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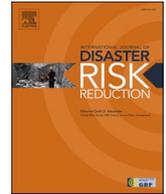
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Long-term recovery from the 2004 Indian ocean tsunami in two Sri Lankan east coast municipalities

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ABSTRACT

Sri Lanka was the second most affected country after Indonesia, in the 2004 Boxing Day Indian Ocean tsunami (IOT). A study mission was therefore carried out twenty years after the 2004 IOT to assess the recovery of the affected regions, especially in the Eastern region of Sri Lanka, focusing on two of the most affected municipalities, i.e. Kalmunai and Batticaloa. The social and infrastructure characteristics of resettlements/relocations/new settlements in the affected regions, presence of critical infrastructure, preparedness and early warning systems installed have been assessed. It was observed that similar approaches have been adopted to plan the community relocation in both of these municipalities, while the significant reemergence of residential and commercial developments in the coastal stretches of Kalmunai municipality have been noted. Exposure analyses have revealed that there are still some critical infrastructure situated in the tsunami hazard zones. It can be construed that these municipalities have recovered from the physical losses incurred, and spatial planning is in place for future developments considering the tsunami risk. Challenges and opportunities from their differing geographical contexts appear to have been judiciously handled. However, shortcomings are noted in actual implementation due to various reasons, such as limited resources, availability of funding and preference of communities to live close to their original lands. Improving the resilience of infrastructure by designing against the expected tsunami hazard and multi-hazards, regular verification of the early warning systems and evacuation procedures are emphasized to mitigate the impacts from future tsunami.

1. Introduction

The 2004 Indian Ocean Tsunami (IOT) was the deadliest disaster in Sri Lanka's recorded history, resulting in over 35,000 deaths and incurring \$2.2 billion economic losses [1]. The impact to Sri Lanka in terms of human and physical losses due to the 2004 IOT have been extensively studied and reported in the past [2,3]. A significant outcome of this disaster was the Sri Lanka Disaster Management Act (No. 13 of 2005), enacted on May 13, 2005 and the establishment of the Sri Lankan Disaster Management Centre (DMC) and

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National Council for Disaster Management (NCDM) specifically tasked with managing and coordinating disaster responses and future disaster preparedness, which did not exist before the 2004 IOT. These entities, along with various governmental and non-governmental organizations (NGOs), bilateral and multilateral agencies, and international NGOs (INGOs), contributed substantially to the reconstruction efforts, community recovery and rehabilitation [4].

Recovery from disasters is dependent on many factors, including the degree of damage, geographical location, resource availability (human and financial), spatial planning, and socioeconomic conditions [5–7]. Previous studies on disaster recovery have predominantly focused on specific recovery elements, such as resettlement or housing reconstruction [8–10], but have not extensively addressed long-term sustainability and resilience. Limited comprehensive studies on tsunami recovery stem partly from the rarity of such disasters globally, with only recent events receiving broader attention (e.g., the 2004 IOT, 2010 Chile, and 2011 Tohoku). Existing literature has primarily concentrated on short- and medium-term recovery, largely overlooking the essential long-term recovery measures necessary for fostering disaster resilient communities. Studies reported on the short- and medium-term recovery from the 2004 IOT in Sri Lanka are detailed in Section 5 of this paper.

Sri Lanka is prone to tsunamis generated from the Sunda Trench, Andaman-Nicobar Subduction Zone and Makran Subduction Zone [11]. In particularly the east coast of the country is prone to tsunamis generated from first two sources mentioned, and would potentially have the shortest tsunami travel time associated with it, as indicated in Fig. 1(a). The districts affected in Sri Lanka by the 2004 IOT are shown in Fig. 1(b), along with reported inundation depths [12]. The Eastern and Southern provinces bore the brunt of casualties and infrastructure damage, with Ampara district experiencing the highest losses, followed closely by Batticaloa—both situated in the Eastern Province. Matsumaru [13] compared the impacts of 2004 IOT in Indonesia and Sri Lanka, using two indicators, highlighted that the casualty ratio and economic damage relative to Gross Regional Product (GRP) were highest in the Eastern Province, at 1.08 and 35.6 %, respectively. Suppasi et al., [14] examined vulnerability and preparedness across Indonesia, Sri Lanka, Thailand, and Maldives a decade later, though Sri Lanka’s Southern Province was their sole focus region. Samarasekara et al. [15] discussed the effectiveness of coastal structures in mitigating tsunami impacts using Hikkaduwa (South-western Sri Lanka) as a case study. Løvholt et al. [16] reviewed national tsunami risk reduction measures in Indonesia (Padang) and Sri Lanka (Galle), but notably excluded the Eastern Province despite its severe impacts.

Detailed recovery studies are scarce in the Eastern Province primarily due to the region’s isolation and limited accessibility during Sri Lanka’s civil conflict, which persisted until mid-2009. Despite these challenges, significant infrastructure reconstruction and community rehabilitation efforts have been implemented, coordinated by governmental entities, NGOs, and INGOs [17,18]. The government initially designated tsunami buffer zones within which construction was prohibited, of 100 m and 200 m inland from the coast in the Eastern and Southern/Western provinces, respectively. However the compliance of these buffer zones was limited, owing to community resistance and land scarcity [19], prompting a subsequent reduction of the buffer zones to 50–100 m and 25–55 m inland from the coastline in the Eastern and Southern provinces, respectively. Twenty years have passed since the 2004 IOT; the communities appear to have recovered from the tsunami disaster. Currently, infrastructure has largely been re-built, particularly in the Eastern province, and it became one of the fastest growing regions in the country in terms of population and economic activities after the end of the civil war in Sri Lanka in May 2009 [18].

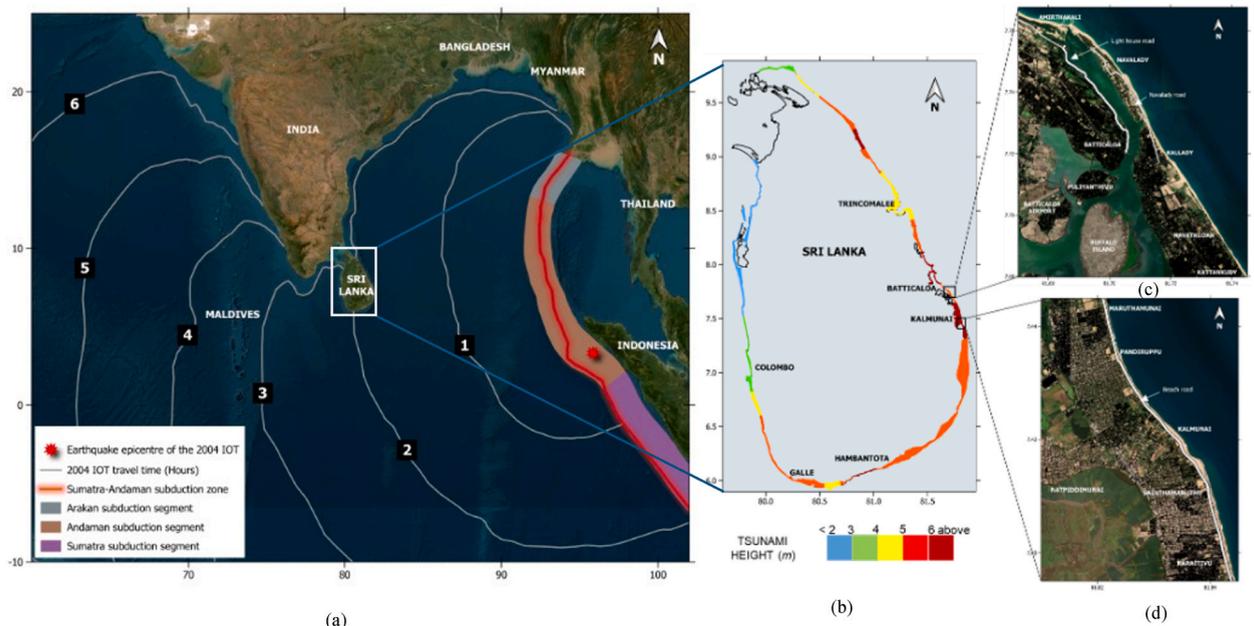


Fig. 1. (a) Sri Lanka and potential sources of tsunami [11] (b) affected districts in Sri Lanka due to the 2004 IOT [12] (c) Kalumani municipality and (d) Batticaloa municipality.

Sri Lanka remains exposed to tsunamis generated from far Eastern Indian ocean subduction zones (Sunda–trench, Andaman–Myanmar (Arakan), Northern Sumatra–Andaman, Southern Sumatra); and the Makran subduction zone (north western Indian ocean). Although an early warning protocol is in place both regionally and nationally, the country’s overall tsunami exposure has not changed [20,21]; in fact, it may have increased due to population growth along the coastal regions. From the perspectives of long-term recovery towards sustainable and resilient communities, the levels of exposure, vulnerability, and preparedness to future tsunami hazards should be monitored systematically, enabling better spatial planning and disaster risk management.

A recovery mission was conducted in December 2024, coinciding with the twentieth anniversary of the 2004 IOT, focusing on the Eastern Province of Sri Lanka. This paper reports observations from this mission and investigates the long-term characteristics of recovery twenty years after the 2004 IOT and the present levels of exposure and preparedness in Eastern coastal regions of Sri Lanka. Two major municipalities in the Eastern province, Ampara and Batticaloa as shown in Fig. 1(c) and (d) were selected for this study, since they were the most affected during the 2004 IOT. The impact of the 2004 IOT in these municipalities are discussed in Section 2. In Section 3, the characteristics of recovery observed during the recovery mission carried out are outlined. The preparedness measures put in place at these regional levels have been assessed and described in Section 4 and the current level of tsunami exposure to these municipalities have been evaluated. Finally, the challenges identified in short and medium term recovery studies have been appraised from the perspective of their effect on long term recovery and impending gaps in preparedness are highlighted, not only against tsunami risk, but also against multi-hazards.

2. Initial impacts due to 2004 IOT

The 9.3 Mw 2004 Boxing Day earthquake in northern Sumatra, Indonesia was the second largest earthquake ever recorded in history (after the 1960 9.5 Mw earthquake in Chile) [22,23]. This earthquake triggered a tsunami that affected fourteen countries in the Indian Ocean. Sri Lanka incurred the second highest amount of losses (after Indonesia) among the affected countries. The first tsunami wave arrived approximately one and half hours after the earthquake, around 8:45 a.m. local time, to the Eastern coast of Sri Lanka. As per the survey conducted by the Geological Survey & Mines Bureau, of Sri Lanka, the maximum inundation extent reported along the Eastern coast varied between 500 m and 2 km, while the maximum inundation depth ranged from 1.5 to 6 m [24].

The two municipalities investigated in this study are shown in Fig. 1(c) and (d): (1) Kalmunai Municipality in Ampara district and (2) Batticaloa Municipality in Batticaloa district. These two municipalities were selected in this study as they are the most populated regions along the Eastern coastal stretch, and the highest number of human and physical losses during the 2004 IOT were reported from this region. Their selection also helps represent the broader regional impacts experienced across the Eastern Province. The coastal front of Kalmunai Municipality is approximately 10 km long and 12 km long in Batticaloa Municipality. These two strips of coastlines (as marked in Fig. 1(b) and (c)) also include key critical infrastructure and commercial hubs that contribute significantly to the GRP of the Eastern province; hence their exposure, vulnerability and preparedness for disasters are critical for the overall resilience of the region.

Table 1 summarises the loss and damage characteristics in these two municipalities. The present and past population levels are also presented in Table 1. The death tolls reported in these two municipalities (including the missing) are about 30 % of the total deaths reported in the country due to the 2004 IOT; indicating that they bore the brunt of the event. The houses reported as partially damaged were in reality, beyond repair and were rebuilt. Where possible they were relocated away from the proximity of the coastal stretch - more details on these aspects are provided in Section 3. It is notable that populations in both municipalities have increased since 2004, suggesting that their exposure and vulnerability to future tsunamis may have also increased. The population increase in Kalmunai municipality was 5.3 % (from 2001 to 2010) and 16.5 % (from 2011 to 2022). In Batticaloa municipality, between 2001 and 2010, the population has grown by 20.5 %, but only by 3.3 % between 2011 and 2022. Comparatively lower increase in population between 2001 and 2012 in Kalumani may be attributed to losses incurred during the 2004 IOT, while the lower growth in Batticaloa between 2010 and 2021 may relate to migration - though this aspect is not explicitly investigated in this study. In both municipalities, the affected communities have been relocated within the municipality boundaries, but further inland (details in Section 3) [25,26].

3. Long-term recovery characteristics observed

A recovery mission was conducted (in December 2024) in these two municipalities, coinciding with the twentieth anniversary of the 2004 IOT, to identify long-term recovery characteristics and assess the current level of tsunami exposure and vulnerability. The

Table 1
Losses and damages occurred during 2004 IOT and present population [25,26].

Description	Kalmunai town	Batticaloa town
Number of deaths + missing	8571	3430
Number of injuries	651	942
Number of people displaced	17,272	53,400
Full damaged housing units	7886	5132
Partially damaged housing units	1850	932
Population in 2001	94,579	78,509
Population in 2010 (↑ %)	99,634 (↑ 5.3 %)	94,609 (↑ 20.5 %)
Population in 2022 (↑ %)	116,030 (↑ 16.5 %)	97,773 (↑ 3.3 %)

mission was led by a research team from the Department of Civil Engineering, South Eastern University of Sri Lanka, with the support of researchers from the Sri Lanka Institute of Information Technology, The Delft University of Technology, Netherlands and Imperial College London, UK. The characteristics of relocation/resettlements/new settlements and critical infrastructures that exist now in these regions and their status prior to 2004 IOT are documented herein. The levels of preparedness in terms of early warning systems, spatial planning, and evacuation routes and procedures also have been appraised. The data used for the discussion and analyses in paper have been taken from various sources, particularly reports available in those municipalities and Urban Development Authority (UDA) offices; and from land usage maps - such details and corresponding references are given in the respective sections below. No specific interviews were conducted during the recovery study mission; rather relevant municipal and UDA officials were approached to gather data (e.g. population and town planning details). Also the first three authors of this paper are residents of these municipalities, and have seen and been involved in the tsunami resettlement and reconstruction efforts. Therefore the long-term recovery aspects of this study were assessed based on observational, qualitative and case-study bases in these municipalities, rather than on more quantitative and index-based approaches for specific aspects of recovery as reported in the literature [27–29]; which could be a limitation of this study. Since broader aspects of recovery (social and ecological, in addition to infrastructure) were covered in this mission, such quantitative measures were not our focus. During the study mission, photographic evidence was obtained (of the present status) focusing on key infrastructure recovery in these municipalities; and compared with photographs taken in the aftermath of the 2004 IOT in Figs. 2 and 3. The third and sixth authors of the paper had captured such pictures of devastation after the 2004 IOT.

3.1. Kalmunai Municipality

The coastal front of the Kalmunai municipality spans approximately 10 km, with a road parallel to the coast (called Beach Road) running along its length. This road is considered to be the second busiest road in the town, and serves as a by-pass road to the A4 national highway, which passes through the municipality center. The proximity of this Beach Road (with developments on the landward side) to the coast line varies between 40 m and 120 m. Local fishing related activities (boat docking yard, retail and wholesale) are located along this road. These are typically housed in temporary, make-shift structures. Fig. 2(a) show a bridge that devastated in 2004 IOT along the beach road, now being reconstructed. Residential buildings are located further inland from this road up to the A4 highway. The 2004 IOT completely destroyed the residential establishments along this coastal stretch, as most constructed of single storey masonry buildings (see Fig. 2(b)). The high number of casualties and physical losses reported in this region can be attributed to the washing away of such single storey masonry buildings, and the relatively high population density (~3500 per km²) [25]. After twenty years, most of the reconstructed residential buildings in this area are made of two to three storey high reinforced concrete frames infilled with masonry walls (see Fig. 2(b)). Single-storey structures are now rare. Further details on the spatial planning of this municipality are given in Section 4.3.

The adoption of reinforced concrete buildings (of two to three storeys) emerged partially due to the new construction practices emphasized after the 2004 IOT that recommending reinforced concrete skeletons in residential dwellings [30,31]. Additionally, population growth, necessitating vertical expansion due to limited buildable land within the municipality promoted the use of taller



Fig. 2. Current stage of the coastal region of Kalmunai municipality, twenty years after 2004 IOT (pictures by authors).

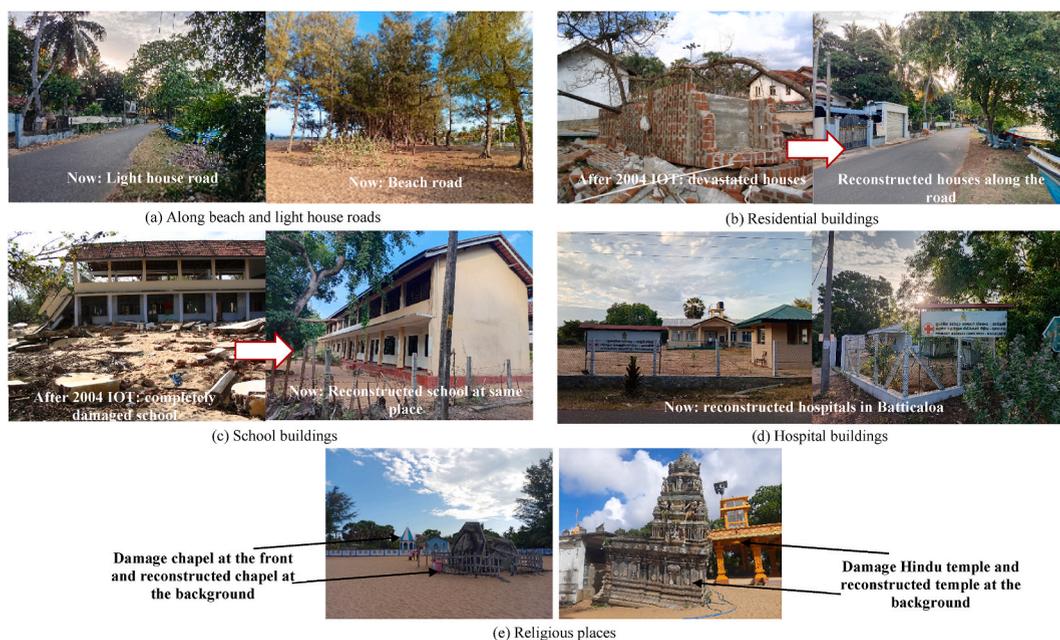


Fig. 3. Current stage of the coastal region of Batticaloa municipality, twenty years after 2004 IOT (pictures by authors).

buildings. It is noteworthy that the residents who lived in the affected zones were relocated further inland, in a purpose-built settlement called the Bolivarian Village, located approximately 1.25 km from the coast. This village now accommodates approximately 5300 residents and is incorporated into the municipality. In subsequent years, many communities returned to previously affected regions reoccupying these places. This was often motivated by family expansion, livelihood continuation (mainly fishing), and cultural ties to ancestral lands [32]. Today a significant proportion of residents in these zones are youth born after 2004 IOT and newcomers with no direct experience of the 2004 IOT.

Some critical infrastructure are located along the coastal stretch of the Kalmunai municipality. Eleven schools are located in the demarcated tsunami hazard zone - more details about the hazard zonation are discussed in Section 4.4. All of these schools were fully or partially damaged in the 2004 IOT and were rebuilt between 2006 and 2010 at the same locations, as per the Tsunami Education Rehabilitation Monitor (TERM) report [33]. Fig. 2(c) shows a school that was completely devastated during 2004 IOT and being rebuilt at the same place. The exposure of these schools to tsunamis has not changed significantly from 2004, as they remain at the same location as they were during the 2004 IOT. Most of these school buildings were earlier constructed with single storey masonry walls. The reconstructed schools in this region are now predominantly two-to three-storey reinforced concrete buildings (see Fig. 2(c)), a configuration that has demonstrated slightly better resistance to collapse under tsunami loads [31]. More details on the affected schools in these regions (and in Batticaloa) can be found in Cels et al. [34].

A district hospital (in Sainthamaruthu) located just 100 m from the coast along Beach Road prior to the tsunami, was completely destroyed (see Fig. 2(d)). It has since been rebuilt inland, about 1.1 km away, along the A4 highway. Several religious buildings (mosques and Hindu temples) located along the coast sustained only non-structural damages and were not relocated. These structures remain in their original locations (see Fig. 2(e)). While this structural survival is notable, it may inadvertently contribute to a false sense of protection among some religious believers, particularly in the absence of technical understanding of risk. Similar patterns of belief-driven risk perception have been observed in other tsunami-prone regions such as in Banda Aceh and Makran coasts, where the perceived divine safeguarding of religious sites influenced evacuation behavior and disaster preparedness [35].

3.2. Batticaloa town

The coastal geography of Batticaloa Municipality is more complex than along Kalmunai (see Fig. 1(b)), since it is entwined with a lagoon, lagoon mouth, coastal line and land mass. The entire Batticaloa municipality is therefore not directly exposed to the coast. The coastal stretch spans approximately 12 km, segmented by the lagoon mouth. Two municipal roads run close to the coast — Navalady Road and Lighthouse Road. Navalady Road lies 60–100 m from the shoreline (see Fig. 1(b)), while Lighthouse Road is set further back (300–900 m), separated from the coast by the lagoon. Most of the losses reported in the Batticaloa municipality during the 2004 IOT were attributed to settlements and infrastructure between these two roads. Fig. 3(a) shows the damaged Navalady Road in post-2004 IOT, and now being reconstructed.

Residential infrastructure was the predominant construction that existed (in 2004) and still exist in these regions, with the livelihood of these communities dependent on fishing and related trade activities. Similar to Kalmunai, the single storey residential buildings were partially or completely damaged during the 2004 IOT. Interestingly, significant portions of residential buildings that

now exist in these regions are also comprised of single storey buildings (see Fig. 3(b)). Unlike Kalmunai, the persistence of low-rise structures here can be attributed to lower population density and greater land availability. Similar to Kalmunai, during post-IOT, communities affected were also relocated. The “Swiss Village” — established approximately 2.2 km inland with support from the Swiss Red Cross and Swiss Solidarity — now accommodates approximately 3500 residents. The communities in this relocation village are originally from the Navalady region, whereas the communities on the Lighthouse Road have remained at the same place, as they incurred comparatively less physical and human losses than the Navalady community.

Three schools were located in the tsunami affected regions in this municipality, one of them was completely devastated (see Fig. 3 (c)) and other two partially damaged in the 2004 IOT; however they were reconstructed/rehabilitated at the same location, between 2006 and 2009, as per the TERM report [33]. Two hospitals are situated (see Fig. 3(d)) in the hazard zone, one having been partially damaged during the 2004 IOT, and other recently established (in 2019). Several religious sites (churches and Hindu temples) were also destroyed and have since been rebuilt at the same locations. Interestingly, remnants of some damaged religious buildings have been preserved as monuments commemorating the 2004 disaster (see Fig. 3(e)). Coastal vegetation is noticeably more abundant in Batticaloa compared to Kalmunai. Following the tsunami, ecological rehabilitation efforts were implemented, including the planting of mangroves along lagoon edges and Casuarina tree plantation along the coast [36]. These serve both ecological and protective functions. More details of ecological rehabilitations carried out in Batticaloa municipality are covered in Section 5.3.

4. Preparedness

Prior to the 2004 IOT, there was no early warning system in the Indian Ocean. Countries in the region were unprepared, and consequently suffered heavy losses. People in the region were also unfamiliar with tsunami behavior, and many succumbed to the inundation after they ran towards the sea to look at the retreating water-unaware it was a precursor to incoming waves. An early warning system is now in place in the Indian Ocean region i.e. through the Indian Ocean Tsunami Warning System (IOTWS) enabling timely alerts to countries like Sri Lanka [37,38]. Given Sri Lanka’s distance from potential tsunami-generating earthquake zones, it typically has sufficient time to issue warnings and evacuate, unlike countries affected by near-source tsunami. Estimated tsunami arrival times to Sri Lanka from different sources such as the Sunda Subduction Zone (comprising Andaman-Myanmar (Arakan), Northern Sumatra-Andaman and Southern Sumatra) and the Makran Subduction Zone, are of the order of 130–160, 95, 160–170, and 280 min, respectively. Therefore preparedness against future tsunami scenarios have been contemplated in these municipalities, given that early warning protocols and systems have been put in place at the national and regions levels, and horizontal evacuation routes demarcated for evacuating communities within the estimated tsunami arrival times.

4.1. Early warning systems

Both the Department of Meteorology and DMC receive the imminent tsunami warning from the IOTWS, but it is the DMC that is responsible for planning, operating and coordinating tsunami early warning dissemination to last mile and evacuations within Sri

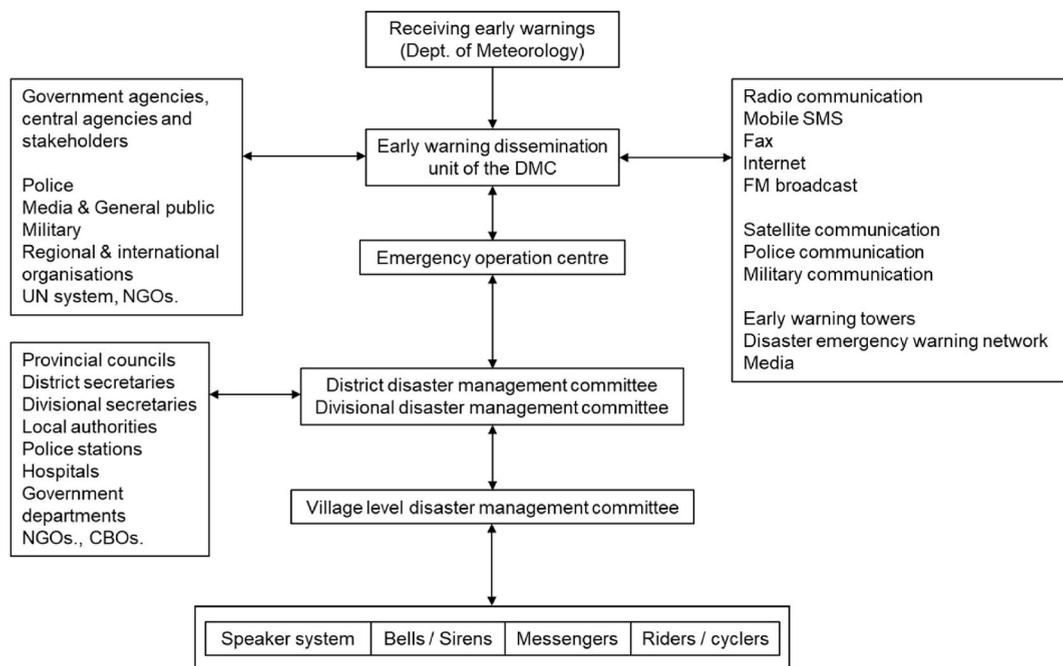


Fig. 4. Disaster early warning protocol put in place in Sri Lanka [39].

Lanka. The channel of early warning communication is from the DMC to district/divisional/local-authority/Grama Niladhari (GN) division (GN division is the lowest administrative level in the state governance hierarchy) as illustrated in Fig. 4. Parallel organizations such as the media, police and military will also be contacted, to facilitate the warning dissemination and evacuation procedures. At the local level, the warning will be channeled to the communities through government officials (available in each divisional secretariat), village leaders, and local police. There are district level DMC offices situated in the Ampara and Batticaloa districts, where both local authorities - Kalmuani and Batticaloa municipalities belong. Further, Divisional Level Disaster Management Committees have been

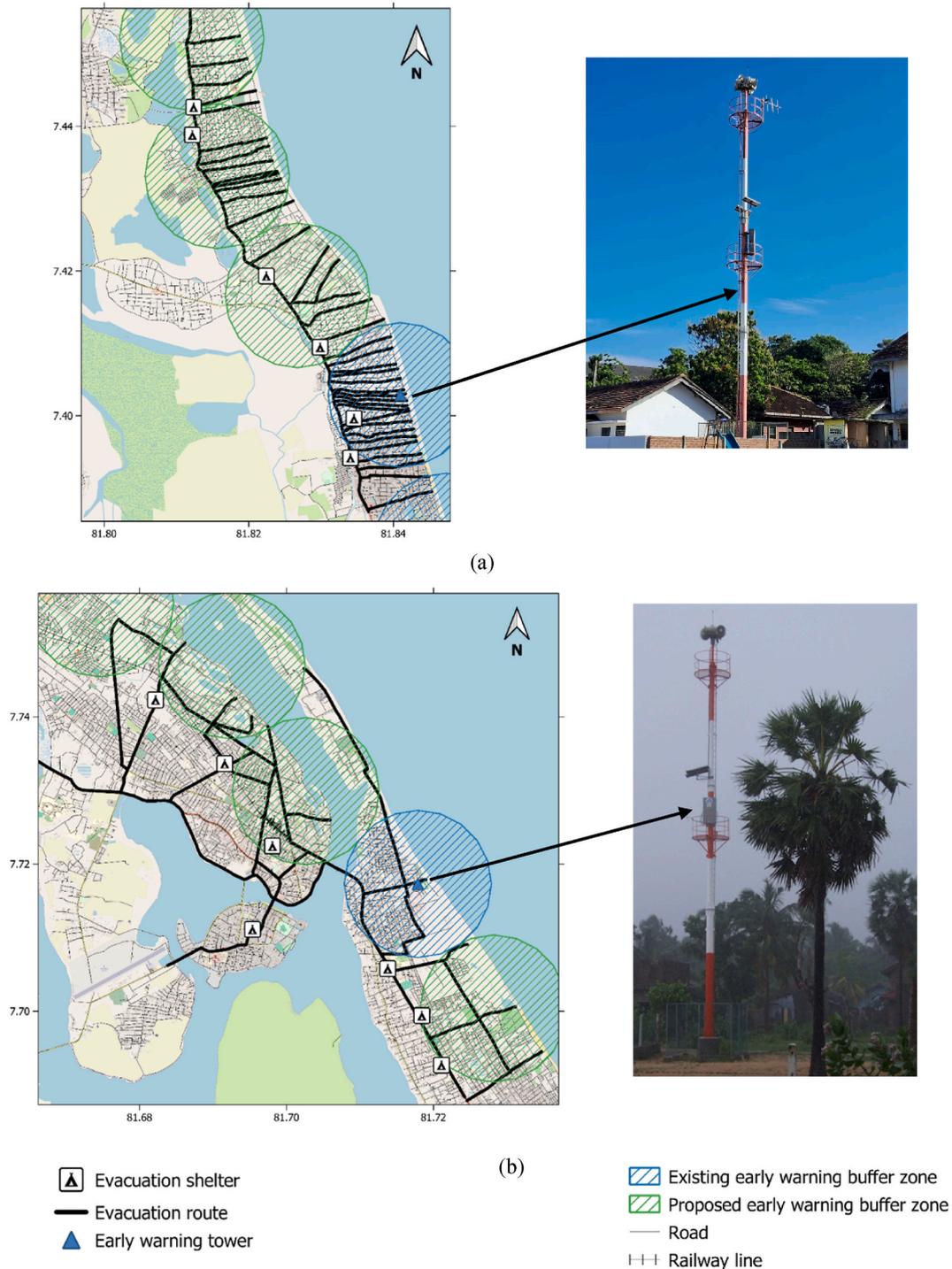


Fig. 5. Tsunami warning towers located in these municipalities and evacuation routes (a) Kalmunai and (b) Batticaloa [25,26].

formed in each of the Divisional Secretariats to coordinate disaster management activities at the ground level; hence it could be presumed that the early warning protocols would effectively be communicated to the communities at-risk.

The Intergovernmental Coordination Group (ICG) and IOTWS regularly conduct “end-to-end” tsunami warning exercises in the region, testing systems from detection to evacuation. Based on such an exercise in Trincomalee, it is estimated that the issuance of tsunami alerts takes approximately 40+ minutes, and the issuance of evacuation orders takes an additional 10+ minutes, leaving about 45 min of effective evacuation time in most areas. This may slightly differ in Kalmunai and Batticaloa municipalities and should be verified through future localized exercises, as these two places are more vulnerable than Trincomalee. While 45 min may seem sufficient in theory, actual evacuation behavior is shaped by psychological, spatial, and social factors — not just by distance alone. Individuals often engage in “milling” behaviors before evacuating, such as collecting information, gathering family members, or preparing belongings, which can delay movement, Also micro-scale vulnerabilities like narrow roads and physical obstructions can also significantly hinder pedestrian flow [40,41]. Hence systematic studies are recommended on the evacuation procedures put in place for these municipalities. Recently, Sarkawi et al. [42] explored lessons learned from the 2004 IOT, including the improved understanding of the characteristics of the Sumatran subduction zone associated earthquake and tsunami hazards, and contemplated possible early warning mechanisms that should be put in place in the region. It was recommended to explore ways of increasing the reliability of tsunami detection and speed of communication by using Global Navigation Satellite Systems (GNSS) in the region; thus Sri Lanka could also benefit from such early warnings.

Tsunami early warning towers play an important role in providing warning sirens for tsunami evacuation. There are 77 early warning towers that have been erected along the Sri Lankan coast since 2009 (twelve of them in the Batticaloa and Ampara districts). Only one early warning tower is located as indicated in Fig. 5, in each of these municipalities. These towers have an audible range of just over 1 km in radius, this range depends also on the climatic condition and the surrounding noise levels. They are directly linked to the DMC head office in Colombo (the capital city) and the district level DMC offices can operate them manually in case of signal failure. Given that these municipalities host dense populations, critical infrastructure and commercial hubs, the presence of just one early warning tower appears insufficient (the coastal stretch of these municipalities is about 10–12 km). Potential locations to install at least two more towers per municipality are indicated in Fig. 5. These locations are suggested based on the present population densities (when the density of municipality sub-divisions are higher than 1000 per km²) and the demarcated evacuation routes (as they are along the evacuation path). However, a more detailed feasibility study is needed to determine the optimal number of towers for multi-hazard early warning coverage. Nonetheless, these towers can also be dual-purposed for cyclone alerts, especially between November and January when the Bay of Bengal is active.

In addition to the tsunami early warning towers that provide a first level warning to communities for evacuation, the public addressing systems in religious places play an important role in disseminating detail disaster related messages. Hence, such locations and networks that have access to public addressing systems need to be mapped, that can help disaster management stakeholders to coordinate evacuation, rescue and relief operations. It should be highlighted that religious places were the coordination centers during the 2004 IOT relief operation for almost a year in addition to public schools. Currently, a number of public halls have also been demarcated as evacuation centers in addition to schools which continue to serve as the main evacuation and assembly point.



Fig. 6. Evacuation signboards and routes in these municipalities.

4.2. Evacuation procedures and drills conducted

The other aspect of tsunami preparedness is the demarcation of evacuation routes and centers. The evacuation signboards noted in these two municipalities are shown in Fig. 6. The signboards pointing out these routes are posted on the sides of the road in the Kalumani municipality, but no such signboards were found in the Batticaloa municipality during field visit. Based on the topography and existing road networks, the evacuation direction in the Kalumani municipality is from the Beach Road to the A4 highway (about 1.2–2 km from the coast) through the by-roads connecting them; and later further inland away from the A4 highway. The evacuation centers established in the Kalumani municipality are marked in Fig. 5(a). However road network designated for evaluation in Kalumani municipality, single track/one-lane roads (see Fig. 6), hence their mass evacuation capacity in the event of disaster evacuation through these roads need to be assessed systemically.

In the Batticaloa municipality, particularly the Navalady peninsular region is bounded by the lagoon and coast, communities have only one choice of road to evacuate inland. The road network in the Lighthouse Road region is similar to the Kalumani municipality, hence evacuees are expected to move through by-roads connecting to the A15 highway as indicated in Fig. 5(b). Though such evacuation routes are available, consultations with the officials, verification of available documents, and literature revealed that no systematic studies have been conducted (in both municipalities) on the effectiveness of these evacuation procedures. There are inter-dependent factors that influence the evacuation of people, such as capacity of the roads, density of the population, behavioral patterns of the people, and mode of evacuation (although it is on foot that people are expected to evaluate) [43]. A systematic, multi-criteria evaluation is recommended to assess and improve evacuation procedures in these municipalities. Such studies have been conducted in other countries, e.g. those by McCaughey et al. [44], Takabatake et al. [45] and Leon et al. [46], in Indonesia (Banda Aceh), Japan (Kamakura) and Chile (four coastal areas), respectively. It must be said that community preparedness has been emphasized over the past twenty years through nationwide tsunami awareness programmes. Unlike in 2004, the awareness of tsunami among the communities living in these municipalities are relatively high [47]. Further, tsunami warnings and evacuation of coastal communities were carried out on March 28, 2005 and September 12, 2007 due to potential tsunami threat, however later lifted as no tsunami occurred. However, their understanding of specific evacuation procedures remains unclear and under-assessed.

Discussions with DMC officials revealed that tsunami evaluation drills have been conducted in these regions, but only targeting schools. This has been further substantiated in a specific study on the tsunami preparedness of schools in Sri Lanka [19]. However, even these drills are sporadic, the latest drill conducted in selected schools in the Batticaloa district having been in 2015 and 2018 in Ampara [19]. The baseline tsunami preparedness is hence arguably low in terms of participation in evaluation drills. The tsunami risk perception among officials has also dropped down in their list of priorities (perhaps due to competing other priorities for risk reduction such as floods which is a frequent event to handle every monsoon season), and hence preparedness measures against tsunamis have received limited funds. With new settlers and younger generations born after 2004 now residing in these areas, ongoing education on tsunami and multi-hazard preparedness (including cyclones and floods) is essential.

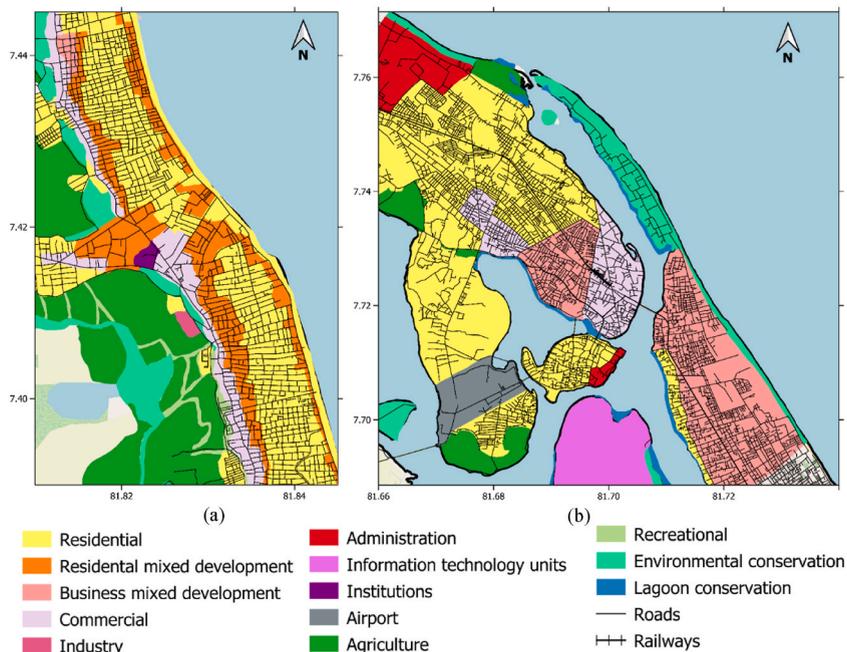


Fig. 7. Town planning of the two municipalities: (a) Kalmunai and (b) Batticaloa [25,26].

4.3. Town planning and building regulations

Since these municipalities that have been severely affected during the 2004 IOT are still exposed to tsunami risk, the spatial town planning prepared after 2004 should have incorporated all potential disaster risks including tsunami risk. During the recovery mission, documents related to spatial town planning of these two municipalities have been appraised from the perspective of tsunami risk [25, 26]. Spatial town planning of municipalities in Sri Lanka falls under the purview of the Urban Development Authority (UDA); and regional divisions of UDA are directed to develop the spatial infrastructure planning and regulate, authorise and monitor developments within the demarcated regions in collaboration with municipal councils. The recovery mission team was directed to refer the 2030 development plan published in 2014 by the UDA for these two municipalities. Fig. 7 shows the spatial town plans made in 2014 for implementation till 2030. It was noted that the tsunami risk has been mentioned and taken in to account when developing the plans. In the Batticaloa municipality, the high tsunami hazard zones have been declared as environmental conservation zones (beyond Navalady and the lighthouse region), as marked in Fig. 7(a). In alignment with the spatial planning, much fewer settlements were noted in this area during the recovery mission, and the current population density in this region is less than 100 per km². However, while areas leading to this environmental conservation zones are also demarcated as high hazard zones, they have been earmarked for development into fisheries and tourism hubs in the Batticaloa municipality; and residential houses were also noted during the recovery mission. It is understandable that entire hazard zones cannot be excluded for developments; however proper infrastructure regulations and preparedness measures must at least be put in place considering the tsunami risk.

In Kalmunai municipality, the coastal segment that is under high tsunami hazard is demarcated as residential, commercial and recreational zones in the spatial planning (see Fig. 7(b)). Limitation in the availability of land and high population density (~4565 per km²) have been noted along the entire coastal stretch; and this would have compelled the authorities to plan infrastructure development even in this high tsunami hazard zone. As mentioned earlier, it is highly desirable that the development regulations are properly enforced in this region to minimise the tsunami risk to infrastructure. Also, the effectiveness of early warning system and evacuation plans should be verified in practice to minimise potential human losses.

4.4. Exposure and vulnerability to tsunami risk

The present level of exposure, vulnerability and potential losses for tsunami risk that could be expected based on the demarcated hazard levels have been evaluated in this section. The DMC has demarcated tsunami hazard zones for coastal regions into three levels, namely (1) high, (2) medium and (3) low. The high hazard levels are defined by expected tsunami inundation depths of more than 2 m, and the medium and low levels as the depths between 0.5 and 2 m and less than 0.5 m, respectively [12]. The tsunami hazard maps for Sri Lanka can be obtained from the DMC website (<https://www.dmc.gov.lk/images/hazard/hazard/Tsunami.html>). The spatial land usage features (for both municipalities), extracted from Google satellite imagery, were analysed using Arc GIS [48] to develop the land usage maps and their spatial distribution. Fig. 8(a) and (b) show the developments in Kalmunai and Batticaloa municipalities, respectively. The tsunami hazard zones were overlapped on to the spatial land usage maps in order to quantify the exposure and vulnerability of the infrastructures situated in those hazard zones. Table 2 gives the areas of spatial land usages in these two

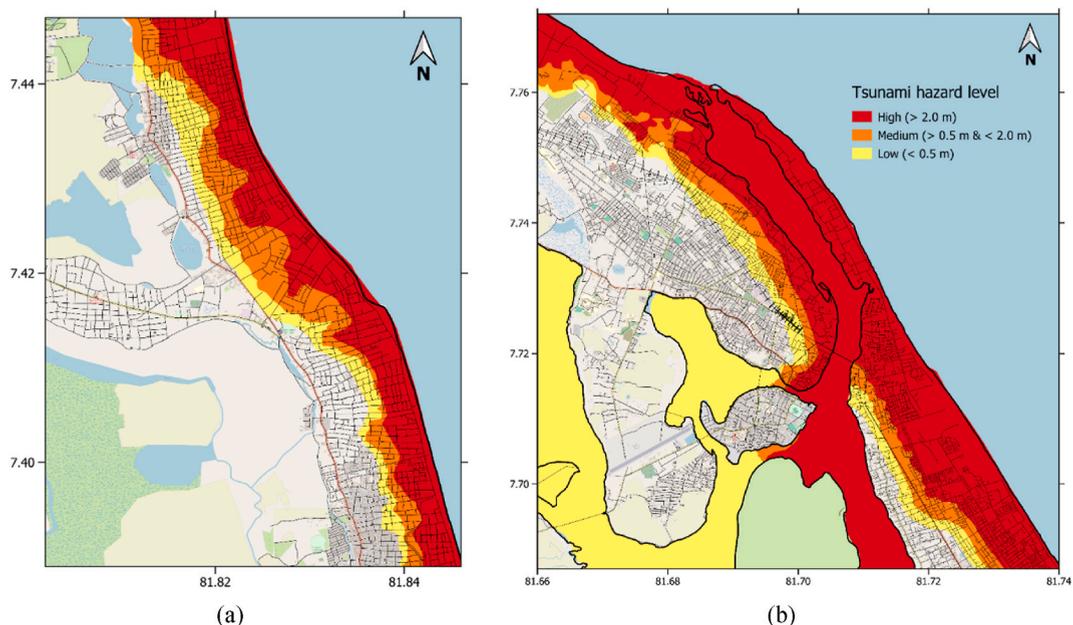


Fig. 8. Tsunami exposure and vulnerability maps of (a) Kalmunai and (b) Batticaloa municipalities [25,26].

municipalities. It can be noted that residential developments are significantly exposed to tsunami hazards in both these municipalities. It is such development that dominates most of the hazard zone areas where the Kalmunai municipality is concerned, while the lagoon in Batticaloa municipality covers the largest extent of such zones, thus limiting the exposure of physical infrastructures to tsunami and coastal hazards. Commercial development is fairly low in these demarcated zones, being mainly related to fishing related commercial centers and community grocery shops/boutique type restaurants. Both these municipalities have similar sizes of farmland areas (mainly coconut estates) exposed, but Batticaloa possess many more parks and vegetation. It should be noted that the Batticaloa airport is close to, but not within the low hazard region. Future studies could weight each of the categories in Table 2 (e.g. with vulnerabilities of residential and commercial areas weighted higher than those of vegetation and water bodies); and also the exposure in terms of inundation levels (high, medium, low). Physical risk for each parcel of land can be arrived at by factoring the weighted category and weighted exposure, as in Ref. [27]. Even without doing so, our analysis indicates that municipalities in coastal 'strips' (e.g. Kalmunai, with most residential areas at high inundation) will be at higher risk than those dominated by water bodies (e.g. Batticaloa, with mainly such water bodies at high inundation). At any rate, our studies focused not only on such physical aspects, but also on social and ecological ones.

It has to be mentioned that the Tsunami hazard maps were developed in 2006 using the technologies available at that time considering national level elevation maps, hence they may not accurately reflect the local topographical nuances and exposure-specificities of these municipalities. Tsunami sciences have advanced over the time and different Probabilistic Tsunami Hazard Assessment (PTHA) method are being suggested to develop hazard maps [49,50]. Thus the tsunami hazard maps in Sri Lanka should be updated with state of the art techniques available.

5. Reflections on challenges for recovery

The tsunami recovery study mission has revealed the long-term recovery characteristics of infrastructures after twenty years and their levels of exposure and vulnerability within the demarcated hazard zones in these two municipalities. The social, cultural, demographical and ecological characteristics have also influenced the recovery of these regions over these years. The recovery of any impactful disaster can be characterised into short, medium and long term stages. The short-term recovery from a disaster is mainly related to addressing the emergency needs of affected communities and restoring the disrupted functional links. The medium-term recovery efforts involve the methodical coordination of reconstructing infrastructure and the rehabilitation of affected communities. The long-term recovery must focus on bringing back complete normalcy in the affected communities, but in ways that prevent or mitigate risks from future disasters [51,52].

While the rebuilding process was taking place in the country, several parallel studies have been conducted over the twenty years to monitor the recovery (short and medium-term) and have highlighted some pressing issues and challenges from the perspective of "building back better" from the 2004 IOT. Those issues and challenges have been reviewed herein, along with the observations made and data collected in this recovery mission, in order to ascertain how they have been addressed and met in long-term recovery. Some of the past studies conducted on monitoring the recovery process from the 2004 IOT are summarised in Table 3 in terms of infrastructure, social and ecological recoveries reported. It can be noted that not all the studies conducted in the past have focused on all the recovery characteristics (infrastructure, social and ecological); hence an attempt has been made here to appraise those studies and report both the holistic recovery that has occurred and the challenges that still persist in order to become a community/region that is resilient to tsunami risks.

5.1. Long-term infrastructure recovery

In the early days after the 2004 IOT, the issues related to infrastructure have been (1) finding of suitable places for temporary shelters, (2) exploring sites and getting regulatory approval for permanent relocation, and (3) delays and disparities in funds allocated for reconstruction/relocation. After the past twenty years, these issues have been addressed to an acceptable level. There could have been disparities, but it could not be explicitly verified during the mission; and the affected communities have been given housing

Table 2
Spatial land usage areas in Kalmunai and Batticaloa municipalities

Category	Batticaloa (km ²)			Kalmunai (km ²)		
	High	Medium	Low	High	Medium	Low
Residential	0.31	0.01	0.01	0.78	0.43	0.33
Commercial	0.01	0.01	0.01	0.01	0.0	0
Public	0.03	0.01	0.01	0.02	0.0	0.003
Farmland	0.02	0.03	0.05	0.08	0.01	0
Parks	0.17	0	0	0.03	0.0	0
Cemetery	0.05	0	0.01	0.08	0.0	0
Roads	0.94	0.36	0.29	0.60	0.35	0.23
Vegetation, and forest	0.39	0.72	0.2	0.14	0.06	0.05
military	0	0.0	0	0.02	0.0	0
drainage, scrub	0.01	0.03	0.04	0.0	0.0	0
Water bodies	6.16	0	0	0.03	0.06	0

Table 3
Summary of short and medium term recovery studies conducted on the impact of 2004 IOT in Sri Lanka

Reference	Year	Infrastructure recovery	Social recovery	Ecological recovery
Khazai et al., [53]	2005–2006	<ul style="list-style-type: none"> • Sustainable reconstruction practices have been highlighted • Multi-storey buildings or single storey buildings with stability elements are suggested 	<ul style="list-style-type: none"> • Meeting the needs of livelihoods of affected people, especially the fishing communities 	<ul style="list-style-type: none"> • Restoration of coastal vegetation and features (sand dunes and estuaries) are recommended
Godavitarne et al., [54]	2005–2006	<ul style="list-style-type: none"> • Issues in securing lands for relocation of affected communities were highlighted • Concerns in the temporary shelters, and facilities provided were suggested to be improved 	<ul style="list-style-type: none"> • Meeting the needs of livelihoods of affected people, especially the fishing communities • Education to the affected children, and their loss of materials are underscored 	–
Wachtendorf et al., [70]	2005–2006	–	<ul style="list-style-type: none"> • Inequities in the disaster relief distribution was highlighted • Vulnerabilities of children, woman and aged at the temporary shelters were stressed 	–
Ruwanpura [71]	2005–2006	<ul style="list-style-type: none"> • Issues in securing land deeds for affected communities was highlighted 	<ul style="list-style-type: none"> • Inequities in the disaster relief distribution was highlighted 	–
Ingram et al. [59]	2005–2006	<ul style="list-style-type: none"> • Issues of ad-hoc rapid reconstruction of houses without long-term plans have been highlighted 	–	–
Ratnasooriya et al. [17]	2006–2007	<ul style="list-style-type: none"> • Lack of inclusivity among all stakeholders, and, confusion triggered by the revision of the buffer zone were highlighted as the challenges 	<ul style="list-style-type: none"> • Prioritizing income generating options such self-employed and small scale businesses were emphasized 	–
Brikmann and Fernando [61]	2006–2007	<ul style="list-style-type: none"> • Disparities in actual damage cost of houses and relief provided were underlined 	<ul style="list-style-type: none"> • Lack of knowledge among the communities regarding future tsunami risk and mitigation measures to be taken were pointed out 	–
Keraminiyage et al. [72]	2007–2008	<ul style="list-style-type: none"> • Shortage of construction workers and high cost of construction materials have been highlighted for delays in reconstruction. 	–	–
Boano et al. [59]	2008–2009	–	<ul style="list-style-type: none"> • Lack of participation of local communities in housing intervention was highlighted 	–
Mulligan et al., [73]	2008–2012	<ul style="list-style-type: none"> • People centered reconstruction of housing was suggested • Complains of house designed not complied to the expectations of the communities 	<ul style="list-style-type: none"> • Inequities in allowing reconstruction activities between residential and commercial (especially tourism properties) were mentioned 	–
Suppasri et al. [14]	2014–2015	<ul style="list-style-type: none"> • Challenges regarding developing urban development considering the tsunami risk were discussed. 	–	–
Hettige and Haigh [62]	2015–2016	–	<ul style="list-style-type: none"> • Difficulties of the relocated communities regarding their loss or changes in livelihoods and inequities between host communities are highlighted 	–
Jayatissa et al. [74]	2015–2016	–	–	<ul style="list-style-type: none"> • Mangrove reforestation and other suitable coastal plants and vegetation are recommended
Rathnayake et al. [75]	2018–2019	<ul style="list-style-type: none"> • Lack of facilities in available evacuation center demarcated were mentioned 	<ul style="list-style-type: none"> • Lack of awareness among the communities regarding the early warning and evacuation routes were underscored 	–

(either at the same location or another) in the medium-term.

Khazai et al., [53] and Godavitarne et al. [54] assessed reconstruction efforts following the 2004 IOT in Sri Lanka. Both highlighted that the multi-storey buildings with reinforced concrete frames mostly survived the tsunami (at least with no collapse). They therefore recommended to building back infrastructure in demarcated tsunami hazard zones using this construction type. Building construction guidelines issued by the Society of Structural Engineers Sri Lanka (SSESL) and the National Building Research Organisation (NBRO) to facilitate reconstruction using multi-storey reinforced concrete frame buildings. As the cost of building reinforced concrete frame buildings can be prohibitive in some areas of Sri Lanka, other guidelines have been developed that promote reconstruction of residential housing using single storey masonry buildings, equipped with reinforced concrete stability elements [55]. The recommended construction form for single storey housing is shown in Fig. 9.

Rebuilt residential dwellings in particular are not engineered buildings. Since the 2004 IOT, design standards for tsunami resistant buildings have been updated, like those in America (ASCE 7–16 [57]) and Japan (i.e. Act on the Promotion of Tsunami Countermeasures [58]), and they could be considered. It is recommended that these be referred in assessing the tsunami resistance of rebuilt houses, and in particular the effectiveness of construction detailing recommendation made in the Sri Lankan guidelines. While the cost of constructing a residential building to fully resist the high tsunami inundation depths that could be expected in the east coast is likely prohibitive, some degree of resilience can be achieved, and it is particularly cost effective if the designs can also cater for other hazards (like cyclone, and floods). Hence, it is recommended that the guidelines be revised, not only in terms of improving tsunami resilience, but also considering multi-hazard scenarios, thus that future losses to all relevant hazards can be reduced appreciably.

5.2. Long-term social recovery

The main challenges in the short-term social recovery after 2004 IOT have been (1) providing immediate and subsequent daily relief to the affected communities, (2) addressing the livelihood issues, (3) counseling the communities for trauma and (4) resolving the disparities and inequities in resettlement/relocation for the affected communities. The phenomenon of fishing communities being displaced while hotels rebuilt and expanded in coastal areas have been highlighted by Ingram et al. [59] and Boano [60]; but this was not a major issue in the municipal areas that we studied. In long-term perspective, these issues raised directly due to the 2004 IOT have to an extent been addressed and the communities seemed to have settled at the same or relocated places and have returned to a “normal” state of life. They appear to have taken up their previous livelihood or adjusted according to the relocated regions - more details on these aspects can be found in studies conducted specifically on the livelihood recovery of affected communities by Brikmann and Fernando [61] and Hettige and Haigh [62]. However consultations with community members, it was gleaned that issues related to livelihood and available social facilities still persist in different forms. From the discussion, this is not perceived to be explicitly due to the 2004 IOT, but rather derived from the current economic situation in the country and inherent social inequalities.

To ensure long term social recovery, the awareness and preparedness of communities regarding tsunami risks have to be appraised and updated. While tsunami awareness sessions and drills have been conducted in the past, they have mostly targeted school children, and seem to be sporadic [19]. It is very important that tsunami risks, associated early warning systems and evacuation strategies are continually highlighted to the communities living in the hazard regions, especially since the new generation of residents has arisen over the last twenty years and that new families who are settling in these regions. Educating the communities living in such zones that their infrastructures (including their houses) should be built with tsunami resistant design is necessary for long-term recovery and to build up a disaster resilient society [63,64], as many communities opted to return to the same locations in which they were affected. This also includes the installation of appropriate tsunami risk signboards and clear demarcation of evacuation routes in the tsunami prone area. Further, municipal authorities need to include a condition for tsunami-resistant design when approving building plans in the tsunami-risk areas. McCaughey et al. [65] found that in Banda Aceh, Indonesia, the tsunami survivors had contrasting preferences to return or relocate; and a housing policy that offered housing aid only in the tsunami-affected area resulted in socio-economic

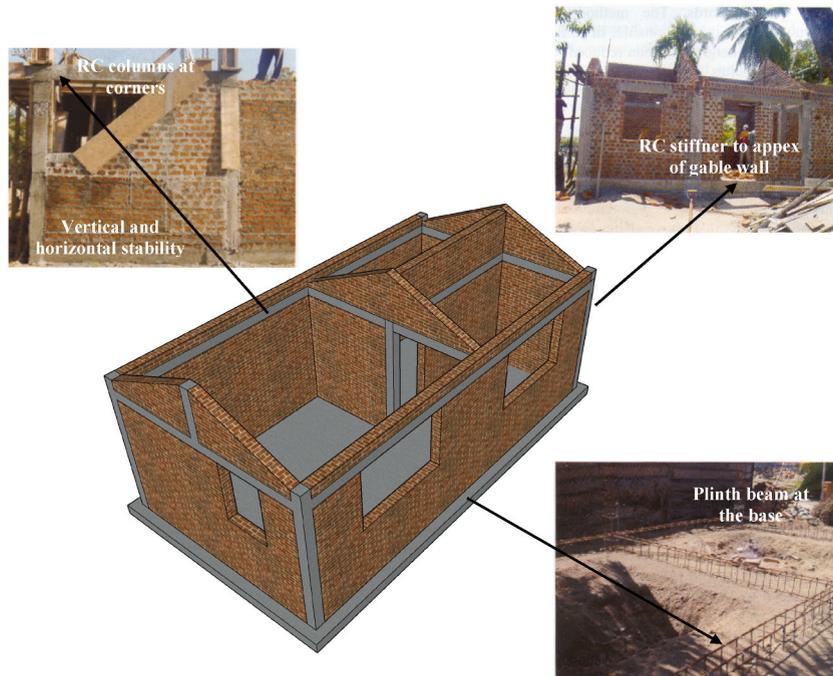


Fig. 9. Building forms emphasized in the tsunami hazard zones [56].

segregation, where only households with greater resources were able to relocate further inland. Thus when preparing for community preparedness schemes, the resources have to be allocated according to their specific needs.

5.3. Long-term ecological recovery

It should be noted in passing that ecological recovery has received the least amount of attention in previous studies, as reflected in Table 3. Nevertheless, the importance of having coastal ecological systems such as coral reefs, sand dunes, estuaries and mangroves has been emphasized in the past [57]. Observations made after the 2004 IOT, highlighted that the areas barriered with sand dunes and mangroves have suffered somewhat less damages [66]. Though the level of actual protection that these coastal features would provide against tsunami waves are not well substantiated through engineering assessments. They would certainly contribute towards long-term recovery of the eco-system itself in the impacted areas, and also mitigate the less impactful but more frequent coastal hazards (like storm surges). Developing ecological barriers are recommended after the 2004 IOT in Sri Lanka [67]. During the recovery mission in the Batticaloa municipality, it was noted that some regions in high hazard zones have been declared as environmental protected areas

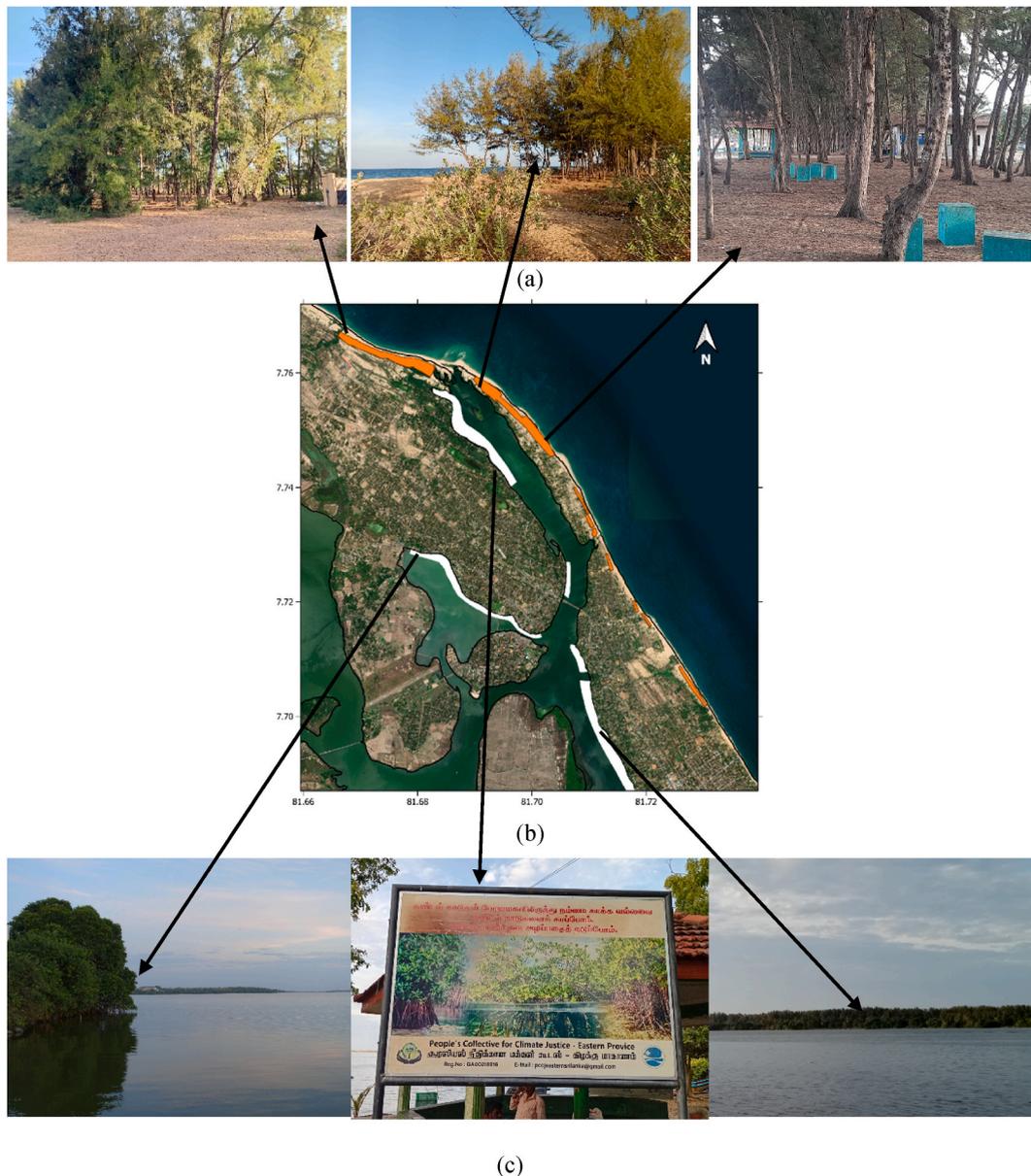


Fig. 10. Restoring coastal ecological system in the affected regions (a) Casuarina plantation, (b) location of ecological developments and (c) Mangrove plantations.

(see Fig. 7(a)), where plantation of mangroves (on the edges of lagoon) and Casuarina plants have been established. Apart from the ecological restoration and admittedly unassessed barrier effects of such plantations, they also preclude human settlement in high risk zones. Under the above scheme, about 400ha of Casuarina plants have been planted along the coast of Batticaloa district since the 2004 IOT, and 50–70ha within the municipality limits (see Fig. 10(a)) by the Forest Department and “Mandru”, which is a NGO. The density of the Casuarina plantation is 1600–3000 plants/ha [68]. Also, mangroves have been planted along the edges of lagoon (see Fig. 10(c)). Such ecological barriers were not noted in the Kalmunai municipality other than few coconut trees in few locations. This could be due to the limited land availability and proximity of development to the coast.

These developments highlight that ecological sustainability and resilience aspects have been considered in the recovery process over the years in these regions. However, there seems to be further potential for ecological development against coastal hazards, particularly in the Batticaloa municipality as it is surrounded by lagoon. A recent study by Villagra et al. [69], exploring the resilience of coastal communities in Chile exposed to tsunamis along the southern Pacific coast, highlighted the fact that places surrounded by agricultural and plantation lands had greater potential for quicker recovery and adaptation.

5.4. Contextual challenges and opportunities

The differing geographical contexts of Kalmunai and Batticaloa municipalities, and the observations made on their recovery make it possible to consider the effects of place-specific contextual attributes on tsunami recovery. Kalmunai is essentially a strip of land just under 1 km between the coast and the A4 highway. The proximity to the coast affords commercial opportunities and has resulted in a high population density in this area. This includes returnees from the relocation village (Boliverian Village) back into this area. This has not allowed the demarcation of areas very close to the coast for vegetation or conservation. However, it has necessitated the construction of multi-storey reinforced concrete buildings to replace the tsunami devastated single storey masonry ones, thus automatically increasing physical resilience. In addition, the ‘strip’ configuration and high street density permits multiple paths for evacuation.

Batticaloa on the other hand is spread over a much larger area to around 3 km from the shore, and features a lagoon. The population density is much lower, and the relocation village (Swiss Village) has in fact been absorbed into the municipality. The reconstructed buildings are single storey masonry, albeit stiffened in the reconstruction with reinforced concrete elements. These are not as tsunami resilient as multi-storey reinforced concrete buildings (as in Kalmunai). The tortuosity of the land mass (due to intertwining with the lagoon) has resulted in evacuation paths being long and devoid of alternatives. However, the availability of land has allowed new planning regulations to declare many areas as conservation zones, resulting in much lower population especially in areas that have long and singular evacuation routes – e.g. the Navalady peninsula. The above comparison demonstrates that differing contexts bring both challenges and opportunities, both of which appear to have been judiciously handled (whether by design or default) in the two municipalities under consideration. The recovery experience in these two types of municipalities (one a ‘coastal strip’ and the other dominated by a water body) can serve as exemplars for what can be expected in other contexts and countries too.

6. Summary and conclusions

Twenty years have passed since the 2004 IOT. Although many studies have been conducted on the impact of the 2004 IOT, only a limited number of studies have explored the long-term recovery trajectory, particularly the recovery and resilience characteristics of the Eastern province which was the most severely affected province during the 2004 IOT. To help address this gap, a recovery mission was undertaken to assess the long-term recovery of two key municipalities, namely Kalmunai and Batticaloa, where a significant portion of the losses were concentrated. This study assessed the reconstruction and relocation of infrastructure, and evaluated social and ecological recovery, alongside a review of interrelated spatial development planning, current exposure, and vulnerability levels within the demarcated tsunami hazard zones in both municipalities.

In terms of infrastructure recovery, residential buildings constructed in the form of low-rise multi-storey reinforced concrete buildings, and single storey masonry buildings with reinforced concrete stiffeners have generally emerged. Although these building forms have been observed and perceived to perform better against tsunamis, they have not been explicitly designed against tsunami loading, but rather have only improved construction details. Therefore, while such constructions will sustain damage or collapse in a subsequent tsunami, the level of tsunami resistance achieved through these improved construction details should be verified using international design standards available for tsunami resistant design of buildings. This will allow for better decision making with regard to evacuation and post-disaster shelter in future tsunami.

The short and medium terms challenges reported on the social recovery process have been addressed to some degree. However issues related to livelihood and socio-economic facilities available for communities still persist, due not only to the tsunami impact, but also to the current economic situation and inherent social inequities in the country. The awareness of tsunami risk is high among the communities; however information related to early warning dissemination methods and evacuation procedures should be regularly updated, as new residents have settled in these regions in the last twenty years. These municipalities are susceptible to multiple hazards such as floods and cyclone too; hence better preparedness at the community level would enable better multi-disaster responses during such events as well. Further, restoring the ecological system along the coastal stretch has been recognised as a natural reduction barrier for storm surge and tsunamis (especially in Batticaloa); however they could be further improved and extended for holistic environmental conservation in these regions.

Sri Lanka is prone only to far source tsunamis, and now an early warning protocol is in place in the Indian Ocean region. Therefore, the long-term resilience in Sri Lankan coastal regions has to be looked at from the perspective of effective dissemination of early

warning messages and mass evacuation once the tsunami warning is issued. From these viewpoints, significant efforts have been made over these years in the country to have national level early warning protocol, dissemination methods and evacuation procedures. However, there is more room for improvement as stated in this study. Regular “end-to-end” tsunami warning mock drills in different regions, considering their demographic and geographic characteristics, are recommended. Lessons can be learnt from other locations that are prone to tsunamis such as Indonesia, Japan, Chile and Hawaii. The tsunami resistant capacity of the buildings (residential, commercial and public) have been improved, but better regulations could be brought in to design and construct buildings (along the coastal region) with an appropriate degree of tsunami resistance. Addressing these aspects would not only improve resilience against tsunamis, but also help to mitigate the risks associated with other metrological hazards (e.g. floods and cyclones) in these regions.

To support more informed, evidence-based, and cost-effective tsunami mitigation and evacuation planning, policymakers should prioritize the development of localized, high-resolution hazard assessment, such as Probabilistic Tsunami Hazard Assessments (PTHAs). These hazard assessments should be paired with behaviorally-informed evacuation planning, incorporating insights from social science on risk perception, community behavior under stress, and pre-evacuation delays. Furthermore, policies should promote multi-use infrastructure, such as early warning towers that can serve tsunami, cyclone, and flood alerts, and incremental upgrades to housing with cost-effective tsunami-resistant features, guided by context-sensitive building codes. Community engagement must go beyond awareness campaigns according to multi-dimensional recovery planning. Integrating participatory drills, community mapping, and inclusive planning processes can significantly improve the practical effectiveness of disaster mitigation strategies while ensuring buy-in from diverse population groups.

Finally, our comparative study (concerning physical, social and ecological recovery) of the two municipalities that have two different land mass features provides an opportunity to ascertain inter-sector interactions; and is a contribution that can inform other contexts elsewhere in the world too. A ‘coastal strip’ such as Amparai district will have many employment opportunities and help social recovery, but the very attraction of the population towards it will increase physical exposure to coastal hazards. This will be mitigated somewhat by construction that will be relatively more resilient to lateral loads from tsunamis and storm surges, since the multi-storey buildings required for the increased population density are inherently stronger than single storey ones. On the other hand, a ‘spread’ municipality dominated by a water body such as Batticaloa district, will not only have better potential for ecological recovery (due to the availability of both land and water), but also have reduced physical vulnerability due to the protection afforded by such ecological features. Evacuation paths will be more straightforward in coastal strips. On the other hand, they will be more tortuous in spread municipalities with water bodies. However, the edges of the municipality that are away from the coast may not even need evacuation, and could be used for locations to house evacuees from the shore itself.

CRediT authorship contribution statement

Julian Thamboo: Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Renee Josiah:** Writing – original draft, Investigation, Data curation. **Aslam Saja:** Writing – original draft, Investigation, Funding acquisition. **Parastoo Salah:** Writing – review & editing, Conceptualization. **Tiziana Rossetto:** Writing – review & editing, Conceptualization. **Priyan Dias:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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