggest that exclusion of older city walls in a map was a practice at the time.

We also noticed a significant advancement in mapmaking practice from Portuguese (17th century) to Dutch (17th –18th century) to the British period (19th century) in India. Portuguese seemed to have mapped the fort mainly for record purposes, while Dutch made these maps mostly for planning and strategic purposes. British were interested in extensive and detailed mapping of offshore, onshore and inland areas and no detailed mapping of the fort as it was insignificant for them (ref. Figure 5.17B).

5.5.3.3. GEOSPATIAL ANALYSIS

5.5.3.3.1. Visual interpretation of satellite image

Knowledge of the scale has been crucial to locate the area of interest on the satellite image. Otherwise, one would be puzzled about the size and extent of the structure, especially along the shoreline, where the shape of the shore looks similar at different scales. Once the scale is known, the satellite images are brought to the scale of the map and then investigated for further analysis. Identification of visual traces of the triangular bastion fort structure (marked in Maps-56 and 57) is carried out using interpretation keys such as shape, pattern, texture, shadow and association. Many high-resolution satellite images are available for this area dating from 2003 to 2018 in Google Earth Pro. Although the fort structure is hard to discern in the images, the signature of the wide moat on the north was discernable. The visibility of this cropmark[46] varies; however, they are more conspicuous in images from before 2011 when the fort area was comparatively less interfered with by recent human activities.

5.5.3.3.2. Identifying remains of old fort and ground-truthing

The identified potential location of the remains of the fort from visual analysis (described in section 5.5.4.2) was marked on GIS software and then uploaded to a handheld sat-nav device to navigate on the field during the survey conducted in December 2019. The

[46] Cropmark is one of the main interpretation keys used for satellite image based archaeological exploration. Positive cropmark shows excess growth of vegetation over a ruin or a buried ditch like features. Negative crop marks show retarded growth of vegetation over a buried hard structure. For further explaination refer Rajani (2021).

presence of the ruins of the fort was recorded photographically, and their location in the handheld GPS device, which were later used for georeferencing.

5.5.3.3.3. Georeferencing

The satellite view of 25th March 2009, available in Google Earth Pro, was selected as the base image for the study area. It was saved with maximum resolution, and the saved image was georeferenced using GCP from the same image in Google Earth Pro, and accuracy of 1-pixel RMSE was achieved. Large and medium-scale maps (viz. Maps-57, 67, 69, and 73) were georeferenced using coordinates of identifiable features on the base image. Maps with oblique views (Maps-52-55) have inconsistency in scale, making them unsuitable for planimetric measurements. Therefore, they were not georeferenced; instead, they were analysed visually. Efforts were made to identify maximum numbers of Control Points (CP); however, their numbers in some maps were limited due to the unavailability of stable recognisable common features. In addition, it was a challenge to find CP that were well distributed across the whole map canvas. The details of georeferencing accuracy are listed in Table 1. In most cases, we could find well-distributed CP, but for Map-69, they were clustered only in the fort area, which resulted in a large distortion in parts that were away from the Fort.

In this case study, the information has been derived mainly through visual comparisons by making the map layer semi-transparent on top of the base image. Polynomial order 1 is found to be giving the best output for all the georeferenced maps.

5.5.3.4. DIGITISATION AND OVERLAY ANALYSIS

The outline of the fort was traced using the georeferenced maps (listed in Table 1) in QGIS (an open-source GIS software), and then the digitised vector file (traced outline) overlaid on the base image.

Table 5.1: Details of georeferencing accuracy.

Map no. (based on appendix I)	year	TT*	Total GCP	Errors (m)			Pixel size (m)
				RMSE^	Highest Residual	Lowest Residual	
Map-57	1687	P1	11	8	15	1	1
Map-67	1766	P1	9	9	16	2	0.14
Map-69	1770	P1	9	24	41	3	4
Map-73	1883	P1	15	13	23	2	4
* Transformation Type ^ Root Mean Square Error							

5.5.3.4.1. Map Integration

The historical maps used in this study are heterogeneous in terms of their content, scale and style. There are 2-dimensional plan maps, sea charts and other general maps, bird's-eye view map with 3D building structures, coastal views and drawings from 1558 to 1883 CE. Here, the term 'map integration' is used for combining the information obtained collectively from a variety of historical maps to enhance the archaeological understanding of the study area. In the present study, this is achieved by combining visual interpretation of non-georeferenceable oblique maps and views with geospatial analysis of georeferenced maps and also historical text records. The analysis is sensitive to the chronology of various sources.

5.5.4. RESULTS

Analysis of historical maps provides interesting aspects about the mapping of Kollam from the 16th century to the 19th century and new insight into Portuguese Fortification (PF) and Dutch Fortification (DF). The geospatial study of historical maps has explored the unidentified structural remains and revealed various aspects of the colonial settlement such as spatial and temporal dimensions, occupancy, chronology and importance. The results are discussed as follows:

5.5.4.1. THE FORTALEZA

The oldest bird's-eye view dated 1515 (Map-52) depicts only a building complex (with a three-storeyed turret) of the factory that is also seen in Teixera's map labelled as 'Fortaleza (fortress in Portuguese). This Fortaleza has more architectural details in Map-54 and is also marked in the earliest Dutch plan (Map-55) (ref. F1 in Figure 5.15). This turreted building is also clearly depicted in an 18th-century Dutch painting (F1 in Figure 5.15G). At present, this building is in ruin and protected by ASI (F1 in Figure 5.15E). The similarity in architectural details in the above-mentioned sources together with the location of its remains on the ground and the layout of various maps suggests that the remains of the 'fortress' protected at present are the oldest colonial structure built by the Portuguese as a factory in 1503 and later repaired to a fortress named as Fort St. Thomas in 1519 (Logan 1887). The maps dating from 1630 and 1635 (Maps-53 and 54) mark a layout of several structures outside the 'fortress' indicating the expansion of the Portuguese settlement, which must have demanded construction of a fort-wall further north protecting the larger settlement. These two maps show a fort wall (PF), about 500 m north of the fortress, protecting the town from north and northeast directions. This structure is also marked in Map-55, a Dutch map of 1672 (Figure 5.16). In fact, the depiction of PF in this Dutch map perfectly matches the description given by Johan Nieuhof who visited Kollam in January 1662, a month after the Dutch captured the fort from the Portuguese. Nieuhof describes that the city was fortified with an 18 to a 20-foot-high stone wall with eight bastions (Nieuhof 1744, 207) (Figure 5.16). The structure of PF is nonexistent in the subsequent maps (ref. Maps-69 and 73), where it is replaced with territorial marking.

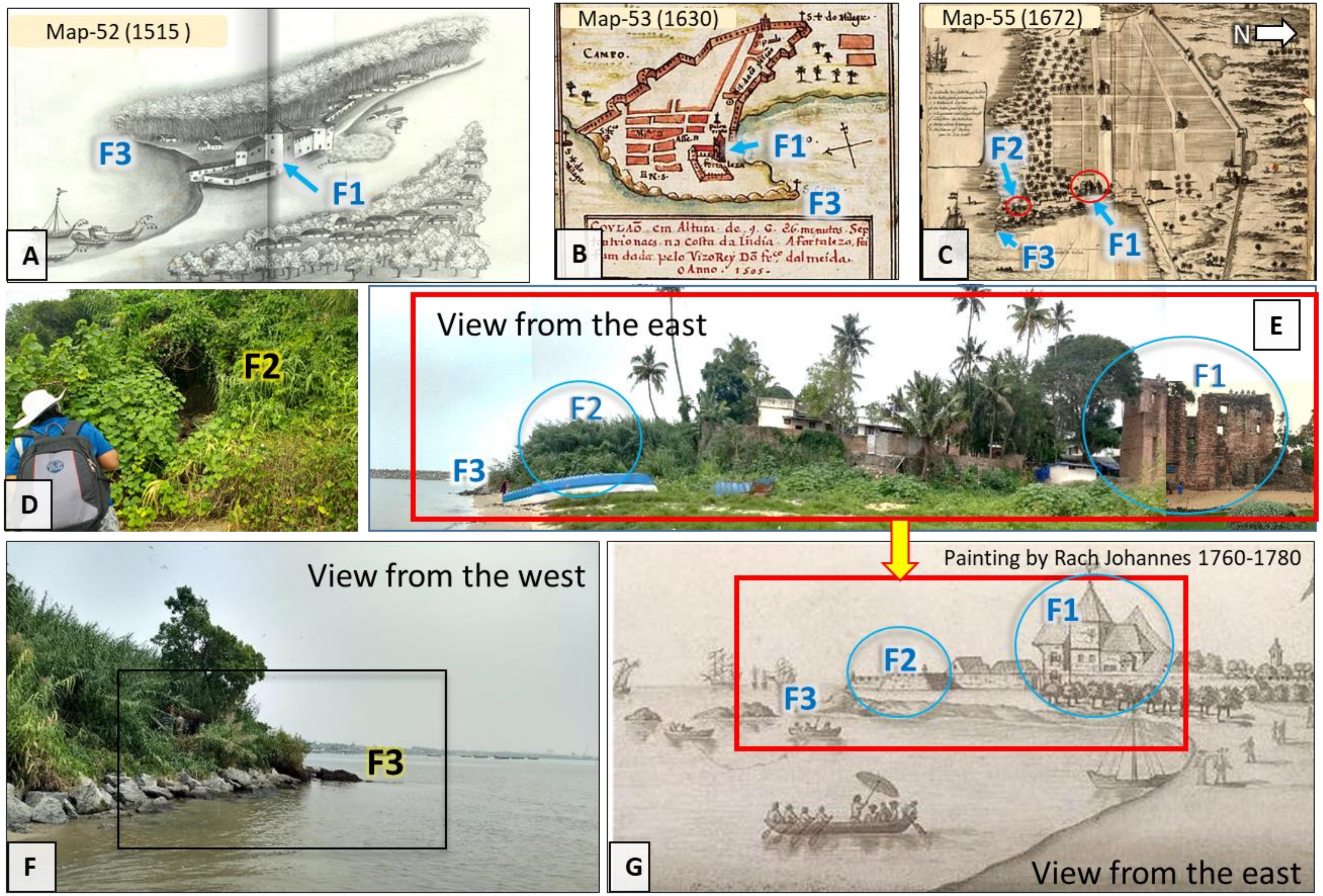

Figure 5.15. Maps and paintings depicting the fortress which is the oldest colonial structure, and laterite deposit; F1 is the fortress; F2 is the location of a bastion identified in Dutch maps and validated on ground; F3 is laterite outcrop depicted variedly in old maps and paintings. (refer 'Appendix' for maps). Source of painting [G]: https://www.atlasofmutualheritage.nl

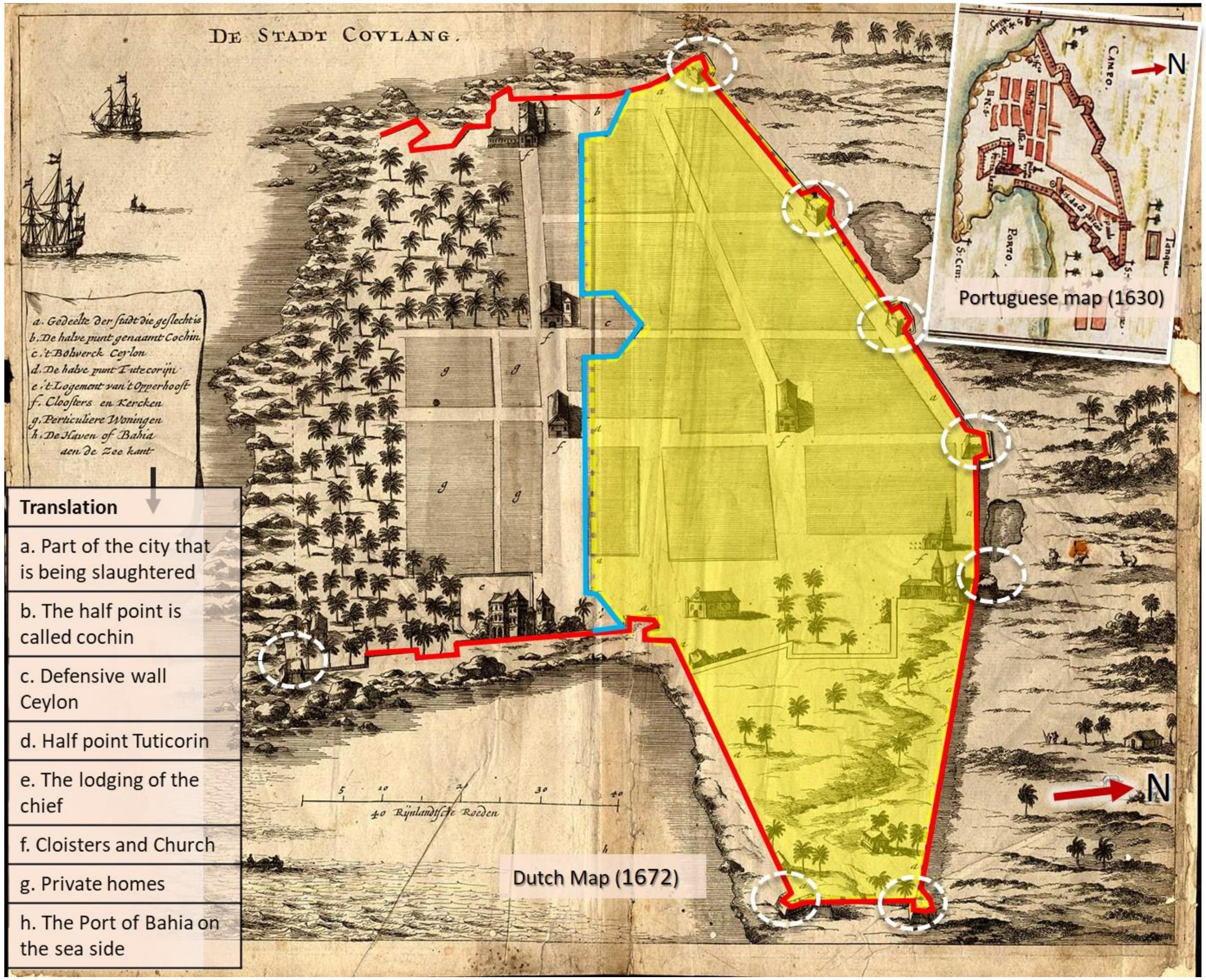

Figure 5.16 Map-55 (ref. Appendix) which records the extents of original Portuguese fort (marked in red) with 8 bastions (highlighted with white circles) in context of the plan of the downsized Dutch fort with 3 bastions (marked in blue); the yellow watermark is of the area of Portuguese fort demolished by Dutch. Inset is a Map 2 for comparing the shape of Portuguese fort as depicted in both these maps.

For instance, in Map-69, a 1770 Dutch map, the identified extent of the PF represented as a boundary of the company's land. Schilder et al. mention it as a boundary of the former Portuguese town (Schilder and et al. 2006, Vol VI; ref. Map 14). The British map (Map-73) of 1883 also marks a dotted line that follows a similar shape; however, no information is provided in the map explaining that dotted line (Figure 5.17B). Parts of this dotted line can be seen as linear cropmarks on high-resolution Google Earth satellite imagery when the two layers are overlaid and analysed (Figure 5.17D). On the ground, an old laterite wall was observed along this line extending in the north-west direction following the cropmark; this wall also formed a compound wall of a 16th -century Portuguese Cemetery (Figure 5.17 E & F). A Portuguese church is also identified in the map of 1672 (Map-55) at this location adjacent to the wall. Evidence from the maps, remote sensing analysis and field suggest that the boundary marked in the Dutch and the British map (Maps-69 and 73) corresponds to the extent of PF. However, an alternative boundary of PF is delineated using street patterns in Rajani (2021). Rigorous field exploration is required to find out any extant remains of PF along with scientific dating of carefully extracted material from the wall. The fort area, measured from the identified extent, is around 85 acres with a north-south and east-west extent of around 600 and 950 m.

5.5.4.2. THE DUTCH FORT

After Dutch took over the fort's possession in 1661, a reduction of the size of the PF was ordered in 1665 to reduce the cost of maintenance. A fort (DF) reduced in the area but enhanced in strength with three bastions (a triangular bastion in the centre flanked by two demi-bastions) on the land side was built under the instruction of Nieuhof (Nieuhof 1744). The testimony of this event is preserved in a Dutch map of 1672 (Map-55). One of the most accurate, detailed and possibly the original maps of the earliest construction of the DF is by Hans Georg Taarant (1687, Map-57). The approximate north-south and east-west extent of this DF are 270 m and 370 m, respectively. The fort was further reduced from the southwest side by the mid-18th century as depicted in the Zijnen, D's map (Map-67, 1766) (ref. Figure 5.18). Records of orders to reduce the fort's size and strengthen its parts have also been found in the historical accounts (Galletti, van der Burg, and Groot 1911; Schilder and et al. 2006) . For the identification of fort remains, Taarant's map has been used (Map-57, 1687). A positive cropmark of the central triangular bastion of DF and the moat along it has been observed in Google earth images (Figure 5.19B). Subtle traces of other bastions and rampart have also been observed. However, these cropmarks were very faint and not readily visible. The road layout in the Thangassery area marked in the British map (Map-73, 1883) was matched with roads marked in Google Earth, and then, crop marks were identified by spatial association. Since satellite image analysis mainly indicated the presence of moat, we were not sure of finding any structural remains of the wall. However, on the ground, the main road that runs east-west is laid on top of the remains of the rampart from where the three bastions are projected northward. Ground truthing of the traces confirmed the presence of the vegetation strewn remains of the fort (Figure 5.19 D & E). Broad step like rampart has been noticed along with the three bastions (F8 in Figure 5.19F). The wide linear space south of three bastions, depicted as F9 in the same figure, is a laterite brick rampart. The central bastion has ruins of a British cemetery (F6 in Figure 5.19D). The portion opposite to it in the southern direction has ruins of a Dutch cemetery. We have also found two huge and tall pillars of laterite bricks standing north side of the British cemetery on the central bastion (Figure 5.19E). Unfortunately, no information on these pillars was found. The land on its south was sloping downward and many modern structures (such as houses, resort) were built on top of old ruins, indicating that the ruins of old settlement is smothered by the modern settlement.

The early maps and remote sensing analysis show gradual advancement of shoreline along the East coast of the Dutch fort (ref. Figure 5.20). The construction of breakwater in the 1990s has caused significant advancement of the shoreline in this region. Although the erosion of the laterite strip depicted in the map can be ascribed to quarry by locals for the construction purpose (ref. Figure 5.20).

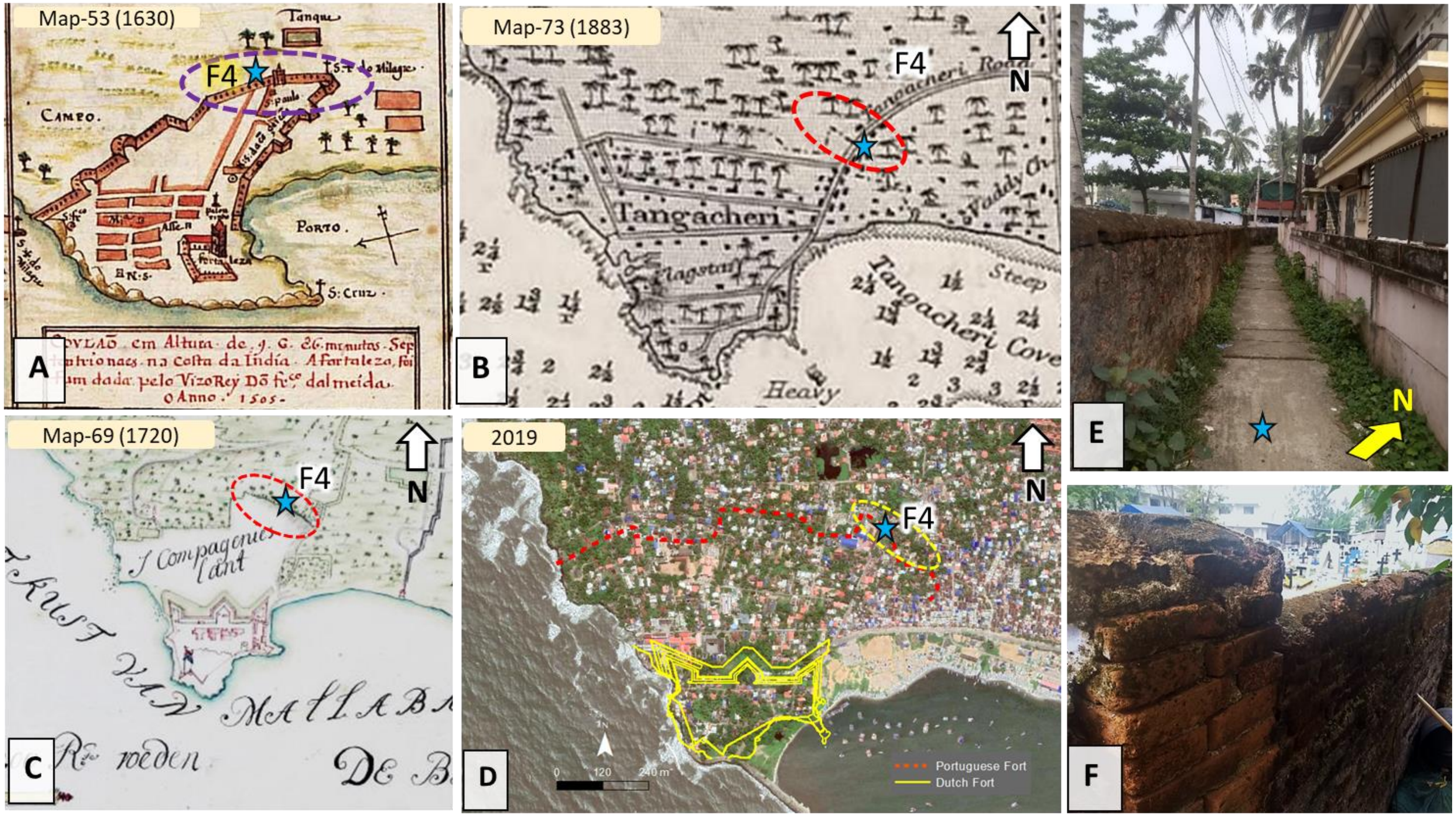

Figure 5.17 Location of remnant of old laterite wall in old maps and satellite image (F4 in A–D) and ground photograph (e, f). (Satellite Image Courtesy: Google Earth, Maxar Technologies, June 10, 2018)

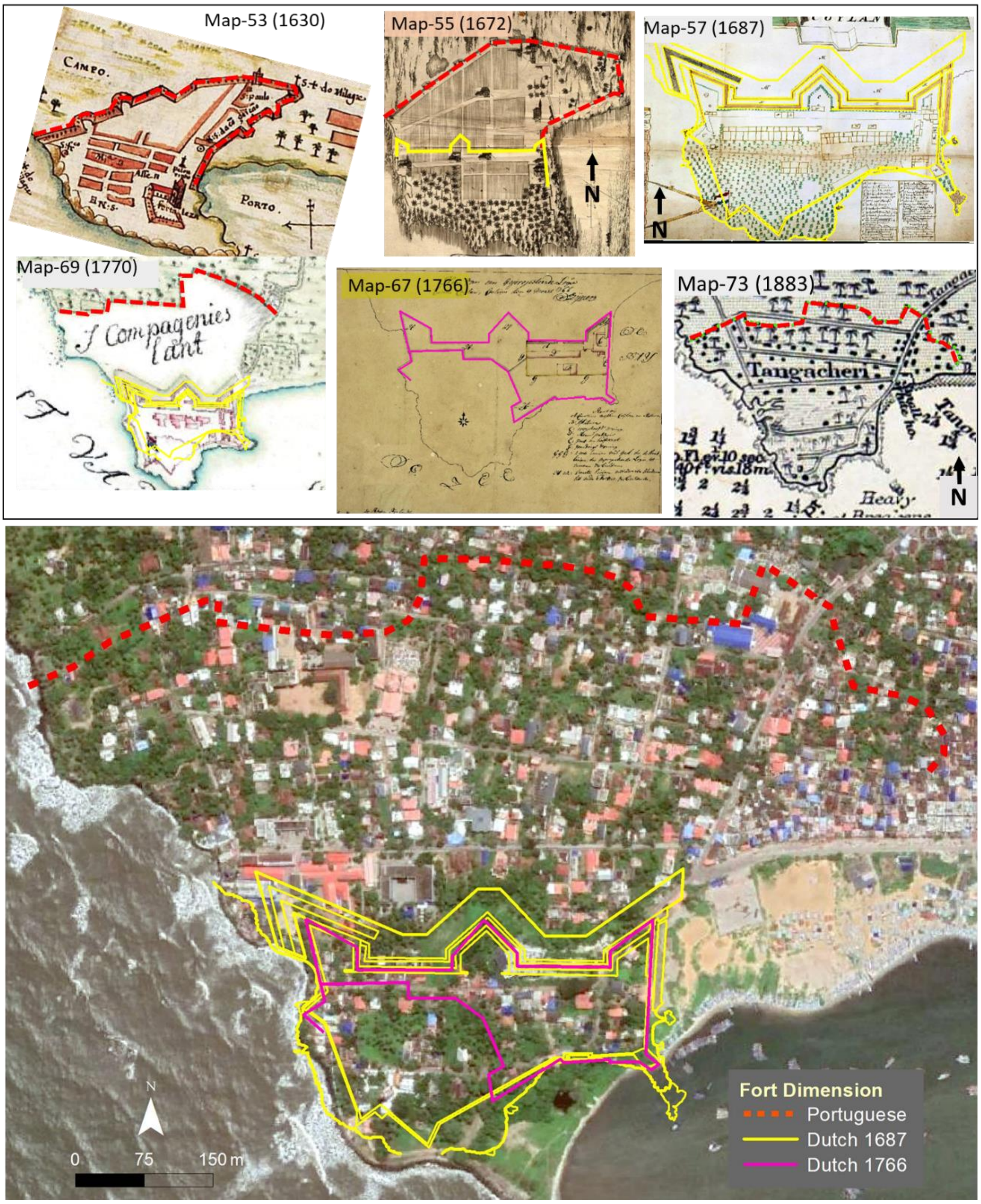

Figure 5.18. Approximate extents of the Portuguese and the Dutch forts. (Satellite Image Courtesy: Google Earth, Maxar Technologies, June 10, 2018)

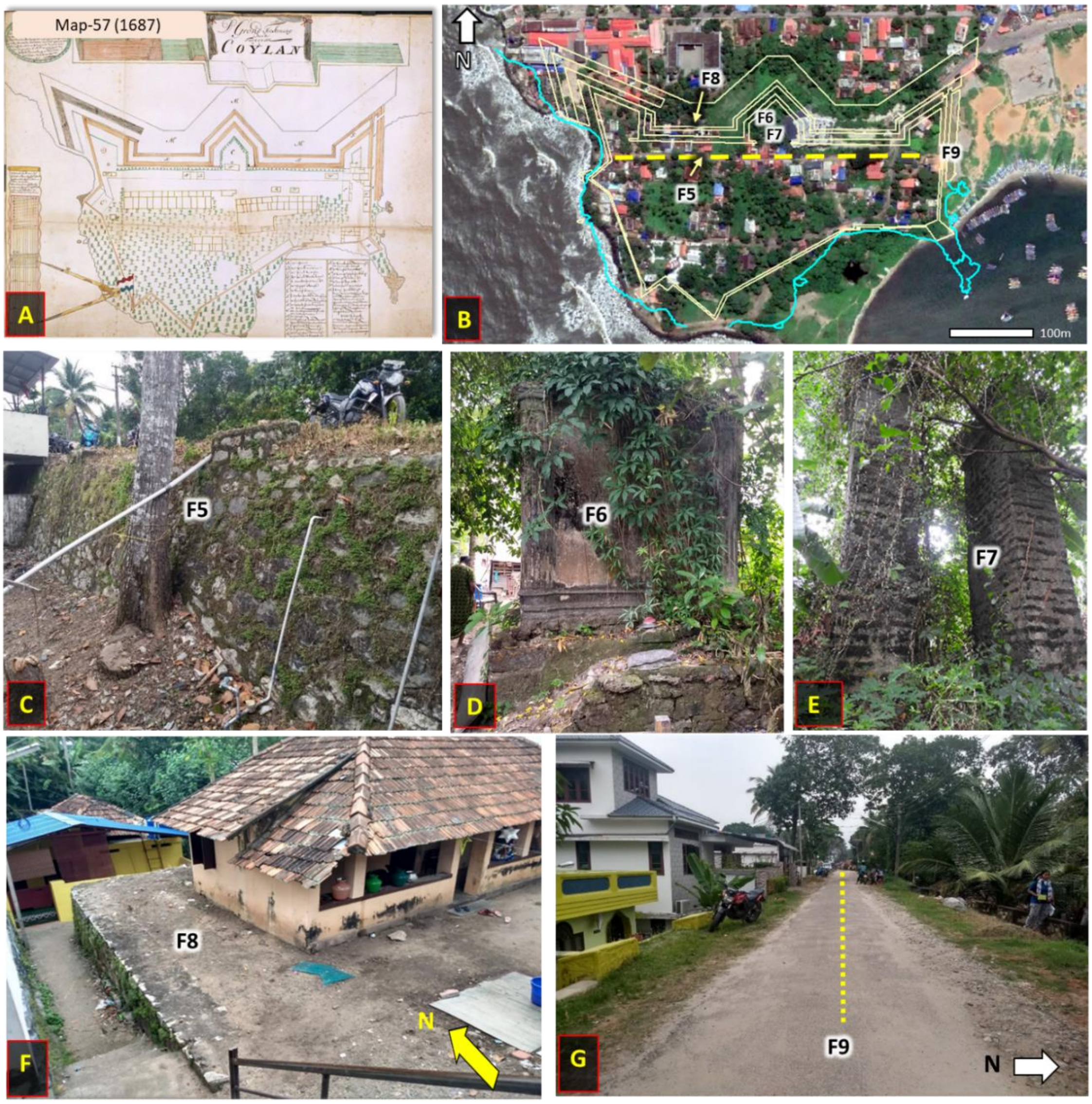

Figure 5.19. (A) Dutch plan map of Kollam fort; (B) outline of the plan map overlaid on the crop mark traced in the satellite image with location of other identified features; (C) rampart of the fort; (D & E) old structures on the central bastion, (F) step-like rampart of fort to the North and (G) Rampart of the fort being used as a road. (Satellite Image Courtesy: Google Earth, Maxar Technologies, June 10, 2018).

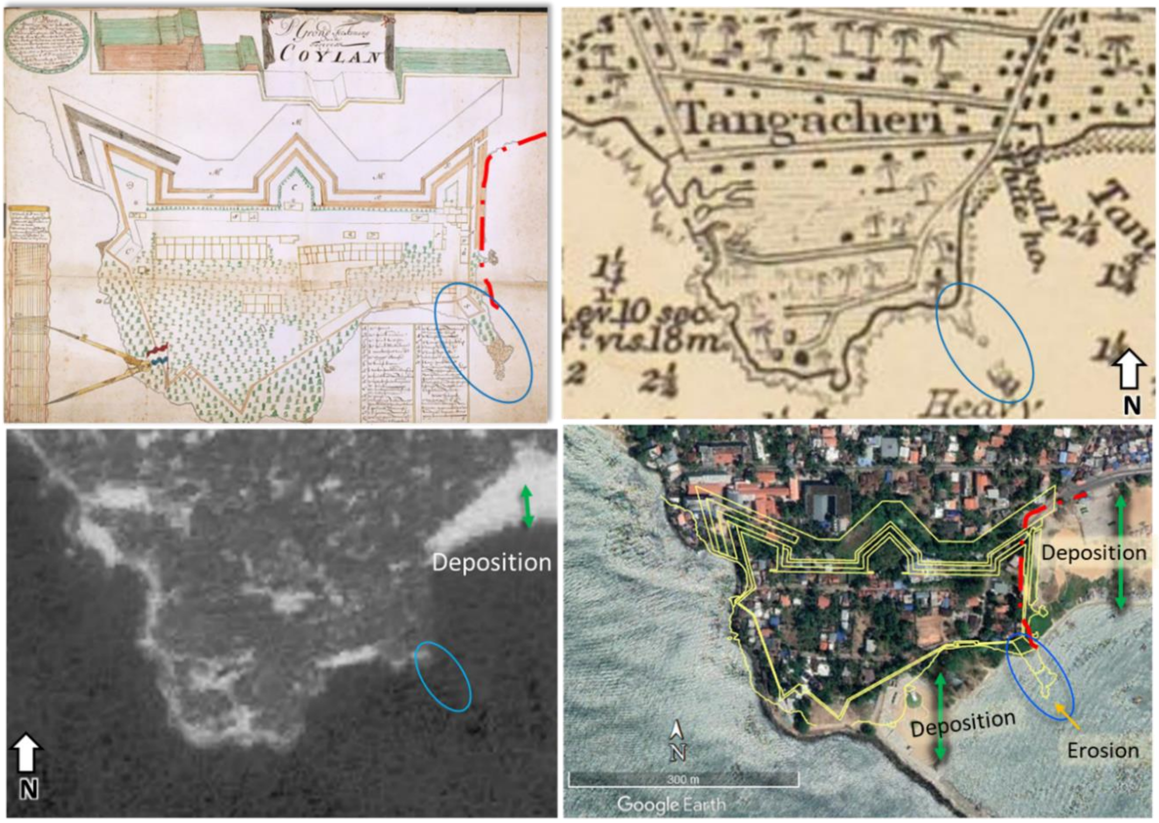

Figure 5.20. Dutch plan map of Kollam fort with the highlighted features that has gone through substantial geomorphic changes (left); present day satellite image highlighting the areas sediment deposition and erosion (right).

5.5.5. FINDINGS

The study has provided new insights about Kollam Fort that is not available in other historical records. The analysis reveals that the Portuguese fortification of the town was extensive and about four times the area of the Dutch fort thereof. The oldest part of the fort and one of its eight bastions are still surviving; however, the Dutch demolished the northern fortification in 1665 to reduce the fort to one-fourth of its size and then built a fort wall with triangular bastions (ref. section 5.5.4.2). Later they reduced it further to almost half in mid of the 18th century. Central bastions and ramparts of the Dutch fort are found to be existing in dilapidated condition and are known only as British Cemetery. More recent encroachment of parts of the fort remains are observed in the historical imageries of Google Earth Pro. It is surprising to see that a very small part of the Portuguese fortress is a well-known tourist spot and has been preserved and maintained by the authorities, whereas a substantial portion of the fort has been left unnoticed and unattended. The reasons could be lack of information and knowledge about the existence of the fort remains and more importantly, the change of land use in historical times (central bastion converted into British Cemetery) creating another layer of the history of a later period causing the fort remains to descend into oblivion. The results of the study also led us to question the authenticity of some of the literature on history. For instance, incorrect measurement of the extent of the Dutch fort in a 19th century record (1 by 2.5 furlong = ~201 by 503 m) and information on submergence of a part of Fort Thomas in the sea in a mid-twentieth century record (Rea 1897; Cotton 1946, 178). Analysis of all the cartographic documents does not reveal any possibility of submergence of the Portuguese fort; in fact, the east side of the promontory has gained land in recent decades (this deposition is the result of the construction of two breakwaters at Kollam).

5.6. CRITICAL ASPECTS OF HISTORICAL MAPS: A DISCUSSION

Methodical study of maps can yield vital information from the seemingly 'unimportant' and/or 'inaccurate' maps; while on the contrary, inadequate knowledge of maps can misinform us. This section discusses the following critical aspect of studying maps of different times and dimensions and challenges in incorporating historical cartographic records in RS and GIS that should be considered while using historical maps for archaeological investigations.

5.6.1.1. AVAILABILITY OF MAPS

The number of maps available for the study is one of the important factors in assessing their contents. The availability of a large number of historical maps gave us scope to extract the principal components by choosing the most reliable and informative ones. There is an advantage of analysing maps of different scales, times, perspectives and dimensions (2D, 3D or a combination of both). For instance, in the case of Kollam, where we have a variety of maps, the analysis yielded more information and rich findings. On the other hand, the paucity of maps of the forts in the Panchagangavalli cluster (Gangolli-Kundapur-Basrur), Honnavar and Goa have led to ambiguous conclusions.

5.6.1.2. ACCURACY AND ERRORS

Understanding the accuracy of the map can be very subjective. For example, some of the early Portuguese maps have planimetric inaccuracy, they depict the exaggerated size of fortresses, and a few of them are found to be oriented incorrectly. However, these maps are rare documents of the time with unique perspectives, which may look insignificant at first sight, but are found to be valuable sources of information for that time. Therefore, seemingly inaccurate maps should not be discarded without carefully examining their content, temporal and spatial context. At the same time, one should also be aware of the possible errors, such as - a map whose content is copied from an earlier map but published after several decades of the original one may mislead us about its temporal context.

5.6.1.3. SELECTIVE REPRESENTATION

Maps are the abstraction of geographic reality, and it is impossible to depict everything present on the surface. The selection of the objects represented on maps is based on the purpose of the map and the choice of the patrons or the cartographer. The exclusion of some of the built structures can pose challenges in interpreting maps and understanding the existence of those structures at that time. For example, the absence of the 'old fort' in Kundapur in the early Portuguese maps and its presence on the map published later in 1639 (ref. Figure 5.2); absence of Cambolim fort and fort of King of Basrur in the Dutch map published in1678 (ref. Figure 5.3), absence of Portuguese's Barcelor fort, Cambolim fort, the Old Fort and Tipu Sultan's fort in the British map published in 1856 created ambiguity on the existence of the forts (ref. Figure 5.4).

5.6.1.4. ORIGINALITY AND TEMPORAL CONTEXT

Finding out the original authentic drafts of the map is a challenge, especially when dealing with a large repository of maps of multiple sites. Generally, maps are drafted earlier and published later. They are also copied later by other draftsmen and engravers and published decades after the original survey dates. Such maps have the potential to misinform us about the temporal context of some features. Therefore, efforts should be made to fetching the information about the cartographer and engraver of the maps.

5.6.1.5. CHALLENGES IN REMOTE SENSING AND GIS ANALYSIS

RS and GIS provided an environment to integrate spatial information present in the various types of cartographic documents and has brought historical maps into the real-world space to be studied in the present context. However, there are certain challenges while bringing historical maps into a GIS platform, such as assigning real-world coordinates to these maps, especially if the target site is not conspicuous from the top due to the encroachment by wild vegetation or human activities. Therefore, sometimes, visual inferences and logic become the only way to identify the probable control points. Despite that, the reliability of georeferenced maps can be judged based on RMSE value and visual analysis of how well the map fits with the cropmarks and the topography of the land (ref. Table 1). The inherent inaccuracies and flaws that maps sometimes may have are dealt with by using maximum numbers of maps available for different dates to check the consistency in the content, and satellite images helps in locating and validating the identified features.

5.7. CONCLUSION

The present study has made several original contributions to history and archaeology. Here we classify them into three groups - archaeological finding, methodological approach and pointers for future research – and elaborate on each of them below.

Contribution to methodology

1) The present study demonstrates that historical graphical records - such as maps, paintings and views of a different time, style and dimension - are an important source of geographical and historical information of the time they were surveyed and/or drawn;
2) a careful study of such records can produce congruous outputs;
3) RS and GIS provide a real-world spatial context for these historical graphical records making them uniquely valuable for archaeological explorations, which facilitates addressing historical inquiries related to their location, extent of the built structures, and occupancy.

The archaeological findings from all the four case studies are

1) Kollam: a) The ruins at Kollam, which is a protected monument under ASI is a small portion of a turreted fortress originally built by Portuguese in 1519; b) As the Portuguese settlement grew, in the early 17th century, a fort was built around 500m north of the fortress protecting the town on the north and northeast sides; the approximate location of this fort wall has been geospatially delineated, and ground-truthing has revealed promising evidence; c) extensive ruins of the Dutch Fort is still extant in the site which has been unrecognised and neglected for centuries, and d) this study has contributed to the scholarship on the construction, restoration, the extent and usage of the fort during its occupation by various European colonies.
2) Panchagangavalli cluster (Gangolli-Kundapur-Basrur): The present study has identified a) the location and remains of Portuguese's Barcelore fort (which is in the present town of Kundapura), b) the 'old Fort' adjacent to the Kundapur town, c) the Fort of King of Basrur at Basrur town and d) Virabhadra Nayaka's fort at Gangolli. e) location of the non-extant Cambolim fort also ascertained.
3) Honnavar: Location, remains, and extent of the 'Onor' fort built by the Portuguese is found on a hill around 5 km inland along the Sharavathi river. The fort is found to occupy an area of around 20 acres.
4) Velha Goa: Location, extent and remains of the fortification of the old city of Goa and one of its gates are found.

Future directions

1) It directs to specific locations where an elaborate field exploration and architectural conservation can be pursued;

2) the study has identified structures whose material can be accessed for scientific dating and other analysis;

3) identifying specific details of the fort remains that are buried under vegetation can be explored through processing data acquired via drone-based laser scanner; and

4) The observed geomorphic changes such as aggradation around Gangolin island and east of Kollam fort can be studied in detail in future.

CHAPTER 6

CONCLUDING REMARKS

"...there is no one 'truth', but that there are many 'truths' with varying perceptions"

-Wallace and van den Heuvel (2005)

This chapter highlights the key findings and integrates conclusions presented in preceding chapters to address the objectives coherently. Following that, this chapter lists several potential areas for future research.

6.1 SYNTHESIS

The present thesis addresses questions from very fundamental level (such as how, when and who mapped the Indian coastline since the classical era and what kinds of maps were produced?) to the advance level such as methods to use early maps systematically and scientifically, long-term evolution of a delta and sand spits, location and extent of hitherto unknown or unprotected archaeological structures. It exposes the richness and potential of underused/undervalued historical cartographic documents in advancing the archaeological and geomorphological understanding the Indian coast by integrating them with historical textual records, Digital Elevation Model, and remote sensing data available from the 1960s. The present work bridges a methodological gap between the systematic methodology to study early maps suggested by Oldham (1925) and Boer and Carr (1969) in pre-GIS era and the more advanced methods suggested by numerous scholars (such as Székely 2009; Thieler and Danforth 1994; Askevold 2005; Levin 2006, to name a few) in the last few decades. The thesis has made original contributions by integrating geomorphological information to identify archaeological site and also by using archaeological sites as references to understand long-term (last 400-500 years) geomorphological changes. More specifically the present work led to finding hitherto unknown remains of colonial forts in coasts of Kerala and Karnataka, and the long-term dynamics of spits, the evolution of the Thamirabarani delta, and the formation of the Tuticorin tombolo.

The objectives of the thesis stated in the first chapter have been achieved as follows:

The **first objective**- '*to provide a conceptual and analytical framework for integrating information from historical sea charts, maps, paintings and satellite images using GIS to derive meaningful geomorphic and archaeological information*' has been addressed in the third chapter, which discusses the critical aspects of studying early maps in detail and devises an integrated methodological framework to study historical cartographic documents. In the suggested methodology, the knowledge, concepts, and methods from different disciplines (i.e., remote sensing (RS), GIS, cartography, archaeology, and geomorphology) have been adopted, and new methods have been evolved to systematically study the non-georeferenceable maps and to validate the content of the historical maps as well as historical text. The methodology has been applied for geomorphological and archaeological investigations in Chapter-4 and 5. The suggested methodological framework enabled the effective study of early maps of heterogeneous nature even if there is limited information about the map and its context. The present study has also bridged the research gaps discussed in Section 1.3 in Chapter 1.

The methodology and various methods, ranging from very simple visual interpretation using logical reasoning to more elaborated remote sensing and GIS approach, suggested in the present study may not be applicable to all the maps in the same way. There could be slight variations while adopting these methods to study different sites based on the location, types of maps and nature of the information. Studying historical maps is a complex process. Their interpretation is prone to an individual's predisposition and prejudice. They may have errors of various kinds; however, they are also correct in their own ways. Thus, historical cartographic documents should be studied considering the possible 'errors' and 'inaccuracies' they may have and accordingly deciphered, keeping their subjective nature and context in mind.

The **second objective** – '*to investigate the lost or unidentified archaeological sites or features with respect to the dynamic shoreline through systematic integration of maps of diverse nature prepared at different times*' has been accomplished in Chapter-5. This chapter has demonstrated the importance of the colonial cartographic documents and landscape paintings as a great source of geographical and historical information of the time they were surveyed or drawn. It has also demonstrated, through case studies, the significance of the suggested methodology in providing a real-world spatial context to these historical graphical records and making them uniquely valuable for archaeological explorations and laid foundation for a broader understanding of the methodology through an in-depth analysis, interpretation and discussions.

Integration of historical maps and views of varied dimensions and types has provided a palimpsest of historical activities that was read through remote sensing data and geospatial tools. The analysis in this chapter has produced congruous outputs, which facilitated exploration of the hitherto unidentified archaeological sites and enabled to address historical inquiries related to their location and extent of the built structures and occupancy of the colonial fort in old Goa, Honnavar, along the mouth of river Panchgangavalli and Kollam. The study also helped in validating the historical travellers' accounts and other records.

The **third objective** – '*to explore the usability of historical maps in understanding long term (few centuries) coastal geomorphology*' has been achieved in Chapter-4. This chapter applies the methods and methodology proposed in the third chapter. The analysis was carried out depending on the presence of landmarks (historical buildings) on the maps, types of maps available for the study area, visibility of paleo-features on satellite images, the nature of landscape and magnitude of changes observed. In this chapter, maps of different scales, time and types were studied logically and systematically to understand the geomorphic changes that occurred in the past few centuries. This chapter reveals the great usability of early maps in understanding the long term coastal geomorphic changes. It demonstrated ways to validate the information and the quality of the historical maps and demarcate the identified paleo-water features with high accuracy even if the historical map that shows them is less accurate. The study has proposed a novel understanding of the evolution of the Thamirabarani delta since the Mid-Holocene and the development of spits of central Kerala (Chettuva estuary and region between Kodungallur and Fort Kochi), particularly in the past 300 years using the proposed methodological framework. The results have also pointed out to the long term cyclicity in erosion and deposition both across and along the coasts.

Chapter-4 also addresses the **fourth objective** – ‘*to assess whether the record from these historical documents matches relative sea level and coastline changes deciphered from other sources, such as excavation of ancient sites, petrology and mineralogy*’ and found that information derived from the study of early maps is aligned with historical text and various studies conducted in other disciplines. Not only that, the information of spatial and temporal context acquired from this study is unique and has not been attained using any other methods before.

These maps are vital source of spatio-temporal information. They can be conveniently used to date significant geomorphic changes that occurred in recent centuries and notice the existence of built structure at that time. Besides, the suggested methods are better in perceiving the spatio-temporal context of past few centuries than any other method.

6.2 THE WAY FORWARD

The interdisciplinary work carried out in the present thesis points to several areas that have scope for further research in the field of cartography, archaeology, geomorphology, remote sensing and GIS, and hydrology which are discussed below in separate categories:

1) Cartography

The present study could analyse only a fraction of maps available worldwide for a few small stretches of the Indian coast. There is tremendous scope of studying historical maps for similar research work in other parts of the Indian coast and the coasts of other countries that were mapped in the late medieval and early modern period. To conduct similar research at national and global scale, it is essential to have seamless access to the cartographic records and its metadata archived in various places across the globe through a single integrated common digital platform that would be possible through collaborative efforts. The present study was limited to colonial maps made by Europeans; similar efforts should be made to study Chinese and Javanese historical maps. It is also possible that hitherto unknown European maps of sites presently studies may surface in some archives in future. Such maps can throw further new light on sites/area explored in this study.

2) Archaeology

Early historical maps, especially plan maps and large-scale maps, record military architectures and other structures built by colonial powers and the contemporary local rulers. The study of such maps would throw light on the military strategy, defensive system and factors that would have decided the selection of sites for building fortresses. The prominent built structures marked on the maps as landmarks have the potential to guide us to the location and extent of ancient structures existing at that time but now buried or submerged or in ruins.

Almost all the colonial forts examined in the present study are found on locations that are stable and have not experienced major erosion in the past few centuries. It would be worth investigating the factors that had determined the location of these sites in order to understand the sustainable model used in the past.

For the effective conservation of our cultural heritage landscape, protection boundaries should be redefined by combining historical data, remote sensing imagery and GIS technologies (Rajani 2021). Therefore, the extent of historical sites identified using the suggested methods can be considered when determining or redefining its Protected Area.

3) Geomorphology: This study recommends potential locations that earth-scientists could explore further by carrying out detailed field investigations of surface and subsurface through drilling, coring and other methods. The methodology developed in the present study has great scope to reconstruct the past geomorphic changes and understand the processes in other coastal stretches of India and across the globe wherever coasts were mapped during colonial period. Understanding the recent centuries' geomorphic changes would help extrapolate the longer-term changes on either side of the temporal spectrum, i.e., the changes that occurred in the past few centuries and the changes that may occur in the near future. Thus, understanding long term changes would help in coastal planning and management.

Further studies need to be conducted to understand the cause of changes observed from the analysis of colonial maps. The process of erosion and deposition and their cyclic nature (as observed in some of the stretches studied in the present thesis) should be correlated with the data on past sea-level, climate and anthropogenic activities such as construction of dams and deforestation. Such studies would advance the understanding of the effect of climate and human activities on coastal changes in the past few centuries.

The study of early maps has the ability to enhance the understanding of long-term sediment transportation, trend and rate of the coastline changes and stability and instability of the coast. Information acquired from such studies can be used to understand the impact of anthropogenic activities on the coastal dynamics by combining information about the change in land use and major human intervention at present and in the past. Moreover, a rigorous study of early maps at a national and global scale can yield very useful spatio-temporal data on sea-level change in the past few centuries.

4) Remote Sensing image processing and GIS

The present thesis suggests a basic model for the comparative analysis of georeferenceable and non-georeferenceable maps to study the sequence of geomorphic changes. However, there is a scope to automate and improve the model by developing image processing tools to recognise, extract and compare shape, pattern and feature present in a sequence of maps and more flexible image transformation algorithms. Attempts should also be made to reduce the subjectivity in the interpretation of maps.

5) Hydrogeological Significance of Paleochannels

The early maps and remote sensing data are great source of spatio-temporal information about paleochannels and dried waterbodies, and thus, are of hydrogeological significance. Paleochannels contains channel-lag deposits that are coarse grained sediments and have good permeability. Therefore, they are generally a rich source of ground water which can serve as a dependable source of water supply. Attempts should be made to trace paleochannels using historical maps.

6.3 IN SUMMARY

The interdisciplinary research conducted in this study has fetched multifaceted outcomes. The suggested methods have largely overcome the challenges of studying early maps of heterogeneous nature. The reference of the archaeological sites marked on the maps provides a fixed and stable reference points that enables very accurate measurement of the shoreline changes even if a map depicting them has large cartometric errors. Similarly, in many instances, the shape of natural features identified on early maps (including the past shoreline and water features such as lagoons and channels active during that time but now silted) are found to be preserved by subsequent human occupation in the form of patterns in roads and agriculture field boundaries in the area where the land has advanced seaward or waterbodies have dried. The present study has successfully established the relationship between maps, historical textual records, satellite images and various human activities. The fast-encroaching urban land use and coastal changes is threatening the archaeological remains; therefore, there is a dire need to mitigate the same. Most importantly, the present study has revealed great scope for future research, which has huge potential to address some of the very important present-day challenges in the study of coastal areas.

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Appendix

(All links are accessed on 5th September 2021)

Map No.	Thumbnail	Year	Mapmaker/ engraver/ Publisher	Title	Source	Link
Maps of Thamirabarani Delta and Thoothukudi						
1		1695	Isaac de Graaff	Kaart van de rivier van Cochin tot Chettua	National Archive, Netherlands Number: VEL0250	https://www.atlasofmutualheritage.nl/nl/Kaart-oostkust-India-gedeelte-westkust-eiland-Ceylon.5126
2		1699	Jan Christiaensz Toorzee	NA	Referred from Schilder and et al. (2006) Volume VI, Sheet no. 311 Original Source: National Archive, Netherlands 1.04.02 1615B KAART/ Map no. 3	NA
3		1656-1725	Anonymous	Map of the Island of Ceylon and the Coast of Madure	National Archive, Netherlands Number: VEL0236	https://www.atlasofmutualheritage.nl/nl/Kaart-Ceilon-kust-Madure.4828
4		1753	Keulen II, Johannes van	De Kust Van Madure	Maritime Museum. SNSM_b0032(109)06[card051]	https://www.atlasofmutualheritage.nl/nl/Kaart-kust-Madure-twee-delen.5845

5		ca. 1770	Anonymous	Map of Toutecourijn	Bodel Nijenhuis / Leiden University Library, Number: COLLBN 002-11-033	https://www.atlasofmutualheritage.nl/nl/Plattegrond-Toutecourijn.6285
6		1756-1780	Johannes van Keulen II	Map of the Coast of Decan from Sualy to Rajapoer	National Archive, Netherlands Number: VEL0227	https://www.atlasofmutualheritage.nl/nl/Kaart-kust-Malabar-kust-Decan.5501
7		1805	Survey of India Scale: 1000 yards (914.4m) to an inch	NA	National Archives of India, Delhi, Identifier: CR_000002286486, File no. 1801-20-19(J)	https://abhilekh-patal.in/jspui/handle/123456789/2691519
8		1822 Pub	Heywood R.N. and M. Wedgburgh	Chart of the Island of Ceylon with the adjacent Coast of India	British Library Maps SEC.12.(813)	NA
9	 Sheet 63 & Sheet 81	Sheet 63: 1829 Sheet 81: 1828 Pub	Surveyed under the direction of Col. C. Mackenzie; Published by James Horsburgh	Atlas of India	Atlas of India, Vol 2, 1862, J Walker, London	https://www.loc.gov/resource/g7650m.gct00196/?sp=2

10		1883	R B Foote Scale: 4 miles to an inch	Geological Map of the Eastern Parts of the Madura and Tinnevelly Districts	Memoirs of Geological Survey of India, Vol 20, Plate 1, 1883	https://www.biodiversitylibrary.org/page/33591676#page/125/mode/1up
11		1948 (Area of interest surveyed in 1919-20)	US Army Map Service 1: 250 000	Tuticorin	Map Index no.: NC 44-13	https://maps.lib.utexas.edu/maps/ams/india/nc-44-13.jpg
12		2002	National Hydrographic Office 1: 1 500 000	India and Sri Lanka Kochi (Cochin) to Vishakhapatnam	Chart INT 754	NA
13		2010	National Hydrographic Office 1: 150 000	India- South East Coast Gulf of Mannar Manappad to Setukkarai	Chart 224	NA
14		2014	National Hydrographic Office 1: 300 000	India and Sri Lanka Gulf of Mannar Cape Comorin to Pamban	Chart INT 7365	NA

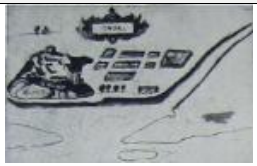
Maps of coast of Chettuva, Kodangallur-Azhikode, Vypin and Kochi						
15		1678	Isaac de Graaff	De rivier van Grangenor, van de mond aan Noordwyk, als voren	National Archive, Netherlands Number: VEL0892	https://www.atlasofmutualheritage.nl/nl/Afbeelding-kasteel-Crangenor-redoute-Paliporto.2588
16		1680	Anonymous	Cochin gelyck het jegenwoordigh in the year 1680 leght with syn buytenwercken	National Archive, Netherlands Number: VEL0897	https://www.atlasofmutualheritage.nl/nl/Plattegrond-Cochin-omgeving.5353
17		1691	Isaac de Graaff	Couchin met syn subordinate Landstreek	National Archive, Netherlands Number: VEL0898	https://www.atlasofmutualheritage.nl/nl/Plattegrond-Cochin-omgeving.2592
18		1696	Hans George Taarant	De waare Grondteyckening van de Hooftstadt Kochin, der Custe Mallabaer, soo als het perfectelyck is naargemeeten enz	National Archive, Netherlands Number: VEL0899	https://www.atlasofmutualheritage.nl/en/Map-Cochin.2593
19		1697	Hans George Taarant	he true picture of the lowlands of the Coast Malabar (Malabar) etc., starting above the fortress Crangapoor and extending beyond the fortress Coylang etc	National Archive, Netherlands Number: 4. VEL0229	https://www.nationaalarchief.nl/onderzoeken/kaartencollectie/detail?limitstart=0&q_searchfield=malabar

20		1718	Anonymous	Plan of the Pagger of Chettuwa	National Archive, Netherlands Number: VEL0918	https://www.atlasofmutualheritage.nl/nl/Plattegrond-pagger-Chettuwa.2610
21		1720	Pieter Gijsbert noodt	Plaan Van Het Nieuwe Fort tot Cituwa[…]	Netherlands Maritime Museum, Amsterdam Number: A.2444 (03)	NA
22		1750	Anonymous	Map of the river from Cochin to Chettua	Bodel Nijenhuis / Leiden University Library, Number: COLLBN 002-09-035	https://www.atlasofmutualheritage.nl/nl/Kaart-rivier-Cochin-tot-Chettua.6264
23		1767	Johannes Wilhelmus de Graaf	Private Map of a part of the Coastal Malabar or the extent of the rivers from Chettua to Coylang	National Archives, Netherlands Number: VEL0882(A & B)	https://www.atlasofmutualheritage.nl/nl/Kaart-gedeelte-kust-Malabar-deel-B.6100
24		1767-1780	Heidenreich, HA(draftsman), Count, Joh. Wilh. the(surveyor / mapmaker)	Map as before, with indication of the Seed fields[…] , this means the title of Private Map of a part of the Coastal Malabar or the extent of the rivers from Chettua to Coylang.	National Archives, Netherlands, Number: VEL0883	https://www.atlasofmutualheritage.nl/nl/Kaart-gedeelte-kust-Malabar.6101
25		1775	From the early editions of Van Keulen	The Mud Bank of Cranganore on the Malabar Coast	• British Library, London Shelfmark(s): Cartographic Items 435.k.17.(149.) Cartographic Items Maps SEC.12.(798.)	NA

26		1785-86	Anonymous	Plan Der Reede En ‘T Inkomen Der River van Cochin	Referred from Schilder and et al. (2006) Volume VI, Sheet no. 214 Original source: Nationaal Archief, 4.VEL 918	NA
27		1787	De La Lustriere and De La Goupilliere	Plan De Cochin Et Des Environs	Referred from Schilder and et al. (2006) Volume VI, Sheet no. 256 Original source: Bibliotheque Nationale De France, DCP SH 18 PE 207 DIV. 1 P.6.	NA
28		1793	Ferdinand Caspar Heupner, toegeschreven	Situatieteekening van het Eyland Waipin	Nederlands Scheepvaart Museum Amsterdam, A.2444(03)	https://www.atlasofmutualheritage.nl/nl/Kaart-eiland-Waipin.5358
29		1840	Engraved by J&C Walker, pub by John Walker	Atlas of India, Tile 62	Library of Congress Geography and Map Division Washington, D.C. 20540-4650 USA dcu Number: G2280 .G7 1862	https://www.loc.gov/resource/g7650m.gct00196/?sp=21

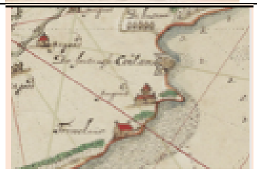
30		1851-53	Lt W B Selby	Sheet XI West coast of India Malabar coast	British Library, London Shelfmark: Cartographic Items Maps SEC.12.(749.)	NA
31		1883	Surveyed by Lt. A. Channer	Cochin River	From the book: Galletti, van der Burg, and Groot 1911	https://archive.org/details/selectionsfromre13madr/page/n4/mode/1up
32		1917-18	US Army Map Service (1: 250,000)	Coimbatore	Map Index no.: NC 43-7	https://maps.lib.utexas.edu/maps/ams/india/nc-43-07a.jpg
33		1917	US Army Map Service (1: 250,000)	Alleppey	Map Index no.: NC 43-11	https://maps.lib.utexas.edu/maps/ams/india/nc-43-11a.jpg
34		Surveyed: 1980-81	Survey of India (Scale- 1:50, 000)	Open Map Series No. C43K2 and C43K3	Survey of India	NA

Maps of Panchgangavalli river mouth (Cambolim (Gangolli) And Barcelore (Kundapur))						
35		1630	Albernaz, João Teixeira	Taboas geraes de toda a navegação	Library of Congress Geography and Map Division Washington, D.C. 20540-4650 USA dcu Call Number: G1015 .T4 1630	https://www.loc.gov/resource/g3200m.gct00052/?sp=9&r=0.512,0.17,0.488,0.383,0
36		1639	Antonio de Maris Carneiro	CARNEIRO, António de Mariz, 15---1642. Descripçam da fortaleza de Sofala, [...] há no mesmo Estado. - VII, [48] f., enc. [page 81]	Biblioteca Nacional Digital, Portugal	https://purl.pt/24313
37		1639	Antonio de Maris Carneiro	Cambolim In: Descripçam da fortaleza de Sofala, e das mais da India[...]. - VII, [48] f., enc. [page 83]	Biblioteca Nacional Digital, Portugal	https://purl.pt/24313
38		1674	Manuel de Faria e Sousa	Forteleza de Barcalor	Accessed from Silveira (1957, p 400) (Ref. Bibliography) Original source: Asia Portuguesa, de Faria E Sousa – 1674, II, p. 476	NA
39		Ca. 1695	Isaac de Graaff	*Logie op Barselor, so als deselve sig aan de Landsyde shows*	National Archives, Netherlands Number: VEL0886	https://www.atlasofmutualheritage.nl/en/Lodge-Barselor.2581

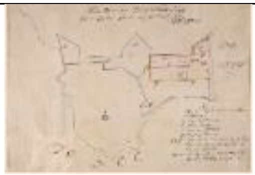
40		1856	A D Taylor	Sheet VIII West Coast of India From Alvagudda to Molky	British Library, London Cartographic Items Maps SEC.12.(745.)	NA
Maps of Onor Fort (Honnavar)						
41		1610	**Godinho de Erédia**	Onor	Accessed from Silveira (1957, p. 396)	NA
42		1630	Albernaz, João Teixeira	Taboas geraes de toda a navegação	Library of Congress Geography and Map Division Washington, D.C. 20540-4650 USA dcu Call Number: G1015 .T4 1630	https://www.loc.gov/resource/g3200m.gct00052/?sp=9&r=0.465,0.136,0.586,0.46,0
43		1639	Antonio de Maris Carneiro	Onor (In: Descripçam da fortaleza de Sofala, e das mais da India[...]. - VII, [48] f., enc. [page 83])	Biblioteca Nacional Digital, Portugal	https://purl.pt/24313
44		1672	NA	Fortaleza de Onor	Accessed from Silveira (1957, p. 397)	NA

45		17th century	NA	Fortaleza de Onor	Accessed from Silveira (1957, p. 397)	NA
46		17th century	NA	Onor	Accessed from Silveira (1957, p. 396) Original source: Atlas de Vila Vicosa.	NA
47		1733	NA	Onor	Accessed from Silveira (1957, p. 397)	NA
Maps of Old Goa						
48		1572	Braun and Hogenberg	Goa fortissima India urbs in Christianorum potestatem anno salutis 1509 deuenit In: Civitates Orbis Terrarum I	NA	http://historic-cities.huji.ac.il/india/goa/maps/braun_hogenberg_I_57_4.html
49		1630	Albernaz, João Teixeira	Taboas geraes de toda a navegação	Library of Congress Geography and Map Division Washington, D.C. 20540-4650 USA dcu Call Number: G1015 .T4 1630	https://www.loc.gov/resource/g3200m.gct00052/?sp=9&r=0.465,0.136,0.586,0.46,0

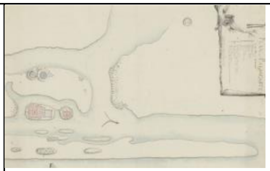
50		1639	Antonio de Maris Carneiro	Goa (In: Descripçam da fortaleza de Sofala, e das mais da India[...]. - VII, [48] f., enc. [page 75])	Biblioteca Nacional Digital, Portugal	https://purl.pt/24313
51		1672	Johannes Janssonius van Waasberge and Johannes Van Someren	Goa	Accessed from Silveira (1957, p. 371)	NA
Maps of Quilon (Kollam) fort						
52		1515	Gaspar Correia	Caulao	Lendas da Índia written between 1558-1563 and first published in 1858, Volume II, Page no. 394	purl.pt/12121/3/var-2326/var-2326_item3/index.html#/412
53		1630	Albernaz, João Teixeira	In: Taboas geraes de toda a navegação (Atlas)	Library of Congress Geography and Map Division Washington, D.C. 20540-4650 USA dcu Call Number: G1015 .T4 1630	https://www.loc.gov/resource/g3200m.gct00052/?sp=11
54		1635	António Bocarro	In: Livro das plantas de todas as fortalezas, cidades e povoaçoens do Estado da India Oriental (Atlas)	NA	http://purl.pt/27184/3/#/279

55		1672	Philip Baldaeus	De Stadt Covlang In: A True And Exact Description Of The Most Celebrated East-india […] with the draughts of their idols, done after their originals	Baldaeus (1672) (ref. Bibliography)	https://archive.org/details/trueexactdescrip00bald/page/n147
56		Surveyed 1678, drafted after 1690	Isaac de Graaf	'T' Fort Coylan' Atlas Amsterdam	National Archives, Netherlands Number: VEL0888	http://www.atlasofmutualheritage.nl/en/Maps-forts-Cananor-Cranganor-Coylan-Calicoilan.2583
57		1687	Hans Georg Taarant	'D'Grond Teekening van de Fortresse Coylan'	National Archives, Netherlands Number: VEL0912	http://www.atlasofmutualheritage.nl/en/Representation-Fort-Coylan.2604
58		1697	Hans Georg Taarant	'De waare afbeelding van de lage landen der Kust Malabaar enz., beginnende […] Allapaar, Aiwike	National Archives, Netherlands Number: VEL0229	http://www.atlasofmutualheritage.nl/nl/De-kust-Malabaar.2644
59		Ca.1703	Anonymous	Affbeeldinghe hoedanigh de afsnyding off verkleyninge van d'fortresse Coylan […] staat te warden	National Archives, Netherlands Number: VEL0913	http://www.atlasofmutualheritage.nl/en/Representation-Fort-Coylans-reduction-size.2605

60		1724	Francois Valentyn	De Grond Tekening van de Fortresse Coylan	Maritime Museum, Netherlands Number: SNSM_b0032(109)06[kaart 046]	http://www.atlasofmutualheritage.nl/en/Map-fort-Coylan.5843
61		1747	Jacques Nicolas Bellin,	Plan de la Forteresse de Coylan	NA	http://www.columbia.edu/itc/mealac/pritchett/00maplinks/mughal/bellinquilon/bellinquilon.html
62		1750	Jacques Nicolas Bellin,	Plan de la Forteresse de Coylan	NA	https://www.ebay.com/itm/1750-Kollam-Kerala-India-Indien-map-view-plan-Kupferstich-antique-print-Bellin-/143688505019
63		1755	Jacques Nicolas Bellin,	Plan de la Forteresse de Coylan	NA	https://www.antiquemapsandprints.com/product/-plan-de-la-forteresse-de-coylan-kollam-fortress-kerala-india-bellin-1761-map/P-6-017459~P-6-017459
64		1756	Jacques Nicolas Bellin,	Plan de la Forteresse de Coylan	NA	https://commons.wikimedia.org/wiki/File:1756_Bellin_Map_of_Kollam_Fort,_Kerala,_India_-_Geographicus_-_Coylan-bellin-1756.jpg
65		1764	Jacques Nicolas Bellin,	Plan de la Forteresse de Coylan	NA	https://mapandmaps.com/en/india-sri-lanka-ceylon-old-antique-maps/386-kollam-kerale-quikon-india-antique-engraving-1764.html

66		1752	Van Keulen family	De Grond Tekening van de Fortresse Coylan In: 'De Zee En Land-Caarten en Gizigeten van steeden en landvertooningen van oost-indien' (Atlas)	NA	https://kollamtourismblog.wordpress.com/2017/02/05/coylan-kollam-quilon/
67		1766	Zijnen, D.	Plan van een geprojecteerde Logie binne Coylan	National Archives, Netherlands Number: VEL0914	http://www.atlasofmutualheritage.nl/en/Map-lodge-Coylan.2606
68		1767	Graaf, Joh. Wilh.	Particuliere Kaart van een gedeelte der Kuste Malabar of de strekking der rivieren van Chettua tot Coylan’	National Archives, Netherlands Number: VEL0882A	http://www.atlasofmutualheritage.nl/nl/Kaart-gedeelte-kust-Malabar-deel-A.6099
69		Ca. 1770	Anonymous	Map of Coylon	Bodel Nijenhuis / Leiden University Library Number: COLLBN 002-11-031	https://www.atlasofmutualheritage.nl/nl/Plattegrond-Coylan.6284
70		1829	J. Walker published by James Horsburgh	Atlas of India (1862)	Library of Congress Geography and Map Division Washington, D.C. 20540-4650 USA dcu Number: G2280 .G7 1862	https://www.loc.gov/resource/g7650m.gct00196/?sp=22&r=0.31,0.181,0.097,0.042,0
71		1866	J. Walker	Sheet XII. West Coast of India. Malabar Coast from 9º 53’ to 8º. 40’ […]1850-2	British Library, Shelfmark: Cartographic Items Maps SEC.12.(750.)	NA

72		1858, Corrected in 1879	Lieyt. A.D. Taylor	Quilon Road (inset of a British Admiralty chart titled ‘Sheet XII. West Coast of India. Malabar Coast. (Quilon Road. Surveyed ... 1858. Corrected to 1879)	British Library, Shelfmark: Cartographic Items Maps SEC.12.(750.)	NA
73		1883	T.C. Pascoe	Quilon Road (inset of a British Admiralty chart titled ‘Sheet XII. West Coast of India)	British Library, Shelfmark: Cartographic Items Maps SEC.12.(750.)	NA
Miscellaneous						
74		1810	Apres de Mannevillette, Jean-Baptiste-Nicolas-Denis d' (1707-1780)	Carte plate qui comprend la partie Septentrionale de la Cote de Coromandel […] Neptune Oriental	David Rumsey Map Collection, David Rumsey Map Center, Stanford Libraries List number: 13102.044	https://www.davidrumsey.com/luna/servlet/detail/RUMSEY~8~1~312722~90081860:Carte-plate-qui-comprend-la-partie-?sort=Pub_List_No_InitialSort%2CPub_Date%2CPub_List_No%2CSeries_No&qvq=q:coromandel;sort:Pub_List_No_InitialSort%2CPub_Date%2CPub_List_No%2CSeries_No;lc:RUMSEY%7E8%7E1&mi=4&trs=15
75		1770	Pierre Joseph de Bourcet	Théâtre de la Guerre dans l'Inde sur la coste de Coromandel	British Library, London Cartographic Items Maps * 54310.(2.)	NA

76		1700-1800	Anonymous	*Plan de Paliacatte et de ses Environs*	National Archives, Netherlands Number: VEL1091	https://www.atlasofmutualheritage.nl/en/Map-Paleacatte.5395
77		1690-1705	Isaac de Graaff	*Grondplan van de stadt Palliacatta, met het Casteel Geldria en het visschersdorp De Coepangh*	National Archives, Netherlands Number: VEL1091	https://www.atlasofmutualheritage.nl/en/Map-city-Palliacatta.4561