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Invited Paper

Geoscientific perspectives of the submerged / lost harbours and ports: Ancient port city Poompuhar, South India

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Abstract: All over the world, there were large number of coastal cities, harbours and ports. These harbours and port cities, besides bringing wealth and prosperity, have remained as legacies for social systems and culture, buildings and architecture and places of cultural amalgamations due to intercontinental linkages. However, these harbours and the port cities have vanished over the years, some of them suddenly. Though these global harbours and the port cities have been studied, these were mostly on archaeology and to some extent on the reasons for their extinction. But as far as the Indian harbours and port cities are concerned, even for the towering port city like Poompuhar not much of information is available, except the archaeology related aspects. In fact, port cities like Poompuhar needs to be studied comprehensively and their life history will have to be reconstructed, which may reveal many hidden virtues about the past. So, under the banner of DST's national programme 'Indian Heritage in Digital Space (IHDS)', the project 'DIGITAL RECONSTRUCTION OF POOMPUHAR' has been undertaken under interdisciplinary mode involving several disciplines and institutions. Since Geosciences / Geodynamics is the major driving force on the life history of such coastal cities/harbours and port cities, the same has been planned to be used in the project deservingly along with under water data acquisition (MBES, SBP surveys, ROV based optical and SONAR imaging), processing and enhancement of these data, sea bed drilling, geochronology and visualisation of the past disasters from 20,000 years onwards. The studies are expected to bring out packages of newer information on the (i) exact geo position of initial establishment, (ii) later shifts, if any, along with driving phenomenon and the time frame (iii) spatio-temporal evolution and (iv) reasons for its extinction and periods like, earth movements, sea level rise, river migration and palaeo floods, storm surges, tsunamis, cyclones and erosion – sedimentation dynamics. The preliminary studies in the first year itself have brought out scintillating information.

Key words: Lost/submerged coastal cities-scientific protocol-digital reconstruction of Poompuhar port city.

1.0 Introduction

In the past, there existed a large number of harbours and port cities around the world. To cite a few, the Dunwich port city, United kingdoms; Heracleion port city, Egypt; Pavlopetri coastal city, Greece; Atlit-Yam, at the mouth of Oren river on the Camel coast; Ravenser Odd, Yorkshire, England; Schichang city, China and many alike. These have been studied mostly from the archaeological perspectives bringing out the architecture, signatures of social systems and civilisation and the maritime history. During the course of narrations, the reasons for the extinction of these ancient cities were also mentioned, mostly attributing it to land subsidence related to earthquakes, landslides and volcanic activity; storm surges, tsunami, sea level rise and floods. In the Indian sub-continent also, there were large number of port cities due to the 7500 km long coasts. Amongst these, Dwarka, along the west coast, was the towering city of mythological heritage related to Great Epic *Mahabharatha.* Whereas, the Poompuhar was the leading port city of maritime importance established by the Chola dynasty around 2000-3000 years ago at the mouth of river Cauvery along the east coast of India (Fig.1) (Pillay, 1977). The Sangam (300 BC- AD 300) and post sangam Tamil literatures *Purananuru, Agananuru, Natrinai, Pattinappalai, Silappathikaram* and *Manimagalai* have made exhaustive narrations on the culture and social systems, buildings, architecture, land use/cover, maritime history and the impact of intercontinental trade over the local systems, etc. The later archaeological explorations showed the scattered remains of Poompuhar for 20 km long in north-south along the coast

from Kadaikkadu in the north to Tharangampadi in the south and up to 2-4 km west in the landward side and up to 8 km in the east to a water depth of 8-15 m inside the Bay of Bengal sea (Fig.1) (Vora, 1987; NIO Tech. Report 1995 & 1997; Athiyaman 1999; Sundaresh *et al*., 2004; Gaur and Sundaresh, 2006; Sundaresh and Gaur, 2011;Tripati *et al*.,2017). Such a towering port city having trade linkages with far-flung countries around the world and further remained as the naval base for the Cholas for conquering the large parts of the Southeast Asia, has suddenly disappeared from the maritime history of the world around 850AD (Nilakanta Sastri, 1935).

Though the above studies have mostly focussed on archaeology, there are observations that tectonic activities and the sea level rise might have caused the extinction of Poompuhar (Sundaresh and Gaur 2011). The Tamil literature *Cilappathikaram and Manimeghalai* have also attributed the sudden disappearance of Poompuhar to the phenomenon of *Kadalkol* (swallowing up of the land by the sea).

As briefly mentioned above, most of the ancient harbour cities became extinct due to geological disasters. In addition, these harbour/port cities were located mostly along the mouths of the rivers and in deltas, including Poompuhar (Pillai 1977). Further, the recent studies by Ramasamy *et al*. (2020) have brought out a major harbour like structure in the offshore region of Poompuhar around 25 km inside the Bay of Bengal sea, over one of the oldest submerged deltas of river Cauvery. In the same way, bundles of beach ridges are seen in Cauvery delta up to Mayuram, 25-30 km west of the present Poompuhar coast (Ramasamy *et al*. 2006a). There are also further evidences like names of the villages (Varakadal - area visited by sea, Thonipuram – boat village) and urn burials indicating the probable maritime activities in the delta region upto Mayuram. All these indicate that the coastal cities, especially the harbours/port cities and the related activities were mostly based on the landscapes/geomorphology and the geodynamic activities of the coastal regions. For example, most of the ancient global harbours were located along the river mouths, deltas, creeks and backwater mouths too, because of the avenues for anchoring the big ships in the sea, small ships into the river channels, delivery and collection of merchandise using boats along the small river channels and swales. Further most of the harbours of the world were lost due to geological disasters as mentioned above. But surprisingly, all these ancient coastal cities/harbours were studied from the archaeological perspectives and this is the reason why we don't have holistic information on the life histories of the ancient coastal/harbour/port cities. In the case of Poompuhar too, in the context of recent discovery of a submerged harbour 25 km inside the sea, there are many grey areas on the (i) exact place and period of initial establishment (ii) pattern and periods of later shifts (iii) spatio-temporal evolution in its past and present locations and (iv) reason/s for the sudden disappearance of such a magnificent port city, due lack of comprehensive studies involving the Geodynamics which is the major driver for the evolution and the extinction of these harbours and port cities.

In the meantime, the Department of Science and Technology, Govt. of India, New Delhi, under the Interdisciplinary Cyber Physical Systems (ICPS) Division has embarked upon an innovative initiative of digitally reconstructing the ancient dilapidated monuments and the heritage sites of historical, cultural, iconographical and mythological importance, so as to understand and preserve the rich cultural heritages of this great country. Taking advantage of it, at the instance and funding of DST, the author has developed the project with the objectives of holistically bringing out the life history of the ancient port city Poompuhar by keeping the Geosciences/ Geodynamics as the core. This has finally emerged as a national networking interdisciplinary project "DIGITAL RECONSTRUCTION OF POOMPUHAR under his National Coordinatorship involving over 12 institutions in India. The article briefly discusses about the scientific protocol being followed to comprehensively study the disappeared port city Poompuhar and the encouraging results flowing in.

2.0 Methodology

In such comprehensive studies of lost port cities, the three major areas to be concentrated are, (1) geomorphology/ landscape, because on the basis of which only the ancient people would have lived and carved out their livelihoods, development, social systems and the culture; the mapping of the scattered remains and the boundaries of the lost port cities in the land using literature evidences (in the case of Poompuhar, Tamil literatures), Archaeology, citations in the History and Epigraphy TAHE (Tamil literature,Archaeology, History and Epighraphy); and in the case of oceans, interpretations of TAHE, mapping of the seabed topography, tectonics and geomorphology using GEBCO DEM (General Bathymetric Chart of the Oceans – Digital Elevation Models), analysis of Multi Beam Echo Sounder (MBES) data, sub bottom profiler data, ROV (Remotely Operated Vehicles) based optical and sonar images and their processing; (2) mapping of the time series sprawl/shifts of these port cities along with time frame using TAHE, past shorelines, drilling beneath the submerged structures and geochronological dating; and (3) reasons or the combinations of reasons for their extinction like earth movements, sea level rise, migration of river systems in the delta region and the visualization of the past flood histories, cyclones, tsunamis and the pattern of erosion - deposition (Fig. 2).

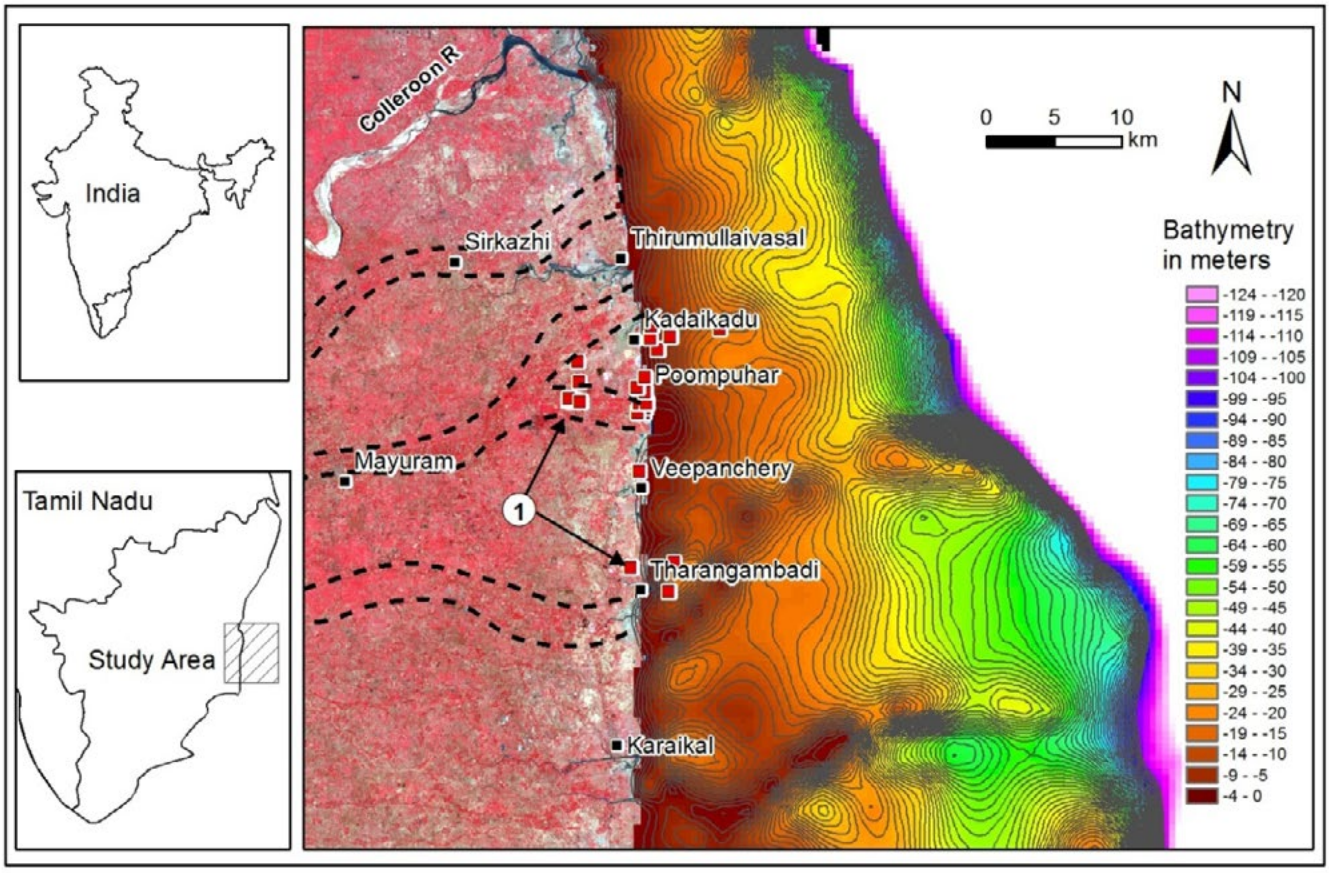

Fig. 1: Location map of Poompuhar region**:** (1) scattered remains of Poompuhar; shades of different Colours indicate the ocean bathymetry by GEBCO DEM (Digital Elevation model of General Bathymetric Chart of the Oceans).

3.0 Reconstruction of life histories of lost coastal/ port cities: Poompuhar

3.1 Mapping the Remains and the Boundary of the Lost Harbour/Port Cities

3.1.1 Inland Region

(a)Based on Geomorphology

For mapping the lost coastal cities, the mapping of the coastal geomorphology especially the fluvial landforms like river channels, abandoned river courses, delta lobes, features of pro delta region and the fluvio-marine and marine geomorphic features like beach ridges, swales, backwaters and creeks are very important, because the locations of the harbours/ port cities are generally geomorphology dependant as briefed above (Fig. 3).

(b)Based on TAHE

Nextly, the collection of data on the scatted remains of the lost port cities need to be done from the literature, archaeological remains, citations in history and epigraphy (TAHE). In the case of Poompuhar, number of such scattered remains of archaeological significance like (1) Pallavaneeswaram, where Budda Vihara is found; (6) Vanagiri where older water inlet of Chola period is found and (7) Keezhaiyur and (8) Manigramam where ancient wharfs (boats anchoring places) are seen (Fig. 3). In addition, (2) Kazhutakaranturai, (3) Melaiyur, (4) Sampapathi Amman Temple, (9) Thiruvengadu, (10) Nangur, (11) Peruntottam, (12) Talaiccengadu, (13) Melapperumpallam, (14) Akkur, (15) Tirukkadaiyur; are also related to the ancient port city Poompuhar (Fig. 3). (Athiyaman 1999, Gaur and Sundaresh 2006, Tripati 2017). The historical evidences show that only from Nangur, the Chola King Karikalan who built the *Kallanai* / Grant Anicut, around 2000 years ago along the river cauvery near Tiruchirappalli ,still atechnological wonder, has married his princess. Further, the Tamil literature *Pattinapalai* and the other few Sangam literatures have made elaborate narrations about the layout of the Poompuhar city and mentioned about temples, gardens, settlements, palaces, locations of foreigners settlements (*Vellayan iruppu*) and other buildings like Kumaravel Kottom and Tharanilakottam and places like Neithalankanal, Maruvurpakkam and Pattinapakkam. The TAHE narrate about several structures like cairon circles, terracotta wells, brick structures, and urn burials that stand as

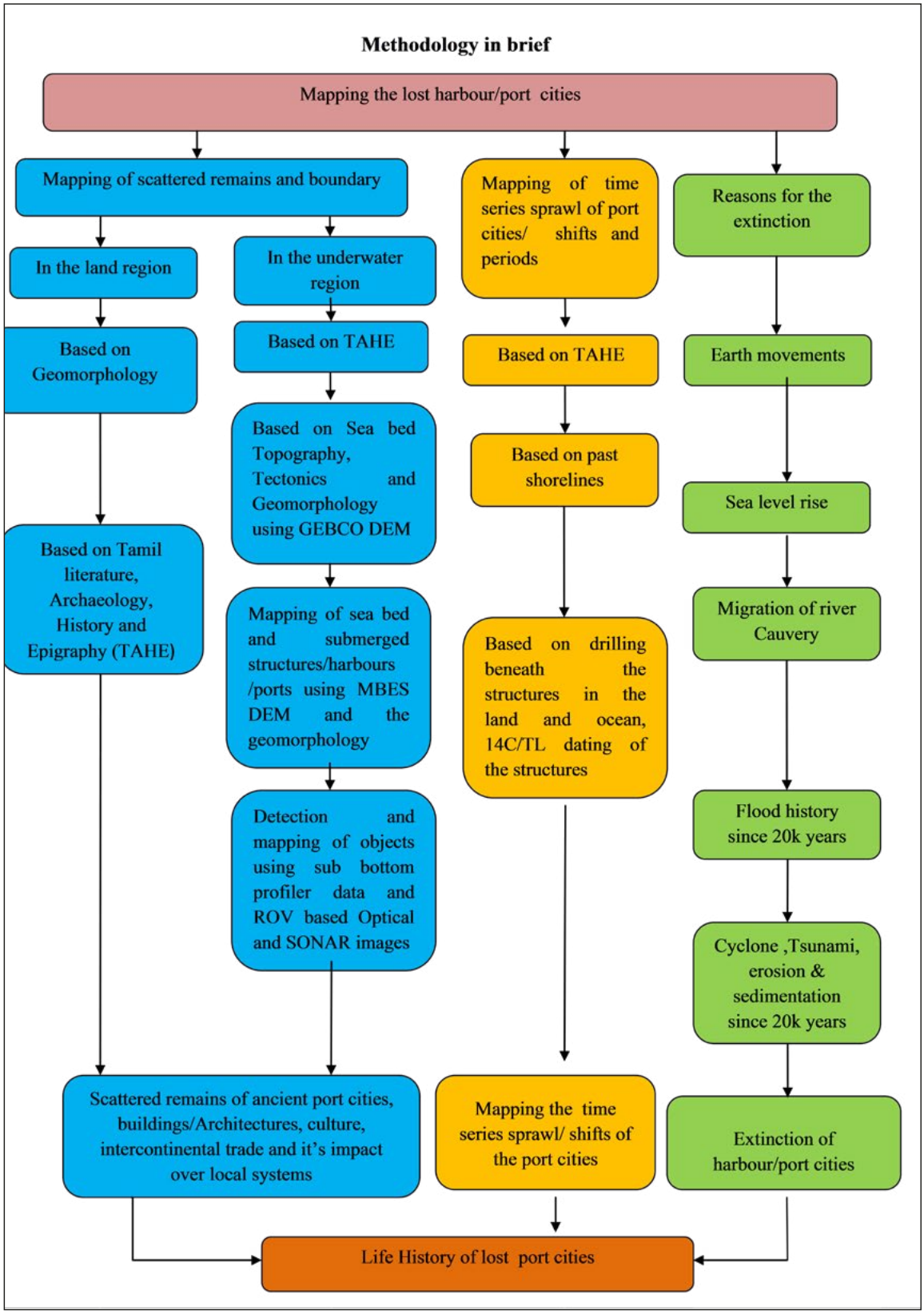

Fig. 2: Methodology in brief

testimony to Poompuhar's civilisation and the legacy. These are few knowns, but much more need to be collected and planimetrically controlled maps will have to be generated.

3.1.2 Underwater Region

(a)*Based on TAHE*

The Tamil literature and archaeological evidences show the existence of many remains in the sea like Somakundam, Suryakundam, Vellidaimandram, brick walls, etc. at the depth 8-15 meters and 15 km from the present Poompuhar which were also confirmed by the later archaeological surveys (NIO Tech. Report 1995 & 1997). So extensive studies of TAHE are required to identify and map such structures, besides the already reported ones.

(b)*Based on GEBCO DEM & Seabed physiography/ geomorphology*

The mapping of seabed physiography and the sub marine tectonic and geomorphic mapping are essential to identify the probable zones for the ancient harbours, which can be accomplished using GEBCO and MBES data. In the study of Poompuhar, the GEBCO data was downloaded from https://www.gebco.net/website. The said data provides bathymetry of the sea / seabed elevations with the spatial resolution of 500 m. The data thus downloaded for 2000 sq. km area were rasterized (8100 pixels) and the seabed topographic contours with 5 meter interval and the digital elevation model were generated for the area covering parts of continental shelf, slope and rise of the offshore region of Poompuhar (1-3, Fig. 4). From the same, (4) the submarine ridges, (5) deep river cut valleys of the river Cauvery and its distributaries and number of lobate deltas (E-L, Fig. 4) developed by the river Cauvery and its paleo distributaries were mapped. Particularly, the river Cauvery has developed a chain 3 lobate deltas (F-H, Fig. 4).

The submarine geomorphology map should show the submerged deltas and river mouths because, our ancestors have constructed harbours mostly in deltas and river mouths and related features. Similarly, submarine ridges must also to be mapped, since these act as barriers in obstructing the littoral currents which could dump the sediments in the harbours. The recent discovery of a submerged harbour (M) in the offshore region of Poompuhar over delta (F, Fig.4) showed that the ancient people were aware of such marine dynamics and only accordingly they have positioned the said harbour (Ramasamy *et al*. 2020). In the same way, the submarine rivers and the river cut valleys need to be mapped, since along which the continental rivers not only discharge the flood waters but also these act as pathways for the Tsunamis and storm surges which could have contributed to the extinction of the ancient port city Poompuhar .

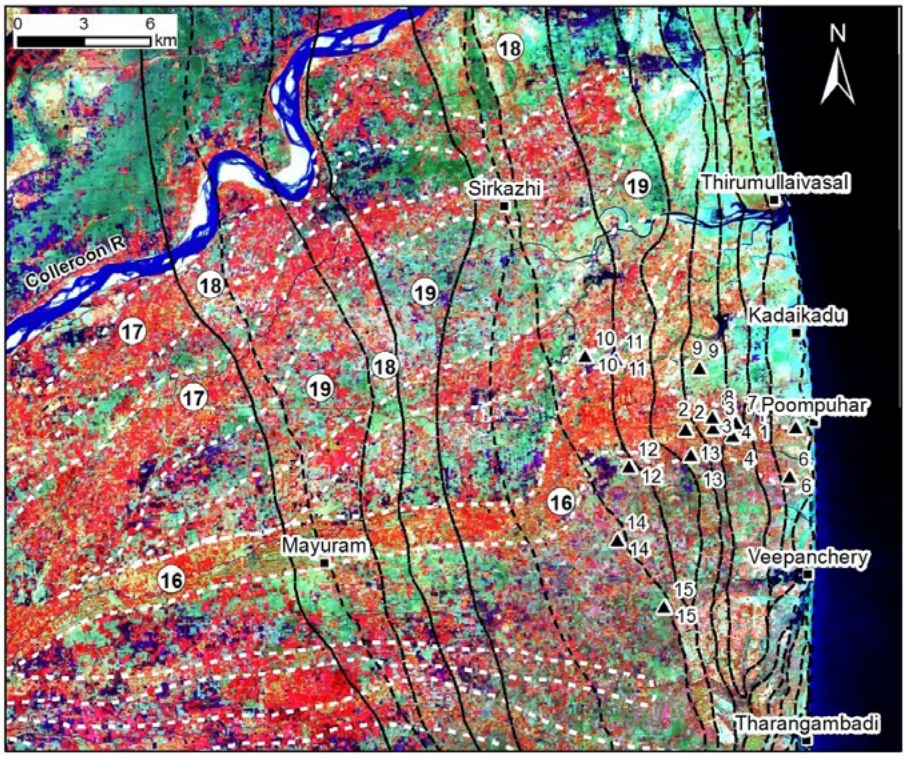

Fig. 3: IRS FCC showing scattered remains and broad boundary of Poompuhar: (1) Pallavaneeswaram, (2) Kazhutakaranturai, (3) Melaiyur, (4) Sampapathi Amman Temple, (5) Keezhaiyur Tank, (6) Vanagiri, (7) Keezhaiyur, (8) Manigramam Village, (9) Thiruvengadu, (10) Nangur, (11) Peruntottam, (12) Talaiccengadu, (13) Melapperumpallam, (14) Akkur, (15) Tirukkadaiyur; (16) Mother Channel Cauvery, (17) old courses/ defunct distributaries of Cauvery, (18) beach ridges and (19) swales.

So in mapping the lost/submerged port cities, these submarine geological/ geomorphological features are to be mapped. In the case of Poompuhar study, all these features were mapped (4-6, Fig.4) using the sea bed topography derived from GEBCO DEM. The inference of a chain of 3 (F-H, Fig. 4) submarine deltas (Ramasamy *et al*. 2017) and the discovery of a harbour in the oldest delta of Cauvery (H, Fig. 4) in the offshore region of Poompuhar (Ramasamy *et al*. 2020) add credential to the concept of sea bed geomorphology mapping using GEBCO DEM. Besides, the younger rivers (A-D, Fig . 4) which have subsequently occupied the defunct distributaries of river Cauvery were also mapped in the delta region, since these have formed a number of submerged deltas (Fig.4)

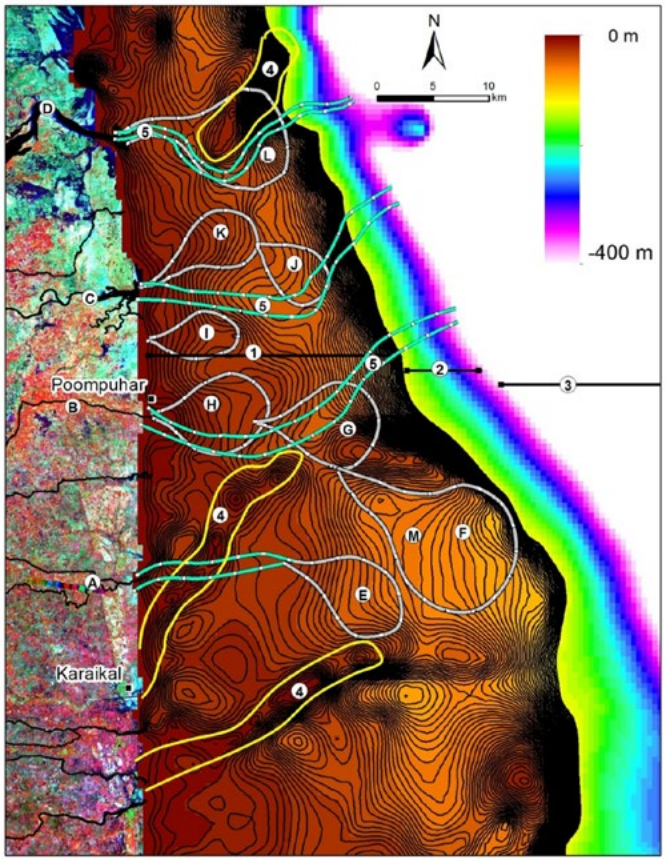

Fig. 4: Physiography and geomorphology of the offshore region of Poompuhar shown by GEBCO DEM and the contours and part of the Cauvery delta of Poompuhar region shown by IRS LISS III FCC ; (1) Continental shelf, (2 & 3) Continental slope and rise, (4) submarine ridges, (5) submarine valleys / rivers; inland rivers (A) Veerasolanar, (B) mother channel Cauvery/Palam Cauvery, (C) Southern Munniyar, (D) Coleroon,; submerged Deltas of (E) Veerasolanar path of Cauvery, (F-H) chains of deltas along Palam Cauvery, (I) Manikaraniar, (J&K) Palavar, and (L) Coleroon path of Cauvery ; (M) submerged harbour and related structures along the western slope of delta –F.

(c)*Based on the MBES DEM*

While GEBCO data can give coarser information on the seabed physiography/geomorphology as discussed above, the Multi-Beam Echo Sounder data (MBES) would give finer information on it. The data collection methods and the other details of MBES are shown in Fig. 5. The trial MBES data collected by the NIOT (National Institute of Ocean Technology) for the offshore region of Poompuhar with the north-south direction of travel and the sea bed elevation with 25 m spatial resolution, was used and from which the DEM and contours with one meter interval were developed. It lead to the discovery of a major harbour like structure of more than 15,000 years old, with 11 km length in N-S and 2-3 km breadth in E-W, with canals in N-S and E-W directions (Ramasamy *et al*. 2020) (1, Fig. 6).

These N-S and E-W canals were 180–250 meters wide, 4–7 m meters deep, meant for movements of ships. In addition, it was inferred by Ramasamy *et al*. (2020) that there was a (2) breakwater, (3) E-W seawall and also (4) a bridge like structure connecting delta-F with delta-E to its west (Fig.6). From these, it was inferred by them that this would have been the original location of Poompuhar and the later it might have been shifted to the present location at the mouth of river Cauvery. In the context of the littoral currents (Sambasiva Rao 1982, Ramasamy 2003), the breakwaters and seawalls might have been constructed to protect the harbour from the sedimentation by the littoral currents; which indicate that the ancient people were aware of the marine dynamics and their impacts over the harbours too. Similarly, the bridge like features might have been laid by them to move from delta -F to delta-G (Figs 4&6), probably when sea level was rising. Thus, this trial study showed the need of the MBES survey, and the geologic/geomorphic interpretation to bring out the lost harbours/ port cities. The MBES data could also indicate other scattered remains related to the submerged ports and cities in the sea bed.

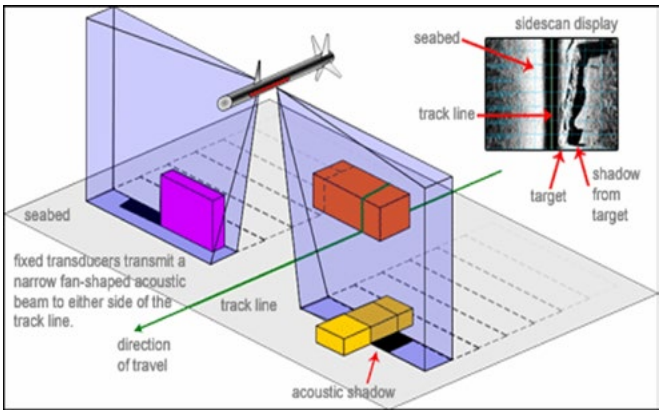

Fig. 5: Data collection by Multi Beam Eco sounder system (MBES)

(d)*Based on Sub bottom profiler survey and the ROV based underwater photography*

Similarly, in addition to identifying the scattered remains of the harbours and ports, the broken objects, artefacts, ship wreck,

etc. related to submerged harbours /ports can be located from the SBP (sub–bottom profiler) survey and the ROV (Remotely Operated Vehicle) based optical and Sonar imaging. These need to be processed in the computer by specially developed algorithms to enhance the quality of the images for the precise interpretation of scattered remains including the broken ones which can be assembled by developing special algorithms. The broken objects are shown in Fig. 7. These operations have also been contemplated and placed in the project digital reconstruction of Poompuhar.

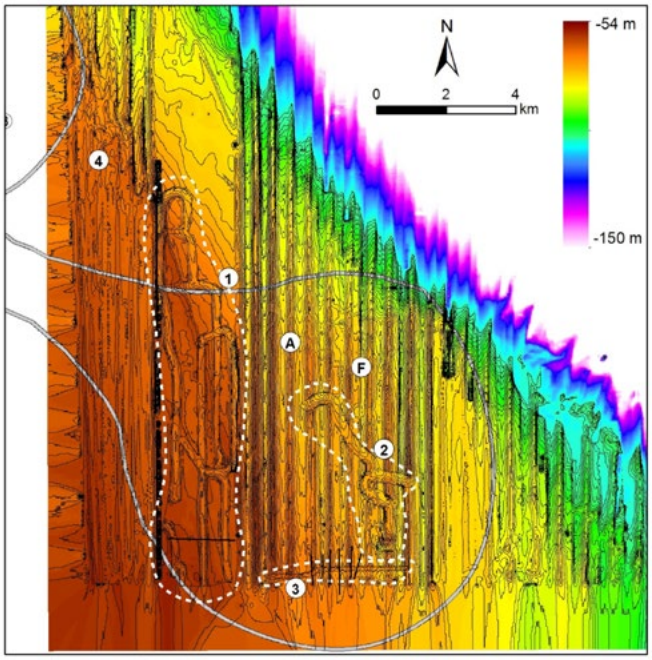

Fig. 6: Multi-Beam Echo sounder (MBES) data: Showing (1) North-south harbour, (2) break water (3) sea wall and (4) Probable boulder bridge along the western slope of the oldest submerged delta-F of Cauvery (shown as M in Fig. 3).

3.1.3 Scattered Remains and the Boundary of Poompuhar

Thus, these types of studies are to be conducted with Geosciences as the core and the sea bed tectonics and geomorphology would provide base line data for narrowing down the areas for the search of submerged harbours and therefrom for mapping the scattered remains and the probable boundary of such lost / submerged harbours. The preliminary studies carried out in the Poompuhar region itself have made a major breakthrough within a short span of one year, with a discovery of a harbour around 25 km inside the present coast (Fig. 6&8), taking maritime activities from 2000 years BP (Before Present) to more than 15,000 years BP. In addition, from the scattered remains that are found in the Poompuhar region both inside the sea up to 15 km (Somakundam, Suryakundam and Vellidaimandram) and the other scattered remains and structures up to 5-7 km in the landward side, the broad boundary of Poompuhar could be tentatively mapped (Fig. 8). In fact, considering the beach ridges and the scanty evidences seen up to Mayuram, it can be surmised that the boundary of Poompuhar and its maritime activities might have extended up to Mayauram. This is how the remains and the boundary of the submerged/lost harbours can be brought out.

3.2 Time Series Sprawl and the Shifts of Poompuhar

In the case of submerged harbour/port cities, if the remains are seen as clusters scattered in a wider area in the sea, then these would indicate the shifting of the harbour from place to place in phases as observed by Ramasamy *et al*. (2017) for Poompuhar. If so, then the time series sprawl in each cluster and the total shift of the harbour from one place to the other will have to be brought out along with time frame to comprehensively reconstruct the life history of the submerged harbour under discussion.

3.2.1 Based on TAHE

Since, the Poompuhar harbour has spread over from 25 km inside the sea in the east and up to 3-7 km west of the present day coast, the time series sprawl of each cluster and the pattern and periods of shifts will have to be brought out and this could be done by collecting detailed information first from TAHE data (Fig. 9).

3.2.2 Based on the past shorelines

The discovery of harbour like structure in delta-A (Fig. 9) 25 km from the present coast inside the sea and the feasibility of the scattered remains in delta-B and delta-C indicate that the Poompuhar city might have been initially established in delta-A and gradually shifted in phases to the present location as observed by Ramasamy *et al*. (2017). So, this must be studied in detail by mapping the past shorelines. The global sea level curve drawn from the Last Glacial Maxima (LGM) of 20,000 years BP to present day by Fleming *et al*. (1998) convincingly showed that the sea level was 125 m below the present MSL and then steadily rose to present level with some standstills in between. From the curve, the sea levels can be identified for 20,000, 11,000, 9,000, 8,000 and 7,000 years BP and marked over the GEBCO DEM of the offshore region of Poompuhar which has 5m contour intervals. The past shorelines thus drawn for demonstration are shown in Fig.9. This indicates the gradual submergence of land from the east to west. Thus by carrying out precise studies using the fine resolution bathymetry contours derived from MBES data, the time series shift of Poompuhar and the other submerged harbours can be brought out.

Fig. 7: Examples of under water data acquisition and processing: Remotely operated vehicle based (A) optical under water imaging , (B) SONAR imaging and (C) raw and (D) processed optical images.

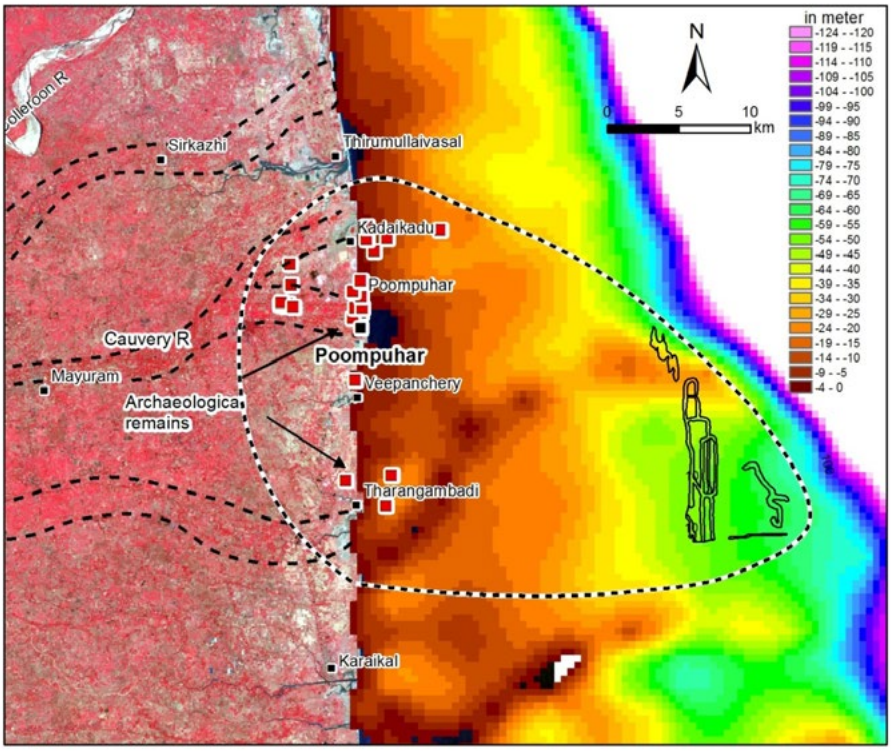

Fig. 8: Scattered remains of Poompuhar in the land and the ocean and the boundary of Poompuhar

3.2.3 Geochronological dating Beneath the Structures

Such time series sprawl of each cluster of the submerged harbours and the total shifts of the harbour from one place to the another location also need to be brought out in the study of building the life history of lost/ submerged harbours. In the case of Poompuhar it had an areal spread of over 140-150 sq. km (Fig.8). In this case, Poompuhar at delta–A, and the present coast are known and near delta-B, it has been notionally shown, making it three clusters. In each cluster bore holes can be drilled from the core to the periphery at the base of the structures and dated using 14C /TL etc methods, which would give the time series sprawl of each cluster. Similarly, the overall pattern and periods of shift from delta –A to the present Poompuhar can also be brought out to build the life history.

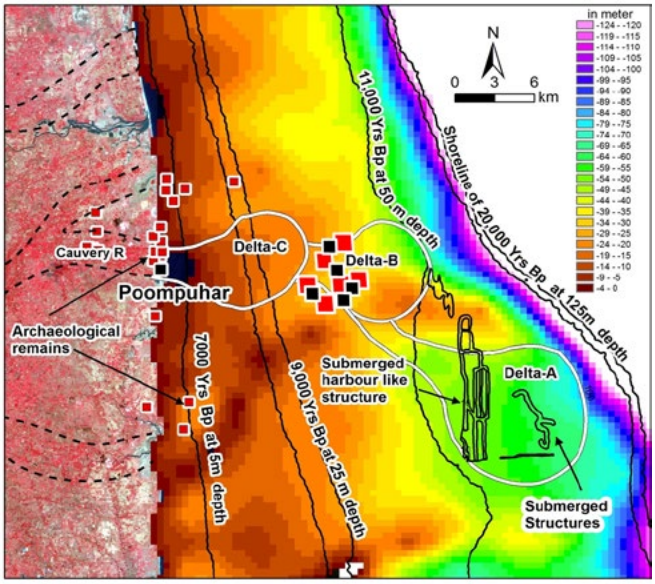

Fig. 9: Time series sprawl and shifts of Poompuhar: past shorelines, periods and depths; (red dots) locations of submerged structures /Poompuhar, (black dots) locations of bore coring for geochronological dating of the structures.

3.3 Reasons for the Extinction of Poompuhar

The extinction of many global cities and harbours were found to be due to various natural disasters like volcanism, earthquakes, land subsidence, sea level rise, tsunami, flooding etc. as briefed above. But as far as the Poompuhar and the many other submerged/lost harbours, not much of studies have been done. This is a major and important aspect to be studied in reconstructing the life histories of such harbours. Further, since Poompuhar is located in a unique geodynamic province, the above geological disasters might have contributed to the extinction of Poompuhar. This could be done as follows.

3.3.1 From TAHE

The Tamil literatures, for example, the Chilapathikaram and Manimeghalai have mentioned that the Poompuhar was swallowed by the sea by phenomenon called *kadalkol*. These literatures mentioned that since the *Indra Vizha* which is an annual fair meant for worshipping Lord Indiran has been stopped in Poompuhar, so the sea Goddess became furious and sent ferocious waves which swallowed the Poompuhar city. Barring this, not much information is available. However, TAHE has to be studied in detail to gull out more information on the extinction of Poompuhar.

3.3.2 Earth Movements

During their studies on the archaeological aspects, Sundaresh *et al*. (2004) and Sundaresh and Gaur (2011) have briefly mentioned that the tectonic activities and sea level rise might have contributed to the extinction of Poompuhar. Beyond this, no information is available on this. However, in the recent years, a lot of observations have been made on the active tectonic movements in parts of south India and the Poompuhar region (Radhakrishna 1993, Subrahmanya 1996, Valdiya 2001, Ramasamy 2006, Ramasamy *et al*. 2006b). However, Ramasamy (2006) has brought out a detailed active tectonic model for the Indian Peninsula in which he has demonstrated that the Indian plate is buckling and fracturing with N-S extension, NE-SW sinistral, NW-SE dextral and E-W release Fractures/faults; and this is due to the still prevalent northerly compressive force which has originally drifted the Indian plate towards northerly and the obstruction of Himalayas from the north. This was also further confirmed by the various drainage anomalies (Ramasamy *et al*. 2011). In the coastal area of Tamilnadu, especially in the Cauvery delta, the number of active faults found are seen to be related to Post collision tectonics (Ramasamy 2006; Ramasamy *et al*. 2006b). So the studies have been initiated on this, in project Poompuhar and the preliminary studies carried out in Cauvery delta (Ramasamy and Saravanavel 2020) have indicated a spectrum of active faults with the above orientations and morphology (Fig. 10); these studies have also observed that the N-S faults are hinge faults and the hinge is located in the north along the East-West Vellar graben bounded by the faults F15 & F16 (Fig. 10) resulting to the northerly tilt of the Cauvery delta between Pattukkottai-Mannargudi-Vedaranniyam in the south and north of Poompuhar region in the north. The northerly migration of Cauvery has also been attributed to such northerly tilting earlier (Ramasamy *et al*. 1992). So, in the context of extinction of Poompuhar due to tectonics, this needs to be studied by coarsely estimating the rate of tilting by 14C dating of the beach ridges in Vedaranniyam area (black dots, Fig. 10), and the old courses of Cauvery (red dots, Fig. 10). The finer estimation of rate of earth movements can be brought

out in the study block –B using SAR interferometry and GPS observations. This would provide information on the input of land subsidence over the submergence of Poompuhar.

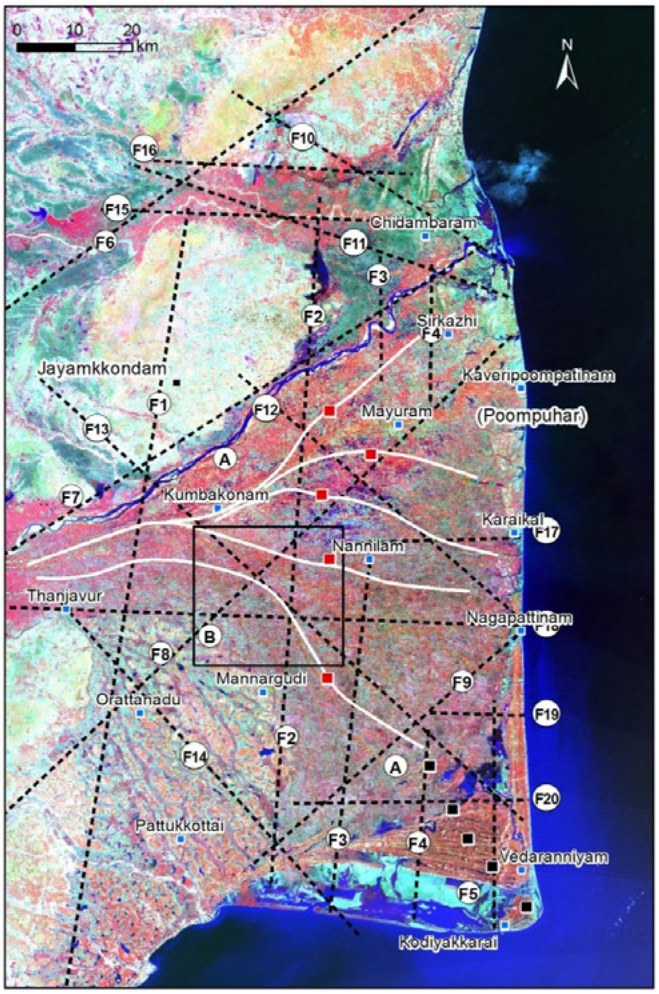

Fig. 10: IRS FCC showing the active faults :Derived from lineaments and drainage anomalies; (F1-F5) N-S Extension, (F6-F9) NE-SW sinistral and (F10-F14) NW-SE dextral faults and (F15-F20 E-W Fracture swarms; (A) Defunct distributaries /old courses of Cauvery; (red dots) locations along old courses and (black dots) locations along beach ridges for of geochronological dating; (B) Study block for SAR and GPS studies.

3.3.3 Sea Level Rise

As discussed earlier, the sea level is rising since the LGM of 20,000 years BP to present day. These sea levels can be identified for different periods at the rate of 2000-3000 years from the Global sea level curve of Fleming *et al*. (1998) and the past shorelines can be drawn for these periods along the corresponding contours using the 5 m contour lines of GEBCO DEM shown in Fig. 9. However, the global sea level curve needs to be calibrated for the tectonic subsidence for the Tamil Nadu coast prior to it. This would bring out the impact of sea level rise over the extinction of Poompuhar along with the pattern and period of submergence of different clusters of Poompuhar from the east to the west (Fig. 9).

3.3.4 Migration of river Cauvery

Most of the harbours around the world have been located in the delta or along the river mouths. So when these rivers shift their courses, the harbours will automatically become defunct. In the case of Poompuhar too, it was located at the mouth of the river Cauvery. The studies show that the river Cauvery has shifted from south to north in between 2300 years BP to 750 years BP (Ramasamy *et al*. 1992). There is also an alternate hypothesis that the Cauvery has developed a fan shaped delta with radiating distributaries from its apex in Tiruchirappalli to Vedaranniyam in the south to north of Sirkazhi in the north. Then due to the uplift of the southern part of the delta in Pattukottai – Mannargudi – Vedaranniyam (Fig. 10) area, these distributaries have become sequentially defunct one after the other thus the southern distributaries pushed their water to the immediate northern counter parts. (Ramasamy *et al*. 2006b). Under this backdrop these defunct distributaries of Cauvery will have to be mapped (e.g. 1, Fig. 11) using finer resolution satellite data, put augur boreholes (white dots, Fig. 11) and carry out 14C dating and sedimentological studies. This would provide clear picture on the pattern and periods of migration of river Cauvery and its input over the extinction of Poompuhar.

3.3.5 Past Flood History

The TAHE data and also the collateral datasets show that the Mother channel Cauvery called Palam Cauvery (1, Fig.12) has been prone for flooding. Since the Poompuhar port city was at the mouth of river Cauvery, the input of such flood over the extinction of Poompuhar needs to be elucidated. This could be done by the precise mapping of Palam Cauvery and it's flood plains, drilling boreholes of 10-15 m depth (2, Fig.12), carry out sedimentological, XRD and XRF studies, identification of the flood horizons in the core samples, carry out TL/OSL dating of those past flood horizons and bring out the spatial GIS databases on the pattern of flood inundation for different periods from 20,000 yrs / oldest possible date to 1000 yrs BP. Similarly, since such flood would have dumped the sediments in the sea, the seabed geomorphic mapping could be done to identify the possible zones of sediment accumulations and drill boreholes (3, Fig.12) and collect samples, identify the flood horizons and date them. From it, spatial GIS data can be generated for various periods from 20,000 yrs/oldest possible date to 1000 yrs BP on the pattern of sedimentation in the sea in the river mouth regions. From such past flood and sedimentation histories, their input over the extinction of Poompuhar can be brought out. This has to be done to identify their input over extinction of Poompuhar.

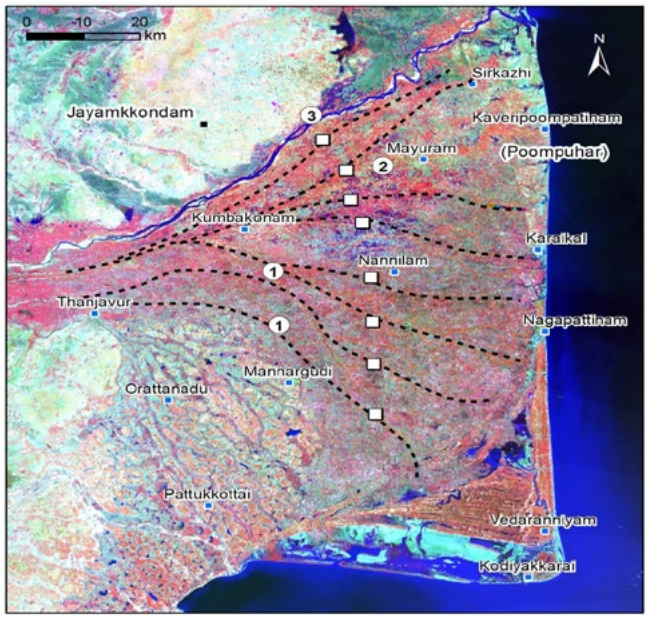

Fig. 11: IRS FCC data of Cauvery delta showing the palaeo courses/defunct distributaries of Cauvery**:** (1) defunct distributaries / old courses of River Cauvery, (2) Mother channel Cauvery, (3) River Coleroon; (white dots) locations for geochronological studies along the old courses.

3.3.6 Past Cyclone and Tsunamis

Similarly, the past cyclones, tsunamis and storm surges also need to be visualized for Poompuhar region from 20,000 years to 1000 years BP to evaluate their inputs over the defunct of Poompuhar. This could be done by mapping the coastal geomorphology and identifying the mouths of creeks, rivers and the wetlands, where the tsunami sediments are normally trapped. Similarly in the context of the extension of Poompuhar much inside the sea, the submarine geomorphology maps must be prepared using MBES data, and identify the possible zones for Tsunami and cyclone sediments. Then boreholes need to be drilled (2, Fig. 13) to the depth of 10-15 meters, carry out sedimentological and magnetic susceptibility studies, identify the horizons of such tsunami and cyclone events in the cores and date them using TL and OSL techniques. The notional tsunami and cyclone horizons thus identified are shown in Fig.14. From these, spatial GIS data bases can be prepared showing the pattern of inundation of tsunamis and cyclones for the multiple periods to bring out their possible impact over the extinction of Poompuhar along with the time frame.

3.3.7 Past Littoral Currents- erosion-sedimentation pattern

It has been observed that all along the east coast of India, the littoral currents are moving northerly in nine months in a year (Feb-Oct) and during which these dump the sediments in the south and the deflected components of the littoral currents erode the coast in the north of the obstructing or protruding structures (Sambasiva Rao 1982, Ramasamy 2003). So such erosion and sedimentation pattern could definitely contribute to the defunct of Poompuhar. To elucidate it, 15 bore holes can be drilled in grid pattern as shown in the Fig.13 up to 10 to 15 m depth, collect core samples, subject to X-ray studies, collect samples from three horizons in the core at 4, 8 and 12 m depths, carry out sedimentalogical, XRD, XRF and other related studies,

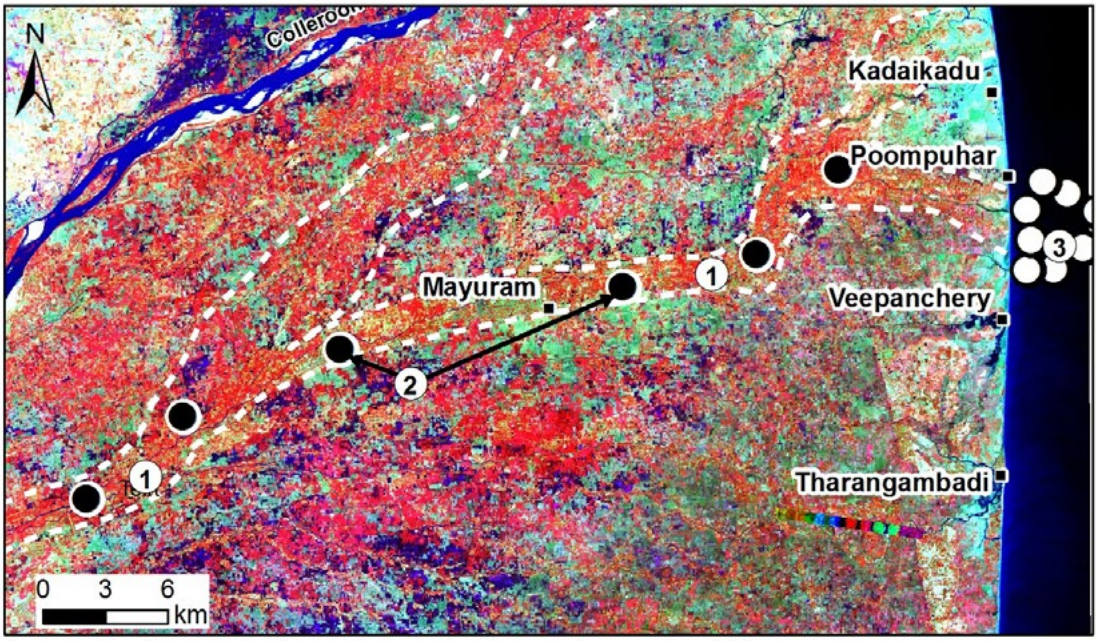

Fig. 12: IRS FCC showing (1) Palam Cauvery river with Poompuhar at it's mouth, (2) Locations for deep bore holes (10-15m) along Palam Cauvery and (3) in the sea bed at the river mouth for core sampling and geochronological dating To build the past flood histories in the land and sedimentation in the ocean.

do 14C dating of the 45 samples and prepare depth-wise and chronology-wise plans on the pattern of littoral currents, erosion and sedimentation pattern (Fig. 13) to bring out its contribution over the defunct of Poompuhar, along with periods.

3.3.8 Spatio-Temporal Model on the Extinction of Poompuhar

On analysing the various natural disasters like earth movements, sea level changes, migration of river systems, and visualizing the past floods, cyclones, tsunamis, erosion and sedimentation dynamics, and their impact over the extinction of Poompuhar along with zones and periods; these can be brought over to a single GIS layer. This would provide a spatio-temporal model on the extinction of Poompuhar city.

4.0 Discussions and Conclusions

The above narrations show that the lost/submerged harbours and ports of the world have not been studied holistically and so far studied mostly on the archaeology and related aspects. But mentions have been made on the impact of natural disasters over the extinction of these cities. In India too, not much detailed studies have been made on the coastal cities in general and the towering cities like Dwarka and Poompuhar port city too have been studied only from the archaeological perspective, thus leaving behind a lot of grey areas on these coastal cities/harbours. Considering the importance of these coastal cities we require their comprehensive life histories, which could be done only if the disciplines like Geosciences / Geodynamics could be involved deservingly. The above discussions clearly show these. Duly realising this, the present

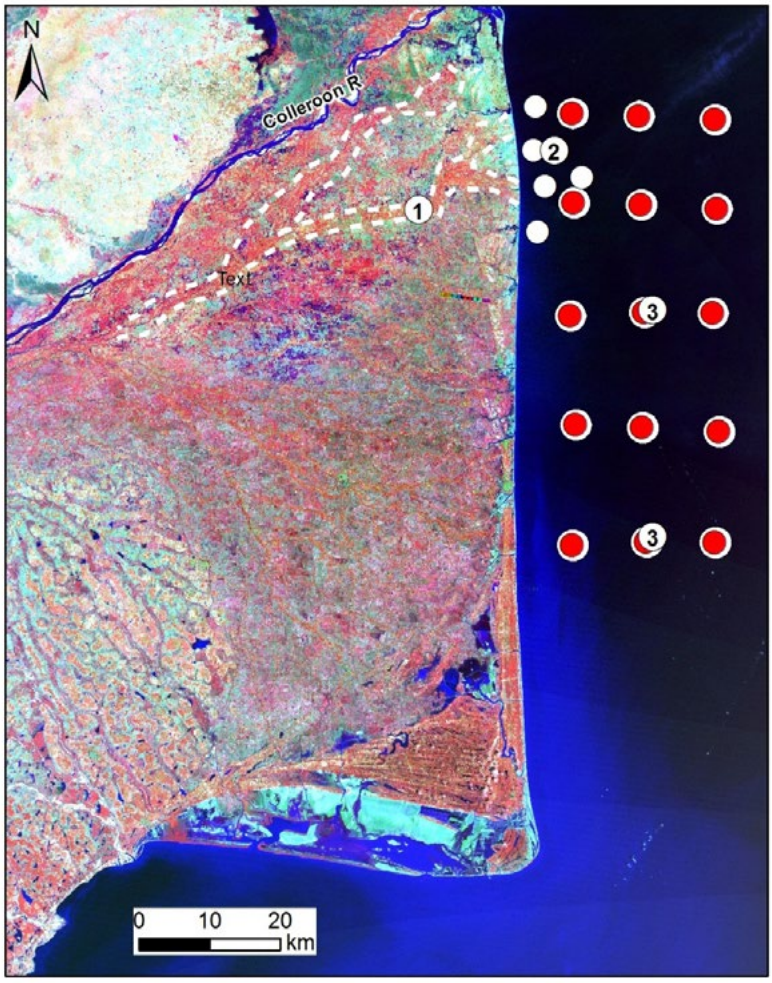

Fig. 13: IRS FCC showing the locations for core sample collection for ocean based palaeo-disaster studies: (1) Palam Cauvery, (2) representative locations for drilling and core sampling for Palaeo cyclones and tsunami studies (3) 15 locations for drilling and core sampling for palaeo littoral currents - erosion - sedimentation studies

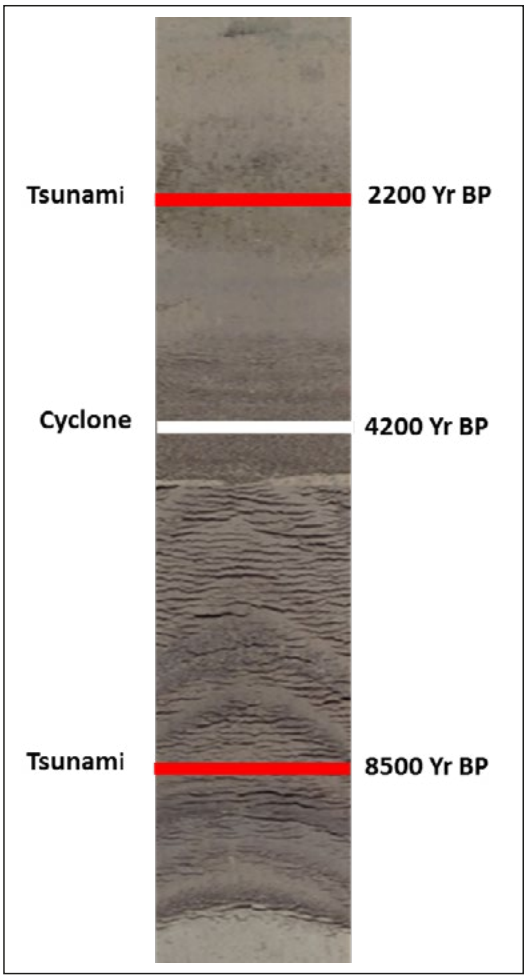

Fig. 14: Horizons of past disasters identified from sedimentology and the dates from TL/OSL

project "DIGITAL RECONSTRUCTION OF POOMPUHAR has been conceived and launched under DST's one of the national programme "Indian Heritage in Digital Space" (IHDS). Again, it is the first time that the branch of Geosciences/Geodynamics has been involved to optimum and deserving levels. The project, in the initial stage of first year itself, has started bringing out fascinating packages of newer information, significantly the discovery of a harbour 25 km inside the sea taking the Poompuhar's age from the much thought off 2000 years BP to more than 15,000 years BP. When the more outputs are flowing from over 12 collaborating institutions and analysed under geodynamic perspectives it would bring out the total picture on it's life history. This study is expected to give new packages of information not only on the life history of Poompuhar but also on the socio – cultural evolution of this part of the country and the significance of geosciences in studying such lost/submerged harbours and coastal cities. This type of comprehensive studies can be /need to be carried out for all the submerged and the lost coastal cities and the harbours around the world.

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