Anatomical studies of timber and EPMA analysis of brass artefacts collected from steam engine shipwreck of Minicoy Island, Lakshadweep, India

The maritime activity of India is datable to the Bronze Age, if not earlier, but the information on shipbuilding, crew and other details are well documented from the early historical period onwards. Ancient Indian literature mentions types of boats, but no precise information is available on the kind of timber used in construction. However, the Harappans must have used teak (*Tectona grandis*) for construction of boats[1]. The *Astadhyayi* of Panini[2] (5th century BC) has mentioned the use of a variety of timbers in the shipbuilding industry. Indian teak is considered the most valued timber because of its wood qualities, namely durability, elasticity, strength and dimensional stability; also it does not crack or split[3]. The worthiness of Indian teak for ship and boat-building and its other uses have been referred to in most of the Indian literature as well by the travellers[4–8].

In order to confirm the above-mentioned facts, it is essential to analyse timber remains found during maritime archaeological explorations. India is one of the oldest maritime nations of the world and several Indian-built ships have been wrecked both in Indian and foreign waters. Moreover, shipwrecks prior to the European period have neither been found nor explored in Indian waters. In India, shipwrecks have been explored in Sunchi Reef[9], St George's Reef[10], Amee Shoals[11], Sail Rock off Goa, Minicoy Island off Lakshadweep[12] and Poompuhar[13] off Tamil Nadu coast, and these shipwrecks are dateable to the post 17th century AD. Among these shipwrecks, timber remains have been noticed from St George's Reef shipwreck and were analysed thoroughly for the wood species[14]. Similarly, during exploration of shipwrecks off Minicoy Island, brass door hinges with timber remains, porthole and other artefacts have been collected[15].

Minicoy Island is the second largest and southernmost inhabited island in Lakshadweep. It lies on the international sea route (Figure 1). Ships sailing either from Colombo and Maldives to Aden or the other way around go close to Minicoy Island. Many ships have been wrecked in Minicoy and other islands of Lakshadweep, but only a few are documented in the Marine Records and other related documents[16]. The records state that ships have been wrecked on the reefs of these islands because of night navigation, cyclones and absence of light houses. Minicoy Island, Byramgore and Cheriapani reefs are the major shipwreck zones of this region. Archival records and published sources[17] mention that between 1862 and 1910, there have been five shipwrecks in shallow waters off Minicoy, including the SS *Colombo* in 1862, SS *Thrunscoe* in 1899, *Duffryn Manor* in 1909, SS *Delagoa* in 1910 and the sailing ship *Tolna* in 1900, which was scuttled off Minicoy while on a world cruise[18]. SS *Colombo* steamer was an iron screw barque, rerigged with 2127 tonnes gross, with two funnels and belonged to the Peninsular and Oriental Company. The ship left Point de Galle (Sri Lanka), for Suez on 17 November 1862. The weather was stormy and cloudy on the early

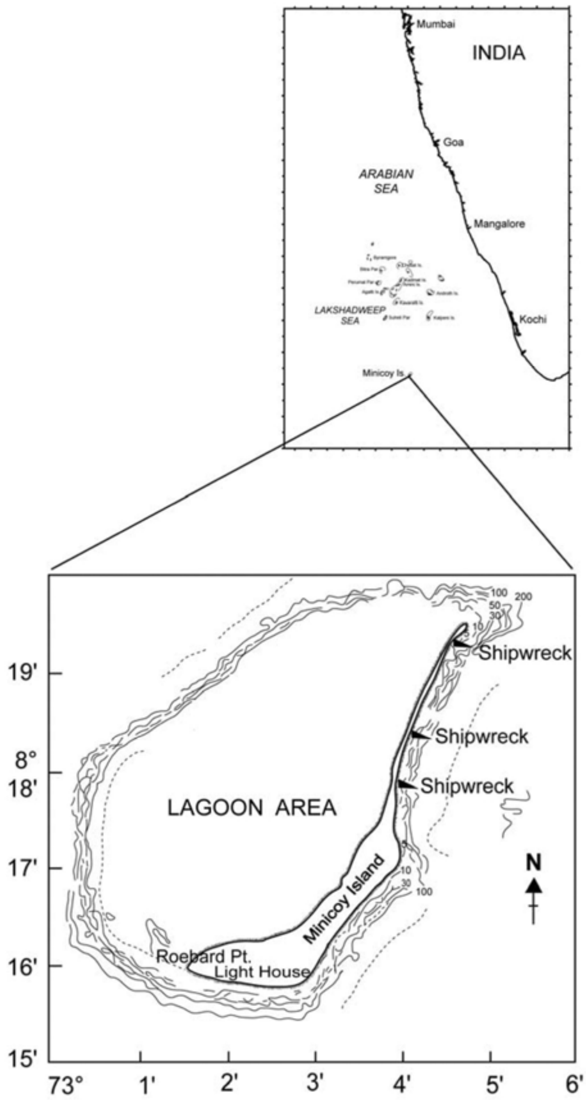

Figure 1. Location of shipwrecks off Minicoy Island and other Islands of Lakshadweep.

morning of 19 November. The sails were set and the ship could have sailed smoothly, but the engines were reversed and hence the ship grounded. The heavy sea struck her on the quarter and threw her right broadside onto the rocks. The starboard side exposed to rolling surf and the amidships and cabins were filled with water. *Colombo* formed a breakwater against the rolling waves, and the distance between the ship and the land was short that women, children and the sick were dragged by the natives through the intervening breakers. The next day, clothes and food were given to the passengers and the local King came and provided shelter. All people on-board were saved; considerable proportion of silk and only one-third of the cargo was salvaged. In the meanwhile, the ship had broken and fully wrecked[19].

SS *Thrunscoe* (*Transcoy*) was a British cargo steam engine built in 1896 and ran ground in 1899. The Court Report of SS *Thrunscoe* 1899 states that the light house of Minicoy was sighted by certain John Leisk. At midnight, after putting the ship in accurate course, the captain instructed the second officer, James Oliver and went to the lower deck. Leisk believed that the course set for the ship was perfectly safe and there was no flow of current. The second officer stated that it was a clear night up to 1 a.m., when patches of clouds began to rise and there were few drops of rain. The clouds prevented him from seeing the trees sooner than he used to do. He saw a dark object across the bow and within a minute the vessel struck. The Court order says that the captain should have remained on the deck until the vessel safely passed Minicoy, because the currents of this region are uncertain and variable. The second officer should have been more attentive than he appears to have done. The Court was of the opinion that both the captain and the second officer were guilty of culpable neglect of duty. The Court ordered the suspension of the captain for a period of three months and to the second officer for a period of six months[20].

The original name of SS *Delagoa* (1910) was SS *Port Albert*, which was built in 1897 at Newcastle. Its length, carrying capacity and speed were 357 ft, 2122 tonnes (3514 grt) and 11 knots respectively. It was sold to M/s. Marc, Wallenberg of Stockholm in 1906. Two years later the company extended her service to the Far East. The Swedish steamer cargo ship SS *Delagoa* was homeward-bound from Singapore and (Gothenburg) Penang with valuable cargo, including a large quantity of silk. The vessel struck Minicoy Island at 1.30 a.m. and grounded. SS *Delagoa* wrecked nearby SS *Thrunscoe*, which had wrecked 11 years ago[21]. Ellis[22] in his short account of the Laccadive Islands and Minicoy mentioned that the cargo steamer *Duffryn Manor* (1909) on her first voyage laden with rice returning home to London from Colombo grounded in Minicoy waters. It wrecked at a short distance from *Thrunscoe*, which was wrecked in 1899. In order to refloat her, some cargoes were tossed away and the rice was given to the islanders, which was almost five years supply of rice. For many years, the ladder of the ship was kept at Minicoy jetty, but it has disappeared now. The whirling motions in the Minicoy Sea caused the stranding of the sailing ship *Tolna* in 1900 at the Island.

As a part of the project work, CSIR-National Institute of Oceanography (NIO) had carried out onshore explorations at Agatti, Androth, Amini, Kadmat, Kalpeni and Kavaratti[23]. During offshore explorations, three shipwrecks were located off Minicoy and one at Suheli Par. Among the three shipwrecks off Minicoy, two were explored in addition to the Suheli Par shipwreck[15,16]. The other shipwreck off Minicoy is being salvaged. During exploration of the first shipwreck propeller, propeller shaft, hull and flywheel were noticed, now overgrown with corals. Octagonal-shaped porthole, *J* bolt with wing nut of porthole (26 cm in length), square and round flanges, hinges, stiffener, doorframe hinge and door latch were recovered from the wreck site for study and analysis. All these artefacts are made of brass and remains of timber are found on the doorframe hinge and door latch (Figure 2). The anchor chain of the ill-fated ship which is more than 50 m in length is found lying on the seabed; probably it is connected with the anchor which is lying in deeper waters. The beams and hull frames of the ship are also in good condition. The other wreck which was explored lies on the northern side of the preceding one. Boilers and other engine parts were observed on the sites, which are well preserved (Figure 3).

Electron probe micro-analysis (EPMA) of the metal artefacts has been carried out to know the mineralogy of brass artefacts and anatomical analysis of timber to identify timber-species and probable provenance of the timber used respectively. Among the metal artefacts, tiny pieces were cut from the doorframe hinge, door latch, porthole and hinge using hacksaw blade weighing a few milligrams for EPMA analysis. These were cleaned ultrasonically to remove foreign material and then dried. Subsequently, the samples were mounted in plastic mounts using a Buehler Simplimet-2 sample-mounting press. These plastic mounts were ground and polished using Buehler Automet-250 polishing machine to get a fine polished surface of the samples. The polished sections were coated with carbon using SPI module carbon coater. The chemical composition of the samples was determined using CAMACA-SX-FIVE EPMA with an accelerating voltage of 15 kV, sample current of 12 nA and beam diameter of 1 μm. The system was calibrated using analytical standards AS 02753-AB 53 Minerals Standard from SPI for different elements, e.g. for sodium: jadeite std., aluminium: plagioclase std., copper: cuprite std. and zinc: willimite std.

Further, the timber remains on the doorframe hinge (sample 1) and door latch (sample 2) were analysed for identification of wood species. Sample 1 was uncarbonized, brittle and in good condition, whereas sample 2 was very small, partly carbonized and deteriorated and comparatively more brittle than sample 1. Small blocks were prepared from these two samples and boiled in water for taking thin sections. Standard laboratory procedures were followed for sectioning using wood microtome. Cross-section, tangential–longitudinal (TL) and radial–longitudinal (RL) sections of about 20 μm thickness were cut using Reichert sliding microtome from sample 1.

Due to its smaller size, sample 2 was moulded in wax for sectioning. As the wood was also quite brittle, sections could not be cut from sample 2 using microtome. Instead thin, double-edged razor blades were used for cutting thin sections with hand. Part of the remaining sample was used for maceration[24]. Observation of the thin wood sections for characterization of vessel, fibre and ray morphology were made using Leica Laburlux microscope connected to image analysis system (Quantimet 500 MC). Fibre wall thickness was obtained by deducting lumen diameter from fibre

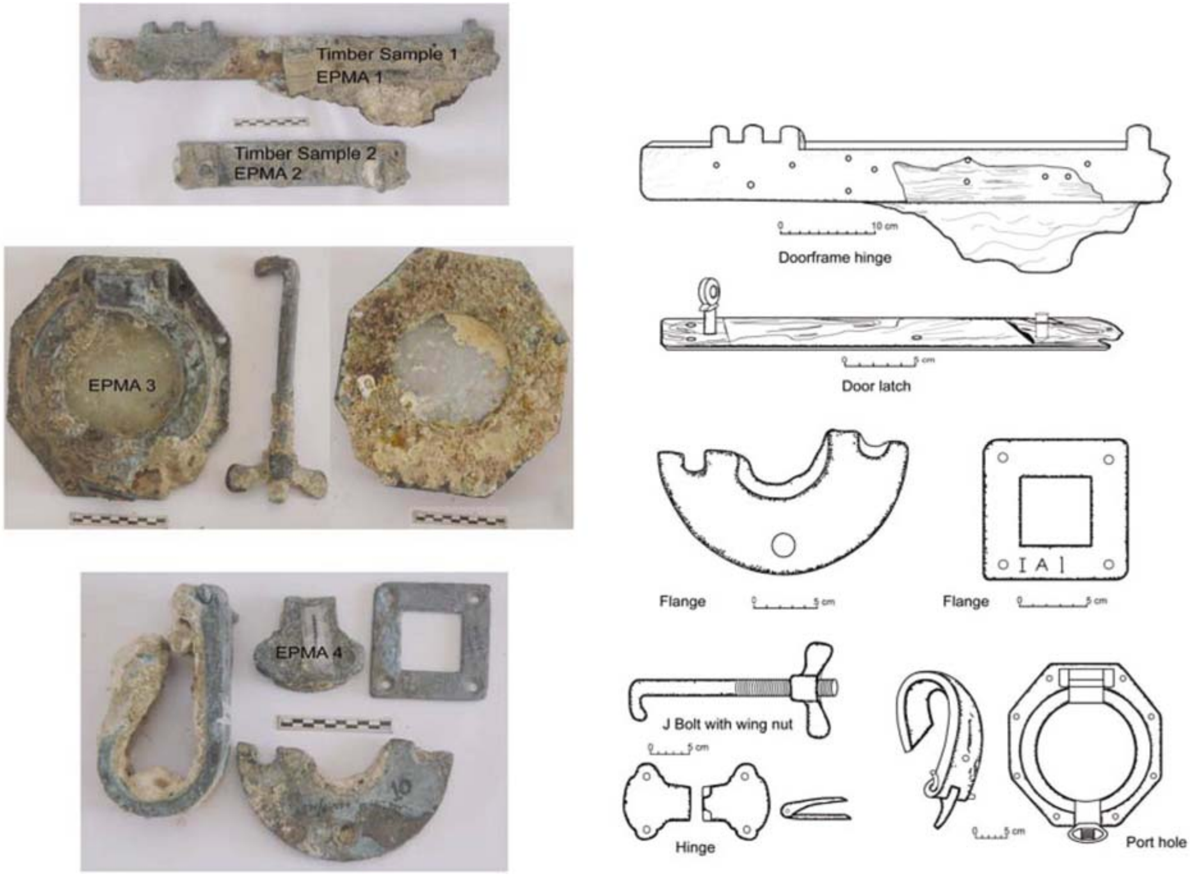

Figure 2. Brass objects collected from the shipwreck off Minicoy Island.

Figure 3. Remains of propeller, boilers and flywheel of the shipwreck off Minicoy Island.

diameter. The samples were also observed with hand lens (10×) and also under stereo zoom microscope (Leica S8APO Trinocular) and described based on their macroscopic features[25] as well as microscopic IAWA characteristics[26]. The basis of identification of wood samples was a combination of physical features, gross structure and anatomical characters. A few representative micrographs were captured using stereo zoom microscope and image analysis system. In order to understand the age of the timber, radiocarbon dating was carried out at BSIP, Lucknow.

Several spots on each of the samples were analysed, but noticeable variation in composition was not observed within each sample. However, an appreciable difference in the metal percentages was found between different samples. The totals obtained were consistently around 95%. The elements Fe, K, Mg, Ca, P, S, Cr and Ti were not observed below detection limit. The standards were again analysed, which provided consistently around 100% totals. This indicates that there is around 5% of an unknown component which may be chlorine (especially due to the presence of Na in all the samples) or carbon from the sea water as the artefacts were lying in sea water for many years. The average of the analyses on each of the samples is presented in

Table 1. The percentages of elements have been normalized to 100. The analysis showed that all the artefacts are made of brass.

Both timber samples showed similar structure and hence only one description is given to both the samples. Figure 4 illustrates the gross structure and microscopic structure of the samples. The gross structure showed that both the samples were ring porous, have growth rings distinct and conspicuous to the naked eye and delimited by large earlywood vessels enclosed in parenchymatous tissue. Vessels in the earlywood were visible to the eyes which were mostly solitary, oval in outline and gradually becoming smaller towards the latewood. Latewood vessels were moderately large to small, mostly solitary or in radial pairs and round-to-oval in shape. Rays were distinct, as shown in Figure 4 *a*.

The microscopic structure showed that the transition from earlywood to latewood was gradual. Larger vessels in earlywood and smaller vessels in latewood were observed (Figure 4 *b*). The diameter of earlywood pores (vessels) was up to 314 μm in sample 1 and 311 μm in sample 2. The maximum diameter of latewood vessel was found to be 176 μm in sample 1 and 156 μm in sample 2. Inter-vessel pits were alternate, vestured and 4–7 μm in size. Vessel members have simple perforation plates, as shown in Figure 4 *c* and *d*. Parenchyma was paratracheal, delimiting the growth rings. Crystals were absent. Figure 4 *c* shows the TL section of the wood sample exhibiting predominant multi-seriate rays, inter-vessel pits and septate fibres. Rays were 1–5 seriate, homocellular to weakly heterocellular. A few vasicentric tracheids were observed in macerated material. Fibres were septate to non-septate containing silica. The macerated fibres showed damage by soft-rot fungi as evidenced by soft-rot cavities, indicating that the wood had undergone deterioration. Figure 4 *d* shows RL section exhibiting procumbent ray cells and ray–vessel pitting in the wood sample. Table 2 lists the average and range (minimum and maximum values) of different anatomical features of the two wood samples analysed in the present study. A combination of characters like ring porosity, vestured pits, simple perforation plates, septate fibres, presence of silica and multiseriate rays and other quantitative features of vessels, rays and fibres suggests both the samples belong to *Tectona grandis* (teak wood)[27]. The origin of the samples is difficult to discern as teak has wide distribution in the tropics[28]. However, it is to be mentioned that teak was one of the preferred wood materials for boat and ship-building in India known since centuries[14,29].

Table 1. EPMA analysis of metal objects collected from Minicoy shipwreck

Metal object	Na (wt%)	Al (wt%)	Cu (wt%)	Zn (wt%)
Doorframe hinge	0.81	1.20	62.15	35.79
Door latch	0.78	1.37	62.72	35.10
Porthole	1.26	0.93	66.69	31.70
Hinge	0.53	0.56	74.86	23.89

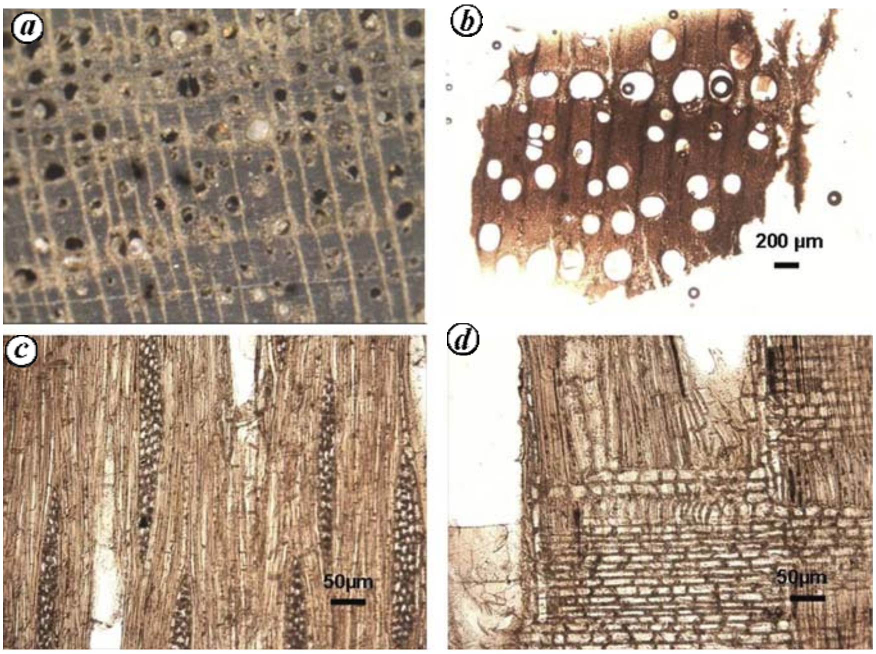

Figure 4 *a*–*d*. Anatomical analysis of timber remains found on the doorframe hinge and door latch. ***a***, End grain pattern showing ring porosity and growth rings of sample 1 as seen under stereo zoom microscope (20×). (Micron bar is not given as there was no facility for calibration in the stereo zoom microscope; hence the magnification has been shown as ×.) ***b***, Cross-section showing gradual transition from earlywood to latewood: larger vessels in earlywood and smaller vessels in latewood in sample 2. ***c***, Tangential–longitudinal (TL) section showing predominant multi-seriate and homocellular rays, inter-vessel pits and septate fibres. ***d***, Radial–longitudinal (RL) section showing procumbent ray cells and ray–vessel pitting.

The topography of Lakshadweep Islands suggests that there might have been several shipwrecks during ancient periods. However, shipwrecks prior to the 18th century are not reported in Lakshadweep waters. All the shipwrecks of Minicoy Island lie on its northeastern side and at a short distance from each other. Profuse coral growth is noticed on the shipwreck remains because Lakshadweep region is prone to coral growth, whereas all the brass objects have a green layer on the surface because of copper alloy oxidation. Exploration brought to light anchor chain, boilers, fly wheel, propeller, propeller shaft, brass artefacts, etc.; but names of the ships could not be found or established. Hence it is difficult to state which ships were explored among the four shipwrecks. Further, SS *Colombo* wrecked in very shallow waters and hence the local people could rescue the passengers from the wave breaker zone, whereas other shipwrecks namely *Thrunscoe* (1899), the *Duffryn Manor* (1909), the *Delagoa* (1910) are lying in 5–7 m water depth and parts of the ships are scattered all over the area.

EPMA analysis shows that among four brass objects, three are similar in their composition, whereas the fourth one is

Table 2. Wood anatomical features of samples 1 and 2

Anatomical features	Sample 1 Average (μm)	Sample 1 Range (μm) (Minimum–maximum)	Sample 2 Average (μm)	Sample 2 Range (μm) (Minimum–maximum)
Vessel diameter – earlywood	275	214–314	256	204–311
Vessel diameter – latewood	133	58–176	128	65–156
Vessel member length	397	350–474	367	217–433
Fibre length	1290	1113–1460	1318	1165–1454
Fibre diameter	25.5	18–29	24.5	18–31
Fibre lumen diameter	19	11–24	18	12–24
Fibre double-wall thickness	6.7	5–10.5	6.7	4.4–11
Ray height	563	395–808	497	374–924
Ray width	57	48–88	59	47–78

different; probably it could have been made for some specific purpose or brought from a different firm. The analysis of brass artefacts shows that corrosion is considerably much less when compared with iron and biological growth on iron is abundant. It shows that copper and the high copper alloys like brass were resistant to all environments and generally had lesser corrosion rates when compared to other metals such as iron. Aluminium makes brass stronger and more corrosion-resistant – traces of the presence of aluminium can be noticed in the analysis. Earlier accelerated corrosion analysis of these brass objects had been carried out to study corrosion and cathodic–anodic polarization curves[30]. The analysis showed that among other metals, brass artefacts were in a good state of preservation and a thin layer of corrosion which is formed on the surface is because of copper alloy oxidation and the presence of sulphate in sea water. The polarization curve of brass was obtained; its dissolution rate was found to be very low and the cathodic curve showed that brass is more passive. Because of its non-corrosive property, easy availability and cost-effectiveness, brass has been used extensively in the construction of ships since centuries.

None of these ships were built in India but the analysis of timber attached to the doorframe hinge and door latch showed that both the samples belong to *T. grandis*, which has wide distribution in the Indian subcontinent region. It could be presumed that either teak was imported from the tropics, including India for its use in making the doorframe hinge and door latch of the ship, or while undertaking maintenance of the ship doorframe hinge and door latch were made using teak. Varieties of timber were used for construction of ships and use of teak was exceptional for its superior quality. The ^{14}C date of timber shows that it is ± 90 years old (type of sample, timber; sample no S-4145; Lab no BS-3291; BSIP, Lucknow, 2011). This is because the sample has sufficient carbon and hence the age is indistinguishable from modern. Except *Tolna* all other shipwrecks of Minicoy were steel-hulled steam engine ships. During the 18th and 19th centuries, wooden-hulled ships were replaced by steel-hulled ones. This period was the transition phase between wood and iron and sail to steam. Therefore use of timber became less in the construction of ships. This study shows that in spite of availability of various timbers, teak was used for ship construction through the ages due to superior wood qualities, including its higher durability in the marine environment.

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Model simulation of tide-induced currents in Gauthami–Godavari estuary

Estuaries are often surrounded by protected ecosystems, and harbour significant human populations which exploit the area for leisure and tourism. Studies on Indian estuaries can be found in Qasim[1]. Several studies[2–11] reported various aspects of the estuaries, viz. Mandovi, Zuari, Cochin, Hooghly, Mahanadi and Godavari. Very few modelling studies[8,12–15] have been done for the Indian estuaries. Three-dimensional and two-dimensional models are commonly used to characterize hydrodynamic and transport processes in the estuarine, coastal and open ocean systems. Hydrodynamic models (3D) have the capability of simulating both spatial and vertical time-dependent frame, which is not possible with the 2D models. However, limited resources can make use of a 3D model infeasible for a particular study. In such cases, a 2D model, either a vertically or laterally averaged model must be used to understand the basic physical processes of a particular estuarine system. The application of 2D models with different types of closure schemes to determine the tidal circulation in the estuaries was reported from many parts of the world. A comparison of various closure schemes[16], and turbulence closure models[17] for stratified shallow water flows with application to the Rhine outflow region, have been reported. The laterally averaged flow and salinity structure in the Godavari estuary in July and only salinity structure in January were simulated[12]. In Mahanadi, laterally averaged velocity and salinity structures were simulated[8]. The model results could not be compared with the observations. A 2D numerical model to derive tides and residual currents was attempted in Thane Creek[13]. Sinha *et al.*[14] studied the laterally averaged currents and salinity distribution in the Hooghly estuary.

To our knowledge, no attempt has been made so far to study and validate the spatial currents pattern in the Godavari estuary, which is the third largest river in India. Here we have made an attempt to compare the model results with the systematic and accurate datasets collected in the estuary using sophisticated equipment. It may be mentioned that most of the earlier studies could not compare their model results in the estuaries, which could be due to lack of observations.

Godavari estuary is the third largest estuary in India and receives significant amount of freshwater from the upstream river. The discharge of freshwater from the upstream is mainly controlled by Low Dam at Dowleiswaram, where it bifurcates into two channels as Vasishta and Gauthami Godavari estuary (Figure 1)[18,19]. Discharge was maximal in August, and virtually no or negligible discharge between January and May[19]. Mixing in estuaries results from a combination of various effects such as tide, wind, the Earth's rotation and inflow from rivers. The interaction between dense saline waters entering from the sea and the freshwater derived from the upland discharge gives rise to a wide spectrum of circulation patterns and estuarine mixing. Virtually no discharge during the dry season made the estuary turn into well-mixed type and circulation is dominated by tides. Several investigators studied the seasonal variations in circulation and mixing characteristics of the Godavari estuary from the mouth to ~22 km upstream and observed that salinity in the estuary was mainly controlled by discharge during SW monsoon season with strong stratification, whereas