RP Current Trends In Agriculture And Environmental Sciences
Vol. 4, No. 1 (January – March 2025) pp. 8–24
e-ISSN: 2583-6293

Cite this article: A. Sangwan, Climate change and marine pollution in Southern India: Consequences for politics and practices related to coastal management, *RP Cur. Tr. Agri. Env. Sci.* **4** (2025) 8–24.

Review Article

Climate change and marine pollution in Southern India: Consequences for politics and practices related to coastal zone management

Anita Sangwan*
Department Physics, G.S.S.S., Neemli, Charkhi Dadri – 127306, Haryana, India
*Corresponding author, E-mail: sangwananita.098@gmail.com

ARTICLE HISTORY
Received: 12 Nov. 2024
Revised: 17 March 2025
Accepted: 19 March 2025
Published online: 20 March 2025

KEYWORDS
Consequences of synergy; Plastic waste and climate change; Climate resilience; Management of coastal zones; Indian Ocean; Gulf of Mannar; Reserve on the Malabar Coast.

ABSTRACT
Marine litter and climate change are closely related, and their interactions take on diverse forms based on the biological and environmental factors as well as other human activities. The numerous products and services that coastal and marine ecosystems offer are in danger due to the detrimental effects that arise from those synergistic interactions. This is especially prevalent in the Indian subcontinent's coastline region. India is already suffering greatly from the effects of climate change, and these effects are only expected to get worse. Meanwhile, the nation is engulfed in a litter problem that is overwhelming communities and authorities and impeding the nation's efforts to achieve sustainable growth. Communities and the coastal environment in Tamil Nadu and Kerala, two southern states, are especially susceptible to the effects of climate change. The magnitude and seriousness of these problems are growing even though these state governments and authorities are working harder to manage their coastal areas better. Here, we examine the joint impacts of marine litter pollution and climate change in Southern India, with a particular emphasis on the Malabar Coast in Kerala and the Gulf of Mannar Reserve in Tamil Nadu. Lastly, we go over practical management solutions that might enhance sustainability and resilience.

1. Introduction

Depending on local biological and environmental traits as well as other human activities, the synergistic interactions between climate change and marine litter differ across oceanic regions. The ensuing widespread effects endanger the many goods and services that coastal and marine ecosystems provide as well as their ability to function [1, 2]. Furthermore, these interactions pose a hazard to essential earth system functions, possibly on a global level [3]. It is opportune and feasible to take action using frameworks for climate resilience, for example, even though there are still significant knowledge gaps and research should go on [4–6].Marine litter is becoming more widely acknowledged as a threat multiplier that, when combined with other stressors like climate change, can cause far more harm. For instance, increased storminess brought on by climate change may result in more litter entering the marine environment, which further erodes the ability of habitats and species to withstand climate change [1, 2].The majority (59%) of published studies on the prevention and control of plastic waste seem to focus on microplastics that are already present in the aquatic environment [7], rather than focusing on solutions at the source and ignoring the role of climate change in modulating marine litter pathways. Microplastics, which are defined as plastic particles ≤5 mm, are the subject of increasing attention due to their presence in the human food chain and their potential to act as vectors for chemical contaminants. The coastal zone is crucial because it offers numerous and significant ecological services [8], but because it is exposed to the frontline, the coastal boundary is especially vulnerable to climate change. Coastal waters are subject to growing loads of nutrients, pollutants, and litter from point and non-point sources, in addition to the effects of sea level rise and extreme weather [9]. Global coastal zones are undergoing some significant changes as a result of the combined effects of pollution and climate change [8], with the Indian subcontinent being particularly affected. India is already dealing with the serious effects of climate change, which are expected to get worse unless current greenhouse gas emissions are reduced. The nation is also dealing with a growing problem of marine litter pollution, which is overwhelming communities and authorities and impeding the country's efforts to achieve sustainable development. About 170 million people reside along India's coastline, where they are subject to destructive heavy rains, floods, erosion, droughts, heat waves, and destructive tropical storms and cyclones due to a changing climate [10]. The floods in Chennai, Tamil Nadu, in December 2015 [13], Mumbai, Maharashtra, in July 2005 [11], Kerala, in August 2018 [12], Odisha, in May 2021 [14], and Chennai again in November 2021 are recent examples. Climate change is making droughts and heat waves more severe and frequent [15], which causes massive trash accumulations in arid riverbeds that might cause even more devastating debris flows from floods when it rains [16]. According to models, India's monsoon rainfall will keep rising as global mean temperatures climb [17]. Of all ocean basins, the North Indian Ocean receives some of the largest inflows of plastic garbage, and the issue of marine litter is engulfing the nations along the coast, including India [18]. A significant source of marine litter is the Indian monsoon, with plastics from the rim countries accounting for 96% of the total [19].India itself is one of the world's main sources of plastic marine litter, generated principally from the ship-breaking industry (in addition to a variety of other scrap materials like metals and rubber), followed by fishing and coastal recreational activities, combined with inadequate waste disposal practices and littering behaviour [20]. India has been designated the world's 12th highest provider of unmanaged trash [21]. Less than half of the estimated 150 thousand tonnes of solid trash produced daily gets recycled, and around a third is left unaccounted for and probably dumped into the environment. When extrapolated, these figures indicate that almost 9 million tons of plastic garbage are produced annually, with nearly 4 million tonnes going uncollected [22].India is predicted to rank fifth in terms of trash supply by 2025 as a result of this issue getting worse [23]. Once in the environment, wind action will also help move a large portion of the litter to the sea through waterways [24]. Uncollected waste in India is likely to end up in the Arabian Sea and Bay of Bengal, either directly or through riverine systems like the Meghna-Brahmaputra-Ganges river system, which is the sixth most polluted river system in the world and is thought to release about 73,000 t of plastic waste annually into the Bay of Bengal in the North Indian Ocean [23]. Chennai, the state's coastal capital, is expected to have a population of over 11 million by 2023. Apart from the difficulties caused by dense and fast population growth, coastal populations in both states are particularly vulnerable to the effects of marine trash and climate change, which endangers their means of subsistence and essential ecosystem services [25].State governments are making more efforts to better manage their coastal and marine areas [25], but considering the population and geographic scope of the risks, the magnitude and severity of these two challenges taken together are overwhelming. Given the significance of the marine resources and ecological services provided by the Malabar Coast and the Gulf of Mannar, we present here a review of the published literature on the combined effects of climate change and marine litter in Southern India, with a particular focus on the coastal states of Tamil Nadu and Kerala. This review's objective is to:

(i) assess the consequences for coastal management;
(ii) better comprehend the particular effects on the south-western and southeast coasts; and
(iii) make suggestions for efficient management techniques to improve the resilience of the coastal zone.

2. Materials and methods

After Smithers, the rapid evidence evaluation approach was modified to do a literature review [26]. Secondary searches yielded more bibliographic references, while the writers included those they knew about. The North Indian Ocean served as the review's geographic backdrop, with particular attention paid to Southern India, the coastal states of Tamil Nadu and Kerala, and the Malabar Coast and the Gulf of Mannar, two significant maritime regions, respectively (Figure 1).

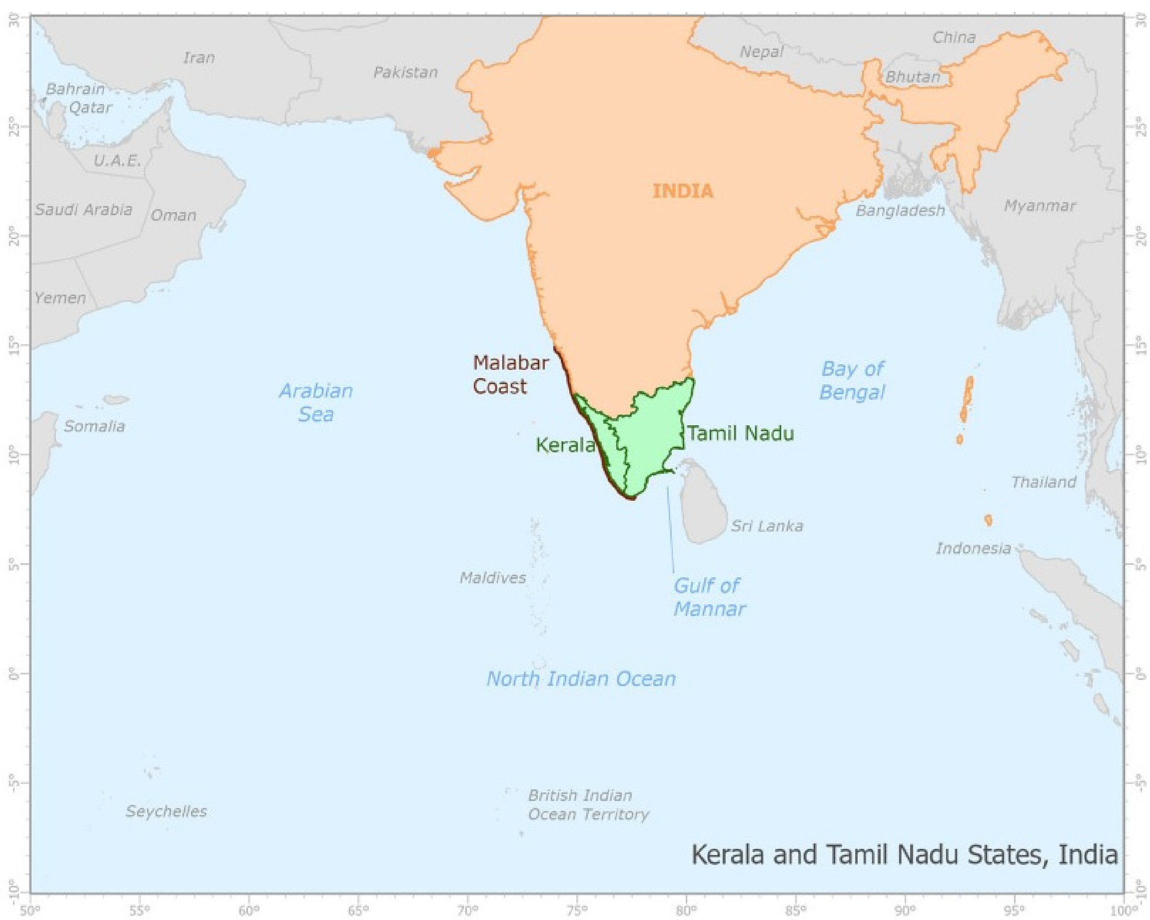

Figure 1: Map of the Indian subcontinent (top panel, a) displaying the Malabar Coast, the Gulf of Mannar, the southern coastal states of Tamil Nadu and Kerala, and the surrounding area of the North Indian Ocean.

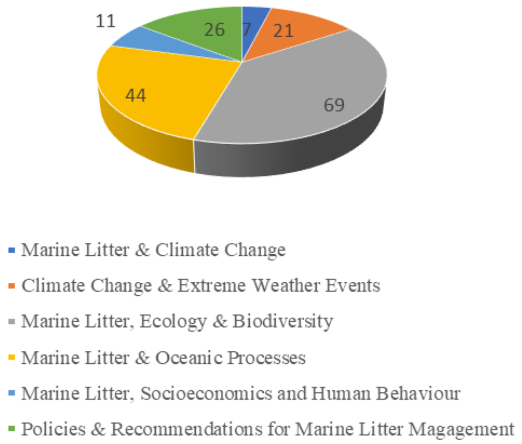

Figure 2: Results of the bibliographic searches and the quantity of articles that were found for each of the indicated topics.

3. Results

During the literature searches, 178 articles and reports were located; 150 of these addressed different facets of marine litter and were broadly categorized into the following areas: impacts on biodiversity and ecology, the role of oceanic processes, human and socioeconomic implications, and information on policy and recommendations (Figure 2). Just seven articles explicitly addressed the interplay between these two global emergencies, while only 21 articles were found to be related to climate change, the majority of which dealt with extreme weather events, some of which included a link or application in relation to marine litter issues (Figure 2). The results for Southeastern and Southwestern India are then summarized, with particular attention paid to the coastal states of Tamil Nadu and Kerala, as well as the maritime regions of the Malabar Coast and the Gulf of Mannar.

3.1 Consequences of pollution and marine climate change on a global scale

Two of the biggest threats to the world's ocean and coastal ecosystems right now are pollution and climate change, and their combined effects may be more detrimental than either stressor alone [27]. Complex and contingent on environmental features, as well as the particular stressors and receptors involved, are the synergistic relationships between marine pollution and climate change [28]. Figure 3 illustrates a few common synergistic effects. Warming ocean temperatures can increase the bioavailability of mercury, which can have detrimental effects on the health and survival of marine organisms [29]. At the same time, the toxicity of metals like copper and lead varies with pH, which may increase the cumulative risk of ocean acidification for certain organisms [30]. These examples illustrate how the relationship between climate change and marine pollution varies with environmental conditions. An additional illustration is how ocean acidification affects trace metal bioavailability [31] and directly decalcifies [32, 33]. Extreme weather, changes in land use brought on by climate change, and variations in rainfall can all increase runoff and nutrient fluxes into coastal areas, leading to eutrophication and oxygen depletion [8].

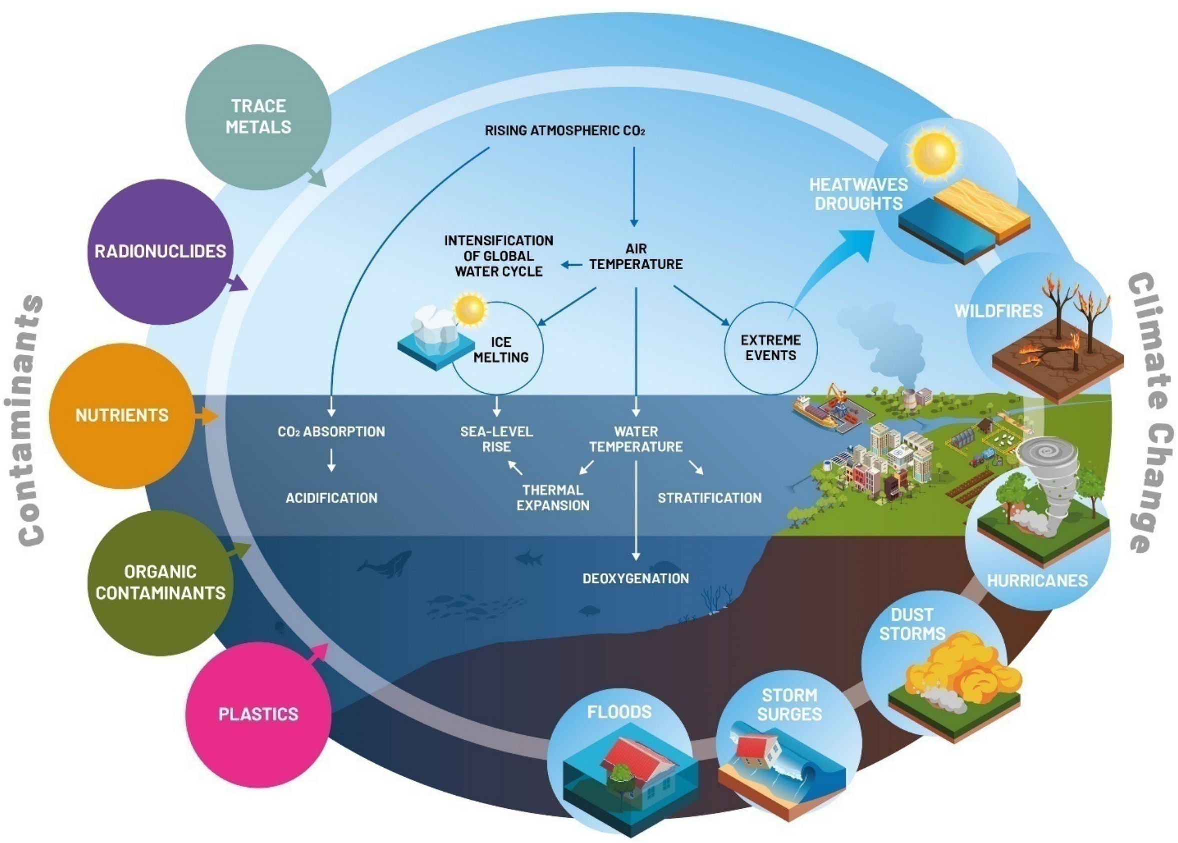

Figure 3: Illustration of common ways that marine pollution and climate change interact to worsen negative impacts on marine and coastal ecosystems.

3.1.1 Litter routes and ocean circulation

Significant amounts of plastic debris from the global ocean enter the North Indian Ocean [18], however it is yet unknown what happens to buoyant plastic litter once it adrift [34]. Subtropical gyres cannot form in the North Indian Ocean because the Asian continent borders the Arabian Sea and the Bay of Bengal. Compared to the Pacific, where garbage patches are found, there is little indication that they are present in the Indian Ocean basin [34]. Models indicate that the majority of drifting litter is eventually deposited on the coastlines and beaches of rim countries. In the North Indian Ocean, winds and currents move floating debris back and forth between the Arabian Sea and the Bay of Bengal as their direction changes with the seasonal monsoons [18]. Litter travels from the Arabian Gulf eastward through the Indian subcontinent and into the Bay of Bengal during the August southwest monsoon, while the opposite path is taken during the February northeast monsoon [18]. With an average of 0.34 ± 0.80 items per m^2, the Bay of Bengal has one of the highest levels of microplastic pollution in the world's oceans, which may be explained by this cyclical reversal combined with the ongoing and growing land-based litter imports [35]. Because the amount of litter that comes ashore rises after the southwestern monsoon, the Bay of Bengal's coastlines are most affected by litter between September and November [36].While the eastern coast's longshore currents are comparatively moderate during the northeast monsoon and spring inter-monsoon (March–May), they are stronger during the southwest monsoon and travel from west to east [37]. Plastics are more likely to become stuck in the Palk Strait due to the weak currents and subsurface barrier effect; their fate will be determined by their buoyancy, the tidal and coastal currents, and the kind of coastal ecosystem they come across [37].The Gulf of Kachchh (also called the Gulf of Kutch, Cutch, or Kachh), the Gulf of Khambhat and the Lakshadweep Islands in the Arabian Sea, and the Gulf of Mannar and the Andaman and Nicobar Islands in the Bay of Bengal are examples of possible accumulation zones where heavier or less buoyant litter is likely to sink and accumulate on the seafloor [37]. With the help of southeast trade winds, the winter monsoon current is likely to carry buoyant debris that escapes into the South Indian Ocean south of the Bay of Bengal all the way to the Nicobar Islands, the Seychelles, and the East African coastlines and islands [38].Over the course of this century, current, wave, and wind regimes in the Indian Ocean basin will be influenced by changes in large-scale oceanic and atmospheric patterns, especially future modifications to the El Nịno-Southern Oscillation (ENSO), which drives El Nịno and La Nịna events. However, future simulations remain highly uncertain [39]. For example, notable long-term variations in the El Nịno and La Nịna phases' timing and duration may modify the kind and amount of marine litter that reaches the Indian Ocean, as well as its distribution and destiny at sea [39].

3.1.2 Inputs of litter from erosion, flooding and coastal wave action

Satellite and tidal gauge data have verified positive sea-level trends for the North Indian Ocean [40]. The North Indian Ocean's sea level is expected to rise by 1-2 mm year, which is in line with the IPCC's worldwide forecasts, albeit on the lower end [41]. Sea level increase is also significantly influenced by wave height. According to a thorough state-by-state analysis, the majority of India's coastline is seeing a notable increase in wave height [42]. In contrast to projected declines in significant wave height, the broader Indian Ocean is expected to see considerable increases in extreme waves. Wave time is another crucial factor that can alter sediment transport patterns or wave penetration into harbors because it influences crucial wave propagation processes such shoaling, refraction, and diffraction [42]. The wave period has risen by at least 20% throughout the Indian coast, indicating a larger likelihood of erosion and swell waves, especially when Southern Ocean swells are present [42]. Compared to wind waves, the rate of sediment movement caused by longshore swell waves is an order of magnitude higher [43], and this is also anticipated to be the case for solid litter. Litter deposits are carried farther from the shoreline by higher waves [44].More debris is expected to be mobilized from coastal locations into marine environments in the future due to rising sea levels, increased rainfall, higher wind speeds, stronger waves, and changes in oceanic currents brought on by climate change [45]. There are signs that this area will likely see increased wave action and coastal erosion in the future, which could raise the risk of pollution, for instance, by exposing coastal landfills to more light. Coastal erosion and increased marine litter inputs are directly linked in studies of European coastlines. For instance, Andriolo and Gonçalves [46] described how dunes serve as reservoirs for litter on both natural and urbanized beach and dune systems, which are then exhumed by storms and erosional processes and released into the ocean.According to other research, a significant source of mercury entering the marine environment may be the abrasion and mobilization of sizable sedimentary deposits brought on by climate change [47].

3.1.3 Extreme weather-induced litter mobilization

According to a study on cyclonic activity across the North Indian Ocean, the frequency, length, and severity of tropical cyclones over the Arabian Gulf increased by 52% between 2001 and 2019, while the Bay of Bengal had an 8% reduction in the same period [48]. Increases in sea surface temperature, heat potential, ocean to atmosphere heat flux, tropospheric humidity, and static energy were among the changes in regional thermodynamics that were associated with the most notable escalation of cyclonic activity in the Arabian Gulf during May–June and October [48]. Conversely, a decrease in relative humidity was associated with a decrease in cyclonic activity over the Bay of Bengal [48]. Additionally, cyclones are more prevalent during La Nịna regimes than during El Nịno regimes; with the cold temperatures imposed by La Nịna, there are more extreme tropical cyclones over the Bay of Bengal [49]. However, due to significant seasonal and inter-year variability as well as the influence of ENSO forcing, which has a significant impact on the frequency, position of genesis, and intensity of tropical cyclones during the primary cyclonic season in the Bay of Bengal, long-term trends in cyclonic activity in this region are still unclear [49]. Coastal debris is mobilized and accumulated in the Indian Ocean by storms that range from cyclones to low-pressure depressions [50, 51].While cyclonic overwash dumps more garbage onto beaches than usual, cyclone-induced extreme weather events like flash floods can increase the movement of plastic debris from land to the coast [52]. The coastal topography, the distance from rivers and cities, and the role of local human activities during non-cyclonic conditions—like fishing—may all have an impact on this, in addition to wind direction and strength, storm wave conditions, and surge conditions [50]. In conclusion, debris accumulation on beaches are expected to rise in tandem with the frequency and intensity of storms, strong winds, and waves. Globally, it is anticipated that if CO_2 concentrations in the atmosphere continue to rise, the intensity of heavy rainfall events would also increase [53]. Climate change is expected to increase the frequency of major flooding events and heavy rainfall on a global scale. Although most locations in Asia have low to medium confidence in documented patterns of heavy precipitation, statistically significant trends have been reported at the subregional level, especially for India, especially during the monsoon [54, 55]. The Indian monsoon's extreme rain occurrences exhibit a favorable tendency from 1901 to 2005, with the trend seeming to be stronger after 1950 [16].Overall, monsoon rainfall is also expected to increase, but maybe more so in the northeast of the Bay of Bengal than on India's west coast [17]. Flooding is more likely during periods of heavy rains [56]. Depending on the topography and drainage, floods can last anywhere from a few hours to several days. However, inappropriate waste disposal and buildup in sewage systems can result in obstructions, which can prolong floods and increase the risk of socioeconomic harm and health hazards [57].The potential for plastic mobilization is ten times higher during 10-year return-period flood occurrences than during non-flood conditions, according to a research of mobilized plastic potential that combined data on unmanaged plastic trash with worldwide flood maps [58]. The potential for global plastic mobilization is further increased in high-risk areas for flooding, which are nearly always found along the coast [58]. With an estimated 0.12 million metric tonnes annually under non-flood conditions, India is one of the ten countries with the highest potential for plastic mobilization. Under a 10-year return-period flood, this amount increases to 1.36 million metric tonnes annually, representing an increase factor of 11.45 [58].

3.2 Southern India's primary review results

3.2.1 Outlining the areas of attention

Because of the great significance of their marine resources and ecological services, we concentrated this assessment on the coastal states of Tamil Nadu and Kerala in Southern India, particularly the Gulf of Mannar and the Malabar Coast. The state of Tamil Nadu has a 1076-kilometer coastline along the Bay of Bengal, as seen in Figure 1 [59]. A number of rivers flow into the Bay of Bengal, including the Vaigai, Tamiraparani, and Pennar Rivers, as well as the Cauvery River, which creates Tamil Nadu's largest estuarine delta [60].With the exception of the monsoon season, these rivers are typically seasonal, meaning that their estuarine sections are primarily tidal and that their riverbeds have minimal flow and predominantly stagnant water, which allows trash to collect [61]. The rainy season, which lasts from October to December, depends on when the monsoons arrive. The state's west mountainous areas receive the majority of its 630–1900 mm of precipitation annually [62]. Three large seaports, seven captive ports, sixteen smaller ports, fishing harbors, and coastal businesses like fertilizer factories, power plants, and oil refineries are all located in Tamil Nadu. Chennai, the capital, is a significant financial and commercial center and a coastal megacity. Increased inputs of sewage and untreated wastewater are causing significant stress on the Adyar River, which flows through Chennai [61]. A biosphere reserve of worldwide importance, the Gulf of Mannar off the coast of Tamil Nadu (Figure 1) was included in the South and Central Asia Man and the Biosphere Network in 2001. It is regarded as one of the most biodiverse marine reserves in the world and is home to large coral reefs, seagrass meadows, and mangroves. The reserve is home to numerous fascinating marine species and serves as the final habitat for the acorn worm, or Balanoglossus sp., a "living fossil" that serves as the evolutionary bridge connecting vertebrates and invertebrates [63].Additionally, the Gulf of Mannar is home to 5500 km2 of commercial fishing grounds, which support the livelihoods of thousands of fishermen spread throughout more than 200 towns and account for 25% of the state's yearly fish production [64]. In addition to drawing over a million visitors a year, the reserve holds a significant position in India's history and cultural legacy [65]. Pollution from the land and overharvesting are putting pressure on the Gulf of Mannar Reserve. The coastal ecosystem of Tamil Nadu is experiencing eutrophication, dissolved oxygen depletion, and a rise in marine litter due to pollution from point and non-point activities. Important reef, seagrass, and mangrove habitats are under risk of degradation due to these pressures as well as the serious threat posed by climate change [66]. Kerala's coastline runs 580 kilometers along the Arabian Sea to the southwest. With seasonally excessive rainfall ranging from 890 to 3940 mm yearly, Kerala has a tropical monsoonal climate [67]. The temperature fluctuates between 22 and 34 °C, and the humidity is high. The southwest monsoon (June–October), the northeast monsoon (October–December), and a brief winter (January–February) follow drought conditions, which are often caused by its greatest levels during the summer months (March–May) [25]. The state is traversed by the Western Ghats mountain range, but it also has huge coastal plains and lowlands that are less than 300 meters high [25].A large portion of the state's population and economic activity are concentrated in the sandy dunes and ridges, barrier flats, alluvial plains, floodplains, river terraces, marshes, and lagoons that make up the majority of the Malabar Coast. With almost 33 million residents, Kerala boasts one of India's highest population densities, with 860 people per km^2 [25]. The manufacturing of chemicals and fertilizers, oil refineries, seafood, cashews, coir, minerals, and metals are the main industries [20]. The region's main port, Kochi (often referred to as Cochin), serves as a hub for shipping [20].The state boasts a wealth of freshwater, brackish, and marine resources, and fisheries directly support the livelihood of more than 3% of the population and make a significant economic contribution [67]. About 39,000 km^2 make up the continental shelf off the Malabar Coast, while 218,536 km^2 make up the exclusive economic zone, which includes globally recognized fishing grounds [67]. There are 113 communities inland that work on freshwater or brackish fisheries, while there are more than 200 fishing towns along the coast and nearly as many marine fish landing centers [68]. More than 300 species are found in landings, including mackerel and other pelagic species, as well as penaeid prawn, lobster, seer fish, prawn, and ribbon fish, are among the most common commercial catches [69].Over 391,600 t, or almost 77 billion rupees, were produced by Kerala's marine fishing in 2020–21 [70]. The principal source of income for Kerala's coastal fishing communities has historically been marine ecosystems, and the state's economy depends on the fisheries industry for about 1.6% of its total gross added value. Apart from fishing, the state also makes a substantial amount of money from beach and backwater tourism.

3.2.2 Climate change and marine pollution in Gilf of Mannar

Sea-level rise is speeding up coastal erosion, causing beaches to lose breadth and slope, and raising the risk of flooding, according to a coastal vulnerability study conducted in the Gulf of Mannar's Thoothukudi region. The majority of Tamil Nadu's coastline is low-lying, with sandy beaches and a few patches of rocky and muddy shoreline. It is anticipated that beach erosion along the southeast coast will continue at its current high rates, which are being made worse by unethical sand mining, urbanization, and industrialization of the coastal zone [71], all of which are contributing to the coastal area's degradation. Climate change-driven weather-related disasters are rapidly increasing in the state of Tamil Nadu in terms of the area impacted, the frequency of occurrences, and the reported losses [72]. Approximately 13,500 t of solid trash are produced daily in the state of Tamil Nadu, and 91% of this waste is disposed of in landfills. This waste primarily consists of plastics and electronic devices, along with hazardous, biomedical, and municipal materials [23]. About 4500 metric tonnes of solid trash are produced daily in Chennai, the state capital, alone. Litter frequently builds up in yards and landfills in the surrounding megacity, where it is then transferred into waterways [73].Large amounts of solid litter and other pollutants are mobilized by flooding and erosion during the periodic monsoon, especially during periods of intense rain or storms [74], especially from landfill sites or regions where there is a lot of littering. Prior evaluations in the Gulf of Mannar have revealed physicochemical parameter and microbiological indicator values above allowable limits, indicating pollution from uncontrolled industrial and urban flows. The microplastic abundance in Chennai, which comprised virgin (i.e., not yet bio-filmed) objects, tripled during post-flood periods compared to pre-flood times, according to Veerasingam et al. [52]. This shows that a significant amount of plastic was mobilized and washed out during the floods. Litter studies on the neighboring Marina Beach—the second-largest beach globally—confirmed this, showing that the daily amount of plastic debris on the shore was far less than that left over after the storm. It is confirmed that the majority of the trash entering the marine environment after flood events comes from local land-based sources because a large portion of the litter discovered on the beaches surrounding Chennai after the flood may be linked to the neighboring Cooum and Adayar Rivers. As was seen after the 2015 Chennai floods, where a significant volume of litter acted as a substrate for microbial biofilms, including dangerous fecal coliforms, litter can act as a vector for microbial dissemination once it enters the marine environment [73]. Chennai is at great danger of experiencing major floods and cyclone impacts. A study of beach debris at Silver Beach in Cuddalore conducted in November 2020, after storm Nivar made landfall, revealed that meso- and microplastics were more prevalent in post-cyclonic sediments, while macroplastics were more prevalent in pre-cyclonic sediments [50]. The majority of the large-sized things that are dumped during fishing and tourism are swept away from the beach by wind and waves during cyclones, although the area does get a considerable amount of trash from these activities [50].The majority of litter is frequently discovered to be local rather than washed up from the sea at well-known coastal locations that receive large numbers of visitors throughout the year. Then, in November 2021, Chennai had the second-most severe flood on record due to disastrous flooding brought on by more than 1000 mm of rain in a single month. Large volumes of post-flood litter accumulated along river mouths and adjacent public beaches as a result of the massive amounts of litter that were mobilized from urban and catchment areas. According to assessments of beach litter conducted between 2013 and 2014, 31 beaches in the state were classified as "clean" (1–10 g of litter per m^2), 11 as "fair" (10–20 g/m^2), and 3 as "moderate" (20–50 g/m^2). 75. The typical beach litter, according to Kaviarasan et al. [76], was consisted of 505 ± 121 micro (≤5 mm) litter particles per kg of dry sediment, 8.2 ± 5.6 items/m2 of meso (5 mm to 2.5 cm) litter, and 0.24 ± 0.14 items/m2 of macro (2.5 cm to 1 m) litter. Overall, beaches nearer cities had larger litter abundances than more isolated beaches, and the backshore of the beach had more macro litter (average 0.28 ± 0.34 items/m^2) than the intertidal area (average 0.20 ± 0.13 items/m^2) [76]. Indicating the impact of runoff during the southwest monsoon, high abundances of microplastics were also discovered along the Krishna River, the Penna River, and off Chilika Lake between June and September [77]. Due to poor waste management in densely populated regions of the mainland, microplastic pollution appears to be more severe and pervasive offshore over the coral islands in the Gulf of Mannar [78]. High-energy waves and landward winds deposited beach debris along the high tide mark at Nallathanni Island, a small, inhabited island in the Gulf of Mannar. The debris includes fishing lines, floats, and nets; textiles; plastic bags; water bottles; wrapping and packaging materials; cosmetic materials; and resin pellets. However, some lighter items were scattered farther into the island, likely carried by wind [79].On these coral islands, the distribution of microplastics is influenced by proximity to the mainland, and abundance is consistently higher in sediment samples than in water samples, indicating that the sediments serve as a sink for microplastics [78]. Microplastic pollution has been reported to be 209 ± 99 particles per kilogram of dry weight in shelf sediments and 5.3×10^4 particles per km^2 in coastal waters in the larger Bay of Bengal [77]. The most prevalent polymer kinds, polyethylene and polypropylene, are found in surface water more frequently than in sediments and are linked to packaging and single-use plastics. When evaluating the risk of microplastic pollution, it is important to take into account the fact that microplastics have the ability to adsorb chemical contaminants, such as metals or medications, and then move them up the food chain, posing an extra threat to marine life [78]. One of India's four primary coral reef regions is the Gulf of Mannar, where coral mostly grows along a chain of twenty-one uninhabited islands that stretch between Thoothukudi and Rameswaram.Due to the effects of climate change and local human pressures, these reefs are under a lot of stress and disturbance. Their loss has accelerated over the past ten years, and it has been connected to heat stress, hypoxic die-offs [64], disease outbreaks, and invasive species [80]. Significant bleaching events between 2005 and 2017 led to macroalgae proliferation under the influence of terrestrial runoff, which impedes the settlement of new coral polyps and jeopardizes reef recovery, as well as coral mortality, especially among fast-growing corals like Acropora spp. and Pocillopora spp.The Gulf of Mannar's coral communities are changing as a result, with more thermally resistant species (usually simpler, larger corals) replacing assemblages of sensitive species (usually structurally complex corals). The Gulf of Mannar's yearly risk of severe coral bleaching is predicted to rise in the future under an RCP8.5 high emissions scenario, with the easternmost reefs experiencing the commencement of the bleaching 20 years earlier than the westernmost islands [81]. On the other hand, mass coral mortality following non-toxic green tides of Noctiluca scintillans in the Indian Ocean, and specifically in the Gulf of Mannar, has been reported more frequently in recent decades [83], despite the fact that records of coral mortality due to hypoxia are uncommon worldwide [82].Following bloom decay, a massive N. scintillans green tide in 2019 caused oxygen levels to fall below 2 mg/l. This brief hypoxia led to a coral mortality rate of over 70% among Acropora spp., Montipora spp., and Pocillopora spp. corals, as well as fish and benthic crustacean, mollusc, and echinoderm die-offs [64]. Coral respiration and productivity are impacted by hypoxia [84], and because of their greater metabolic needs, fast-growing species like Acropora and Pocillopora are particularly vulnerable. Hypoxia is a worry since it enhances corals' vulnerability to disease, bleaching, and algae proliferation, making it a risk multiplier [85].Red and green tides of Noctiluca can also be an indication of water pollution and eutrophication, while recurrent, large algal blooms have been associated with climate change [86]. Because they are more likely to entangle debris, the structurally complex Acropora spp. corals that make up the Gulf of Mannar reefs are also at risk from pollution, particularly marine litter. The enormous amounts of litter from shipping, fishing, and waste disposal are putting the reefs on the islands close to Tuticorin in special danger since they are directly breaking up coral structures, increasing the risk of illness, and making the reefs more vulnerable to invasive species and bleaching.Furthermore, cyclone Ockhi, one of the strongest cyclones ever recorded in the region, struck the Lakshadweep Islands off the Malabar Coast in 2017 and caused widespread mortality and lithification, including the dislodgment of massive structures in the deeper reef sections, demonstrating that all reefs in southern India corals are vulnerable to cyclone damage [88]. A robust natural defense against the effects of cyclones is provided by healthy coastal mangrove stands.In addition to providing habitat for numerous species and stabilizing sediments and reducing erosion by acting as a buffer against waves, wind, and excess water during surges, flooding, or storms, mangroves' extensive network of above-ground roots helps the trees thrive in tidal and waterlogged conditions, safeguarding infrastructure and coastal communities. However, the entanglement and accumulation of debris are also made easier by this architectural complexity [37]. Another threat to their survival is the fact that mangrove forests around the Indian coast have been shown to be a sink for plastic [37]. Mangroves are comparatively resistant to being partially buried by trash, but an extensive buildup of plastic can produce anoxic conditions, which can cause suffocation and leaf loss in the afflicted trees [89].Furthermore, the extent of coastal mangroves in Tamil Nadu is rapidly decreasing as a result of deforestation and urbanization; between the forestry assessments conducted in 2017 and 2019, an estimated 4 km2 of mangrove cover were lost [90]. One of the busiest sea lanes in the world is the North Indian Ocean. Sensitive marine environments like Palk Bay and the Gulf of Mannar Reserve are especially vulnerable to maritime events and dangerous spills. The worst maritime catastrophe in Indian Ocean history occurred in May 2021 when the container ship X-Press Pearl sank northwest of Colombo harbor, Sri Lanka [91].An oil slick seeping from the ship, the possible release of hazardous materials, the loss of cargo and debris from the vessel, and a significant smoke plume were among the environmental issues, along with the estimated 1600 t of plastic pellets that were spilled [91]. Rescue and cleanup efforts were challenging since the catastrophe occurred during the southwest monsoon, which was characterized by strong winds, a turbulent swollen sea, and heavy rain [91]. Any spills in this area are dispersed according to the reverse monsoonal winds and currents. Large amounts of the plastic nurdles were expected to be transported south of the Sri Lankan coast, away from India, by the dominant strong monsoonal wind-driven currents, according to simulations created after the X-Press Pearl tragedy [60]. Southwest monsoon currents can reach speeds of 0.5 to 1.2 m/s over the Tamil Nadu coastline. They are mostly flowing eastward throughout Sri Lanka until they weaken, veer around the southeast coast of the country, and shift northward [60]. However, any pellets that remain afloat would drift towards India and the Tamil Nadu coastline when the post-monsoon wind and currents reverse [60].After two cargo ships collided in the Chennai area in 2017, around 196 t of leftover fuel oil leaked, causing benthic foraminifera to change morphologically and drop [92] and hydrocarbon-degrading bacteria to proliferate [93].

3.2.3 The relationship between marine pollution and climate change on Malabar Coast

Together with the seasonal inshore mudbanks and the constant upwelling, riverine influx contributes significantly to the biogeochemistry and high productivity of the waters around the Malabar Coast [94]. Three of Kerala's forty-four rivers flow east, while the others flow west into the Arabian Sea. Rich plankton communities from the estuaries, which primarily regulate the biological production along the whole west coast, are flushed out by the massive amount of runoff from the Valapattanam, Chaliyar, Periyar, Kayamkulam, Kallada, and Perumathura Rivers during the summer monsoon rains, enriching the inshore waters. The average air and sea surface temperatures in Kerala have increased by more than 0.5 ◦C during the 1960s [95].Declining catches of some pelagic fish, such as Indian oil sardines (Sardinella longiceps) and Indian mackerel (Rastrelligerkanagurta), along with an increasing trend in cephalopod landings, suggest that fish populations are likely being impacted by sea surface warming, changes in rainfall levels, and changes in the timing and intensity of the upwelling. While mackerel, which are normally found in surface and subsurface waters, are thought to be migrating deeper in search of cooler water, it has been proposed that the distribution and availability of sardines in Indian waters are changing, especially along the Malabar Coast.Sea-level rise, harsh weather, altered wind and wave patterns, rising temperatures, and decreasing oxygen levels in saltwater can all have a negative and multifaceted effect on fisheries [96]. However, these changes in fisheries species are probably not just a result of climate change; they are also likely the result of other local stressors including pollution, eutrophication, habitat degradation, overfishing, and even the expansion of non-native species. Climate change is a contributing factor due to rising temperatures and heavy rain runoff, but increasing eutrophication and pollution from changes in land use have also been blamed for an increase in the frequency and intensity of massive phytoplankton blooms and red tides along Kerala and inshore waters of India's west coast. Commercial fish species like oil sardines have been observed to be impacted by these mass blooms, which frequently lead to red tides that kill fish due to toxicity or oxygen deprivation [97]. The lives of those who directly depend on the fisheries are also impacted by these interlocking consequences, in addition to the sustainability of the fisheries. Many economically poor communities rely heavily on marine fisheries, especially on the Malabar Coast. The coastline is exposed to the effects of climate change, which exacerbates the pollution and unsanitary conditions that are common in fishing harbors, landing centers, and fish markets. Another significant seasonal characteristic in the Malabar Coast is mudbanks, or chakara as they are known locally. In the shallow coastal regions next to estuaries, these mudbanks grow during the southwest monsoon (June–July) and disappear during the northeast monsoon. Demersal and pelagic fisheries use the banks, which are typically semi-circular in form and composed of fine, muddy sediments, as a significant seasonal feeding site [98]. The local fisheries depend on the inshore mudbanks that form annually in Kochi as a result of the flow of roughly 20 billion m^3 of backwater and suspended sediments [99].However, these mudbanks also serve as sinks for marine litter, which causes microplastics to bioaccumulate and transfer trophically in benthic feeders and, most importantly, in a large number of commercial fish [100]. Wave conditions during the southwest monsoons dictate the mudbanks' appearance and length, and throughout the last 40 years, intra-annual variations have been noted [101]. Wave climate variability in the Arabian Sea determines wave height on the Malabar Coast, which in turn correlates with fluctuations of large-scale oceanic and atmospheric systems like the Indian Ocean Dipole and ENSO [101]. The threshold averaged monthly significant wave height for their formation is 2 m. Due to Kerala's economic dependence on regional coastal fisheries, these people and the state as a whole are at serious risk from the interplay between pollution and climate change. Coastal mangroves are suffering from prolonged hot and dry weather, which is making them less resilient to erosion and flooding and putting more strain on the other organisms that these habitats sustain. Mangroves, for instance, are crucial to preserving the wellbeing of coral reefs that are located close to the coast [102]. Approximately 70% of Kerala's yearly precipitation falls during the southwest monsoon [103].Historical rainfall analyses over Kerala show both cyclical patterns in annual rainfall and a long-term pattern of rising post-monsoon rainfall and falling monsoon rainfall between 1871 and 2005 [104]. Since 1976, the number of dry years has likewise increased [105]. The decline of coastal mangroves is being accelerated by these changes in rainfall patterns, which are already being exacerbated by pollution and land use changes. This is causing instability in the sediments and the soils' ability to retain water and organic matter, which is causing additional CO_2 to be released into the atmosphere [106]. Indeed, because of their capacity to store carbon, mangroves contribute significantly to the mitigation of climate change. The desiccation of vegetated coastal ecosystems is another way that heat waves and droughts can impact the quality of coastal water [107]. Surplus surface water runoff and extensive, uncontrolled flooding can result from heavy precipitation over parched and deforested wetlands that have lost their ability to hold water. This surplus material can then be carried directly onto coastal regions. Sea-level rise in this area is predicted to reach 0.3 to 0.5 m or higher by 2100, according to the IPCC [108], which would significantly raise the risk of flooding for a large portion of Kerala's low-lying coastline and the backwater plains beyond. Coastal mangrove forests are also concerned about rising sea levels, shifting rainfall patterns that result in different freshwater inputs, and silt loading from rivers and lakes. Mangrove forests must either accrete enough fresh sediment loading from land runoff sources or be let to recede landwards in order to keep up with rising sea levels. Mangroves are already suffering from pollution, deforestation, and coastal squeeze; climate change is only going to make matters worse. Uncontrolled sand mining, land reclamation, and the building of hard coastal defenses are being fueled by Kerala's fast population expansion, raising concerns that this would accelerate the loss of mangroves and other coastal wetlands. The risk of coastal erosion and flooding will rise as a result of the loss of coastal mangroves, putting vulnerable fishing communities and infrastructural assets at greater risk. Because many fish and invertebrate species rely on mangrove ecosystems for their early life stages, the loss and degradation of coastal mangroves would also directly affect fishing stocks. In addition to having detrimental effects on aquaculture productivity, heat waves and droughts provide a risk to human health because they promote the growth of infections and foodborne illnesses [109]. Disease outbreaks are not limited to the production of seafood; bathers who use contaminated waters are also at considerable danger. Due to the abrupt flushing of accumulated pollutants, solid litter, sediments, and pathogens into watercourses, prolonged droughts and heat waves can significantly worsen the effects of extreme rainfall when it does occur [110].Heavy rains gathered in litter-clogged rivers during Kerala's 2018 and 2019 floods, especially at Thottappally in the Alapuzha district, causing widespread flooding into nearby areas [111]. In addition, heat waves may increase demand for bottled water as they grow more frequent, which could lead to greater littering. Marine trash can originate from both traditional and tourism-related beach uses in India. Depending on the season and the predominant vessel operation—from traditional, non-motorized, single-day vessels to bigger, multi-day powered fishing vessels—the majority of Kerala's beaches function as landing and fishing hubs, with differing levels of activity dictating the craft and equipment. Larger and heavier debris items are deposited as wrack on the coastline by the higher-energy waves typical of the post-monsoon, whereas fishing-related debris is often nearly four times higher during the peak of the pre-monsoon fishing season than during the low fishing season. Because plastics operate as an insulating agent, their accumulation on beaches can change the characteristics of the sediments, increasing the interior temperature by 2.45 ^{o}C during the day and holding more heat at night [112]. This has been noted as a worry in turtle rookeries because it can raise the likelihood of hatchling feminization and breeding failure, which can alter the diversity and quantity of meiofauna like crabs [112].Increased exposure to chemicals, microorganisms, and invasive species are additional possible indirect impacts [112]. It is still unclear how much microplastic pollution there is in the marine environment. Microplastics near coasts and estuaries most likely originate locally from the disintegration, abrasion, or weathering of larger items. Data from the North-East Atlantic supports the idea that plastic items in the marine environment are classified as either oceanic transboundary litter, effluent waste, industrial waste, or vessel waste. Flood plumes carried by the predominant longshore southerly current during the monsoon season are responsible for the high quantity of microplastics in Southern India [113]. According to a study on microplastics in Kerala, sandy sediments had an average of 41 particles per m2 and coastal waters had an average of 1.3 particles per m3, with the concentration of microplastic in sediments rising southward [20]. Microplastic concentrations in coastal water samples are higher than those found in the Bohai Sea, China [115], but comparable to those found in the Baltic Sea [114]. In the same range as previous values recorded for the Gulf of Mexico [116], similar values of 47 particles/m^2 have been reported for Tamil Nadu beaches [59], which are higher than those reported for Malta, the Central Mediterranean, and the Portuguese coast [117]. Microplastic abundance along the Malabar Coast was spatially associated with river runoff levels and urban proximity [111]. According to state statistics, more than 3500 t of solid trash are generated every day, of which less than 1000 t are collected [23]. Rivers and backwaters serve as channels for sewage treatment effluents and industrial waste because the majority of industry is situated on riverbanks and close to the ocean. In addition to an estimated 300 million liters of untreated municipal and rural wastewater per day, the majority of the garbage eventually makes its way to the coast [111].Among the solid litter particles, foam and film are from packing goods, whereas fibers and lines are primarily from boats and fishing [118], though they also suggest potential sewage sources, especially close to shore. Due to their reduced particle density, microplastics in beach sands and coastal waters are probably carried onshore by winds and surface residual currents [119]. Because microplastics closely resemble natural prey, fish come into contact with and consume them. Due to the constant flow of land-based plastic materials from rivers and backwaters to coastal waters, which are primarily linked to fishing-derived debris, more than 21% of fish sampled from major landing centers in Kerala were found to have microplastics in their digestive tracts. The highest occurrence of microplastic was found on bottom-dwelling species that primarily eat benthic organisms [111]. Although they are lower than those from the English Channel [121], these microplastic levels in fish guts are higher than those reported from Southeast India [59] and northeast Brazil [120]. The beaches in Kerala, the second-largest producer of marine fish in India, produce and receive a lot of trash from fishing [111].The presence of Cd, Cr, Hg, Fe, Sb, Ti, Zn, and Pb has been confirmed to be linked to polymer particles, underscoring the additional risk of chemical contamination and trophic transfer associated with microplastics [111]. Heavy metals are also discharged from untreated effluent discharges into the coastal areas surrounding the industrial belt at Kochi. Microplastic fiber concentration (83%) in samples of Indian white shrimp (Fenneropenaeus indicus) from Kochi has been found to have increased during and after the monsoon [22]. In addition to having a significant port and an international container terminal on the estuary's bank, Kochi is a heavily inhabited city and a popular tourist destination. It also boasts one of India's five largest fishing harbors [22]. Inadequate waste disposal facilities, extensive fishing, and the massive river plumes that follow heavy monsoon rains make the coastal area extremely vulnerable to pollution [22]. During the summer monsoon, a lot of garbage, including plastic particles, is released into the Kochi estuary [122]. Shrimp and other benthic animals can bioavailablely consume microplastics due to their large intake into coastal waters [22]. A significant commercial fishery linked to inshore muddy substrates is F. indicus [22]. Changes in the physiological life cycle, including spawning, have been connected to seasonal variations in the concentration of microplastics in shrimp. It has been demonstrated that exposure to weathered polyethylene particles inhibits the growth of the whiteleg shrimp, Penaeus vannamei, another species that is frequently cultivated in India [123]. Although no impacts on lifespan have been verified, ingestion of polyethylene particles had an impact on the antioxidant and oxidative systems [123]. Significant buildup in intestinal tissue was observed in a related investigation on edible green mussels, Pernaviridis. This suggests that prolonged exposure to weathered polyethylene particles may cause oxidative damage and decreased filtering activity, which can ultimately result in starvation [124]. In the end, there is a risk to human health when commercial marine fish and invertebrates are exposed to microplastic contamination [22].

3.3 Key concerns summarized

Table 1 summarizes the key conclusions about how marine pollution and climate change interact in the Gulf of Mannar. Table 2 summarizes the primary relationships between marine pollution and climate change on the Malabar Coast.

4. Discussion

The marine ecosystem and the numerous products and services that society and economies rely on are increasingly under risk due to the combined effects of climate change and marine trash [2]. Although these two global crises are pervasive, the way they interact depends on the physical environment's features, the kinds of habitats and biological communities, and the demands of other human endeavors [2]. The connections between marine litter and climate change are still poorly understood, despite their importance and widespread repercussions. It is imperative that we increase our knowledge in order to manage the combined effects of these two factors. The urgency of this problem is not limited to large, densely populated nations like India; it is also crucial for other areas, like small oceanic islands, where controlling the risk of climate change and transboundary oceanic litter together would be essential to enabling the long-term protection of rare and extremely sensitive species and their habitats [2].In addition to the severe effects of climate change that are expected to worsen and accelerate in the future in the coastal zone of the Indian subcontinent, the nation is also dealing with a litter crisis that is overwhelming communities and authorities and impeding the country's sustainable development. By examining the data demonstrating the combined effects of marine pollution and climate change in the Gulf of Mannar Reserve and the Malabar Coast, we sought to evaluate such connections in Southern India. For instance, the combination of litter and extreme weather, where land-based litter builds up in waterways and is mobilized by heavy rain and flushed out into coastal areas along with other pollutants and runoff, is one example of how climate change and marine pollution act as threat multipliers. Due to the buildup of trash and waste, inadequate drainage systems in India frequently become clogged during periods of intense rainfall [125], which can increase damage linked to floods [126] and cause debris flows. Larger obstructions in watersheds caused by plastic materials collected by debris flows increase the damage to the environment and public health by increasing backwater flood levels [126].

Table 1: Overview of basic climate change and marine trash problems in Tamil Nadu's Gulf of Mannar.

Key issues	Description
Extreme sea levels, coastal erosion, and inundation	The risk of coastal flooding due to future sea level rise is rising as a result of ongoing coastal erosion. Degradation of coastal environments can also result from mining, deforestation, trash disposal, and untreated effluents.
Marine litter and extreme weather	All of the coral islands in the Gulf of Mannar are severely and extensively polluted by plastic. Every day, hundreds of tonnes of waste are produced, most of which are either improperly disposed of or go uncollected. Although the majority of the litter at tourist beaches is local, left by tourists and other users, rainfall and flooding, especially after cyclones, wash enormous volumes of litter and other pollutants into coastal areas.
Coral reefs	The effects of climate change and other local human influences cause major disruptions to coral reefs, which show up as extreme bleaching, coral disease, predation, and the spread of macroalgae. Severe coral bleaching events will probably occur annually, altering the composition and structure of the reefs, depending on the emissions scenario. In addition, the reefs are vulnerable to mortality from cyclone damage, hypoxia brought on by algae blooms, and large amounts of trash from shipping, fishing, and waste disposal, especially in the vicinity of the islands.
Coastal mangroves	Tamil Nadu's coastline is vulnerable to the effects of severe weather due to the decrease of the mangroves. When mangroves accumulate debris, it can suffocate them and cause them to lose their leaves.
Maritime spill risk	There is a chance of dangerous spills when shipping in the North Indian Ocean. During the monsoon season, weather and sea conditions can make rescue and cleanup efforts challenging. The spill would spread either away from the coast or toward Sri Lanka and the Bay of Bengal due on seasonal wind and current patterns.

Table 2: Overview of the Malabar Coast of Kerala's basic climate change and marine trash problems.

Key issues	Description
Fishing	Variations in rainfall, upwelling, and sea temperature are all associated with observed variations in fish distribution. Although overfishing, habitat degradation, pollution, and the introduction of invasive species are probably also contributing factors to the decline in catches of some conventional commercial species. Millions of people depend on fisheries for their livelihood, and these problems jeopardize their sustainability, especially in vulnerable and underdeveloped coastal regions where unfavorable conditions are common. Depending on the season and the most common type of vessel, craft, and equipment, fishing beaches can also be a major source of garbage.
River plumes and mudbanks	The Malabar Coast's productivity is reliant on upwelling and monsoon runoff enriching the nutrients. Another significant seasonal biologically productive characteristic that develops in shallow regions during the southwest monsoon is mudbanks, which serve as both sinks for microplastics and are essential for sustaining local fisheries. In the Arabian Sea, mudbank changes have been connected to wave variability.
Rainfall, droughts, and heat waves	While post-monsoon rainfall is rising, monsoon timing and rainfall levels are shifting due to earlier commencement and decreasing precipitation. In general, dry years are increasing in frequency. Heat waves and droughts can worsen the quality of coastal water and hasten deforestation and wetland desiccation. They also make diseases and infections more likely. When major rainfall events do occur, extreme droughts can worsen their destructive effects by causing debris flows and flash floods. By the way, they also lead to more plastic littering and more people drinking bottled water.
Coastal mangroves	In addition to increasing coastal erosion and inundation, sea level rise and climate change-induced variations in rainfall and sediment loading are hastening the demise of mangroves, which are already vulnerable to damage and coastal squeezing. Additionally, the loss of mangroves has a detrimental impact on fisheries and increases carbon dioxide emissions because it disturbs the sediment layer and reduces the capacity of blue carbon storage, which is a crucial mitigation function for climate change.
Microplastic pollution	There is a spatial correlation between microplastic pollution and both river runoff levels and major urban areas. Untreated wastewater, food packaging, travel, shipping, and fishing are some of the sources of plastic pollution. In addition to indications of heavy metals linked to the plastic fragments, microplastics have been discovered in the intestinal contents of fish and shrimp at landing centers in Kerala. The buildup of plastic in sediments harms marine life in many ways and gives invasive species accidental shelter.

Millions of tourists visit coastal areas in Tamil Nadu and Kerala each year, and this mass tourism fuels soil erosion, forest fires, and widespread littering [111]. In contrast to long-distance transboundary litter, studies of extreme weather events like cyclones and cyclone-induced flash floods in these states indicate that the majority of the identifiable coastal debris comes from local inputs or is mobilized by waterways from farther inland [52]. The fact that even cyclonic overwash deposits on beaches have been linked to local activities, adjacent rivers, and urban areas supports the idea that most coastal litter originates locally and presents a chance to improve or implement control measures. Litter is very difficult to remove or manage once it is in the water. Plastics can float for hundreds of years [127] and are controlled by wind, waves, tides, and currents based on buoyancy. Because garbage floats, sinks, or breaks apart based on its density, size, shape, and chemical makeup, tides in coastal locations also interact with the geography of the shoreline to transfer litter both onshore and offshore. Debris primarily undergoes abrasion and fragmentation into smaller particles after being deposited ashore; unless they are permanently confined in marine sediments, the transfer across trophic levels is more likely to occur with smaller particle sizes [91].Both pathways carry a number of possible drawbacks for marine life, ecosystems, and ecosystem services, and they may even be harmful to human health [128].

4.1 Management of integral coastal zones

India is not an exception to the general consensus that marine pollution and climate change pose major risks to both the environment and human health. At the national and subnational levels, essential plans and policies are already in existence. In order to safeguard the livelihood of coastal communities, protect coastal areas from threats like sea level rise, and limit the growth of industrial areas and the disposal of hazardous waste in the coastal zone, the Ministry of Environment and Forests of the Government of India issued a Coastal Regulation Zone notification in 1991.However, this notification is still in effect, and untreated wastewater discharge, garbage disposal, and illicit mining continue to pose a serious threat to coastal regions throughout India. Kerala's strategy incorporates a State Action Plan on Climate Change (SAPCC) to combine national and state programs, including the National Action Plan on Climate Change of India. The SAPCC addresses other compounding pressures, for instance, through improved waste management, pollution reduction, and the improvement and restoration of vegetated ecosystems, in addition to other important adaptation and mitigation measures that are directly tied to energy use, disaster response, etc. Beach management, mitigation, reduction at the source, and behavior modification through education are all examples of litter management techniques. Following consultation with pertinent authorities, stakeholders, local communities, and non-governmental organizations, a Coastal Zone Management Plan was created in Tamil Nadu and given to the National Centre for Sustainable Coastal Management (NCSCM) in Chennai in 2011 [129]. The Tamil Nadu Climate Change Cell was also founded in 2014 with the goals of concentrating on climate change-related projects and activities, increasing capacity, raising awareness, and gathering and sharing climate change data to support efficient governance and services. Coastal ecosystems and biodiversity are also managed and restored through a National Adaptation Fund for Climate Change [130]. The enforcement of trash management, forestry management, urban development restrictions, and extracting businesses like sand mining, especially when operations take place across the coastal line and involve related catchment areas, still needs to be improved. For instance, mass reclamation of land for agriculture and urbanization is also leading to a widespread loss of backwaters and floodplains in the state [131], exacerbating the effects of soil erosion and flooding. Along the Malabar Coast, mangrove deforestation is exposing coastal villages to a higher risk of impact from extreme weather and is contributing to the depletion of Kerala's fisheries, which exacerbates the effects of flooding and soil erosion. When properly applied, Integrated Coastal Zone Management (ICZM) techniques offer a framework for decision-making that may be customized to meet the individual requirements and features of a given coastal environment. With the involvement of important stakeholders, an ICZM integrates all the intricate processes and ever-changing relationships that define the coastal environment, along with the resources and services offered. Risk maps, constructed using data layers based on, for instance, sensitive habitats and marine protected areas; climate change projections; litter source points (such as coastal landfill sites and open waste dumps); high flood-and erosion-risk areas; tourist destinations; beaches; ports and harbors; and fishing grounds are a few examples of geospatial tools that can be used to support coastal zone planning, management, and decision-making.The following litter pollution control strategies can be tailored for coastal communities: prohibitions on single-use plastics and the promotion of sustainable alternatives; circular economy strategies; enhancements to waste management procedures, such as recycling drop-off sites, deposit-refund programs, and recycling material processing; active recovery of plastics from waterways; policy and regulation reviews; and public awareness and involvement. By taking these steps, coastal towns can benefit economically, enhance the health of marine ecosystems, and successfully cut down on marine trash inputs at their source. For instance, in urban rivers like the Cooum and Adyar, the Tamil Nadu government has erected debris barrier devices, sometimes referred to as debris "booms."Litter is also collected from Marina Beach using surf rakes and other beach cleaning tools. In a similar vein, the Kerala government launched "SuchithwaSagaram," a pilot project to eradicate marine trash that incentivizes fishermen to return discarded fishing gear so it may be recycled into more valuable, useable products.

4.2 Additional management strategies

To address the combined effects of climate change and marine litter (or other local stressors) in extensive coastal and marine areas, alternative strategies to ICZM are advised. One example is the instructions for marine strategy. Usually adopted by nations or administrations that share a marine region, a marine strategy directive, like the European Union Marine Strategy Framework Directive, works by mandating that signatory member states use sets of agreed-upon descriptors and indicators to achieve a specific environmental status in a cooperative manner. The goal of a marine plan is to address the interconnected stresses and effects on the marine environment that result from both onshore and offshore human activities, particularly those brought on by climate change. Climate resilience frameworks can be used to address specific climate change impacts on society, the economy, and the environment at a national level by creating and putting into practice targeted measures to reduce the negative effects of climate change "on the ground" and by utilizing adaptation and mitigation opportunities. These frameworks can serve as the foundation for a marine strategy. According to the IPCC, risk is the possibility of adverse effects in the future brought on by the interplay of ecological and social systems, as well as the susceptibility to exposure factors and physical dangers. Risks can be managed and ecosystem resilience increased by taking steps to reduce or eliminate exposure, vulnerability, and hazard. A framework for climate resilience must include the management and reduction of other synergistic stressors, like pollution (Figure 4).

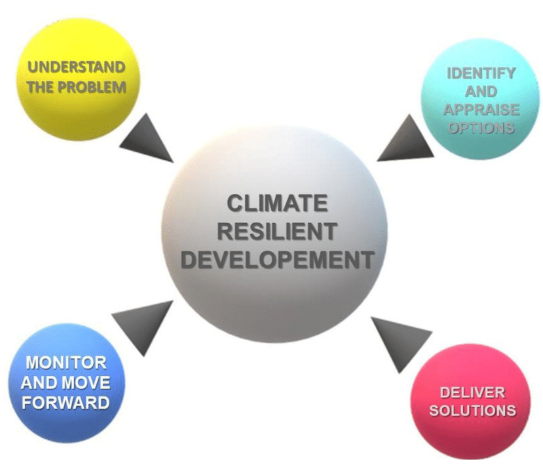

Figure 4: A schematic illustration of the main elements of a framework for climate resilience.

Therefore, by lowering vulnerability and fostering resilience, climate resilience frameworks can help governments and communities better adapt to and respond to the effects of climate change and other co-stressors. To ensure sustainable resource management and efficient risk and impact management, coordination and collaboration across the departments, sectors, and states that share a marine space are essential. This could be accomplished in the states of Kerala and Tamil Nadu, as well as in India, by implementing a comprehensive marine strategy that makes it easier to integrate high-level policies and establishes suitable descriptors and indicators that can be used for assessments, monitoring, and interventions as part of a framework for climate resilience. The following components are commonly found in a climate resilience framework: - Risk and vulnerability assessments By measuring the extent and urgency of their possible effects on various sectors, systems, and populations, climate change risks as well as risks from other co-stressors like pollution must be identified, scored, and prioritized. Depending on the data at hand and the consensus of experts, it may also entail calculating the overall level of confidence in those evaluations.

- *Mitigation and adaptation techniques:* This entails utilizing chances for adaptation and mitigation while creating plans and actions to reduce the effects of climate change and other synergistic pressures. Enhancing building codes, managing catchment areas, managing marine fisheries sustainably, and enhancing natural coastal buffer and protective habitats are a few examples of adaption measures. De-carbonizing industries and activities and preserving natural blue carbon habitats, including coastal mangrove forests, are two examples of mitigation techniques.

- *Institutional and policy frameworks:* These include institutional plans and policies that promote climate-smart financial processes, incentives, and laws. Governments, non-governmental groups, and other stakeholders may need to form alliances and work together.

- *Adaptive structures:* It is recommended that frameworks incorporate monitoring, self-evaluation, self-learning, and evidence gathering procedures in order to be efficient with resources. Frameworks for climate resilience necessitate an interdisciplinary and cooperative approach, involving the active involvement of communities, businesses, researchers, local and governmental authorities, and individuals. Actions and treatments for climate adaptation and mitigation, effective human activity regulation, and lowering environmental stressors such marine pollution can be put into place when priorities have been established [132]. Actions and interventions include things like habitat restoration, tax breaks, and better waste management facilities and procedures, as well as outreach and education promoting healthy lifestyle and behavior changes [133].In a related matter, biological waste and personal protective equipment items composed of polymeric material increased significantly during the COVID-19 pandemic in India, as well as in many other countries [134]. According to estimates, the epidemic produced 47 t of biological waste per day in Chennai, the state capital of Tamil Nadu [135]. One of the biggest environmental effects of the pandemic was the increase in plastic waste, and it has been suggested that India create plastic pollution control plans that take pandemics and climate change into account. Furthermore, limitations on tourism and fishing in Tamil Nadu were thought to have a "positive" environmental impact and highlight the significance of using ecosystem-based approaches to improve and protect the sustainability of ecosystem services and community well-being from hazards like pollution and natural disasters [111]. While successful measures and interventions are put into place, knowledge gaps can be addressed by ongoing study and monitoring. Even while marine litter, including microplastics, is a well-known environmental issue, global frameworks like the Sustainable Development Goals (SDGs) [136] still need to give it more attention. The problem of marine (micro)plastics has been acknowledged under Goal 14 of the United Nations' planned 17 Sustainable Development Goals and 169 goals, which are to: Conserve and sustainably use the oceans, seas, and marine resources for sustainable development [136]. Target 14.1, which will be measured by indicator 14.1.1: Index of coastal eutrophication and floating plastic debris density, states specifically: By 2025, prevent and significantly reduce marine pollution of all kinds, especially from land-based activities, including marine debris and nutrient pollution [136].The global world recognizes that minimizing floating plastic pollution is essential to the sustainable use of the oceans, and governments and businesses have embraced the SDGs to increase their sustainability [136]. However, as long as it is not adequately monitored, the widespread nature of (micro) plastic pollution will make matters worse for governments and organizations. This is because there is presently no internationally recognized index of floating plastics debris density [136].

A regional participatory approach that incorporates risk scoring and ranking, like that employed for the UK Climate Change Risk Assessment and its follow-up applications, could be used to delve deeper into the important issues of climate change and marine litter that this review highlighted. Such an approach helps identify areas of low confidence due to a lack of evidence or expert agreement, allowing for targeted monitoring and research to fill critical knowledge gaps. It also takes into account receptors of climate change risk that may also be threatened by other anthropogenic pressures, such as marine litter. The concepts and methods for the preservation and sustainable use of marine biodiversity can be applied globally to increase the resilience of marine ecosystems and services and to better understand and manage the combined effects of marine litter and climate change [2]. However, in order to effectively address these two crises, it is ultimately up to nations to create and carry out policies and initiatives for marine litter reduction and climate change adaptation and mitigation. To overcome infrastructure barriers and other reasons impeding action, such as poor community participation and lack of knowledge, this calls for integration across sectors and regions, even at the national and sub-national levels [2].As evidenced by isolated oceanic coral atolls in comparatively "pristine" condition, the designation of marine protected areas and the protection of vulnerable habitats and species are effective measures that help build resilience against climate change and other anthropogenic pressures [2]. However, the assessment of that resilience is frequently hampered by a lack of data. As part of marine protection practices, one option is to integrate research, monitoring, and marine planning activities [2]. This is exactly what UNEP's most recent recommendations on the problem of marine litter are: to implement ecosystem-based and holistic ocean governance approaches, measurable targets, and blue economy principles [91].Observed and prospective stressors from climate change and other human activities must be taken into account in ocean and coastal management measures. Additionally, marine spatial prioritization methodologies that recognize the biological interdependence of terrestrial, coastal, and marine systems must be used [137].

5. Conclusions

Given the widespread interplay of these two global crises, which has an unequal impact globally by having a significantly bigger impact on underprivileged coastal areas, the relationship between plastics and climate change demands more attention and action. While coastal states in India have made significant and admirable efforts, the combined effects of climate change and the marine litter catastrophe are overwhelming authorities and communities, impeding their ability to grow sustainably. 18 Indian states, as far as we know, have outlawed single-use plastic, but enforcement is still an issue. The significance and urgency of the problem, particularly in Southern coastal regions, are amply demonstrated by this study. Efforts to accomplish the SDGs may be hampered by the detrimental effects of litter and climate change on the marine environment, as well as the communities and economies that depend on it. In order to address the issue, it is critical to take into account the national and regional context in order to direct focused research, monitoring, and useful policy and management measures. The Gulf of Mannar and the Malabar Coast are significant maritime regions on a worldwide scale, but they are becoming more vulnerable due to factors including litter pollution, climate change, and other effects of the nation's fast economic growth. The magnitude of these problems necessitates coordinated and creative solutions driven by quantifiable, evidence-based metrics and attainable results. Sustainable fishing and responsible tourism, as well as the preservation and restoration of coastal habitats, should be the top priorities of coastal management. To make sure that these practices balance the needs, health, and wellbeing of people and the environment while being culturally suitable, socially acceptable, and economically viable, they can be developed in partnership with local communities and stakeholders. With the right tools and training, local populations may become the best stewards and researchers of their coastlines and seas, identifying and recording signs of ecological change. They also frequently possess important knowledge and expertise about their local area. Additionally, it is preferable to incorporate the representation of environmental organizations, authorities, companies, and communities in the development of coastal management frameworks and plans. Last but not least, we would advise conducting a critical review of the current frameworks, plans, policies, and actions pertaining to the management of coastal zones, particularly for Kerala and Tamil Nadu but also generally for other coastal states in India. This would allow us to identify and highlight any gaps or obstacles that hinder their efficacy as well as opportunities for improvement at the district, state, or national levels, as appropriate. A review like this would assist in determining which areas require a stronger community and stakeholder involvement, where whole-ecosystem approaches are feasible, where policies could benefit from a more solid evidence base, and where opportunities exist to improve integration and coordination across pertinent departments and sectors. Effective, long-term climate change adaptation and resilience, together with a greater chance of success in addressing marine litter, are the anticipated results of these actions.

Acknowledgements

The author is very thankful to the potential reviewers for many useful suggestions to improve the quality of present work.

Authors' contributions

The author read and approved the final manuscript.

Conflicts of interest

The author declares no conflict of interest.

Funding

This research received no external funding.

Data availability

No new data were created.

References

[1] H.V. Ford, N.H. Jones, A.J. Davies, B.J. Godley, J.R. Jambeck, I.E. Napper, C.C. Suckling, G.J. Williams, L.C. Woodall, H.J. Koldewey, The fundamental links between climate change and marine plastic pollution, *Sci. Total Environ.* **806** (2022) 150392.

[2] S. Lincoln, B. Andrews, S.N.R. Birchenough, P. Chowdhury, G.H. Engelhard, O. Harrod, J.K. Pinnegar, B.L. Townhill, B, Marine litter and climate change: inextricably connected threats to the world's oceans, *Sci. Total Environ*. **837** (2022) 155709.

[3] H.P.H. Arp, D. Kühnel, C. Rummel, M. MacLeod, A. Potthoff, S. Reichelt, E. Rojo- Nieto, M. Schmitt-Jansen, J. Sonnenberg, E. Toorman, A. Jahnke, Weathering plastics as a planetary boundary threat: exposure, fate, and hazards, *Environ. Sci. Technol*. **55** (2021) 7246–7255.

[4] K.M. Maltby, E.L. Howes, S. Lincoln, J.K. Pinnegar, P. Buckley, T.S. Ali, B. Al Balushi, A. Al Ragum, H.S.A. Al Shukail, C.O. Balmes, R. Ben-Hamadou, Marine climate change risks to biodiversity and society in the ROPME Sea Area, *Clim. Risk Manag*. **35** (2022) 100411.

[5] M.J. Devlin, B.P. Lyons, J.E. Johnson, J.M. Hills, The tropical Pacific Oceanscape: current issues, solutions and future possibilities, *Mar. Pollut. Bull.* **166** (2021) 112181.

[6] S.S. Yadav, K.M. Gjerde, The ocean, climate change and resilience: making ocean areas beyond national jurisdiction more resilient to climate change and other anthropogenic activities, *Mar. Policy* **122** (2020) 104184.

[7] E. Schmaltz, E.C. Melvin, Z. Diana, E. Gunady, D. Rittschof, J. Somarelli, J. Virdin, M.M. Dunphy-Daly, Plastic pollution solutions: emerging technologies to prevent and collect marine plastic pollution, *Environ. Int*. **144** (2020) 106067.

[8] Y. Lu, J. Yuan, X. Lu, C. Su, Y. Zhang, C. Wang, X. Cao, Q. Li, J. Su, V. Ittekkot, R.A. Garbutt, S. Bush, S. Fletcher, T. Wagey, A. Kachur, N. Sweijd, Major threats of pollution and climate change to global coastal ecosystems and enhanced management for sustainability, *Environ. Pollut*. **239** (2018) 670–680.

[9] F. Gazeau, S.V. Smith, B. Gentili, M. Frankignoulle, J.P. Gattuso, The European coastal zone: characterization and first assessment of ecosystem metabolism, *Estuar. Coast. Shelf Sci*. **60** (2004) 673–694.

[10] S. Agarwal, T. Deb, Climate change induced migration with special emphasis on the coastal zones in India; In: Global Climate Change and Environmental Refugees: Nature, Framework and Legality. Springer International Publishing, Cham (2023) pp. 105–119.

[11] A.K. Prasad, R.P. Singh, Extreme rainfall event of July 25–27, 2005 over Mumbai, west coast, India, *J. Indian Soc. Remote Sens*. **33** (2005) 365–370.

[12] K.M. Hunt, A. Menon, The 2018 Kerala floods: a climate change perspective, *Clim. Dyn*. **54** (2020) 2433–2446.

[13] K. Ray, P. Pandey, C. Pandey, A.P. Dimri, K. Kishore, On the recent floods in India, *Curr. Sci*. **117** (2019) 204–218.
[14] S.K. Kundu, H. Santhanam, A report on the impacts of cyclone Yaas over a fish landing centre vulnerable to cyclonic storms and natural hazards–Talsari, Northern Odisha, *Local Environ*. **26** (2021) 1043–1050.
[15] J.H. Christensen, B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Maga˜na Rueda, L. Mearns, C.G. Men´endez, J. R¨ais¨anen, A. Rinke, A. Sarr, P. Whetton, Regional climate projections; In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller (Eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (2007) pp. 847–940.
[16] M. Rajeevan, J. Bhate, A.K. Jaswal, Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data, *Geophys. Res. Lett*. **35** (2008) L18707.
[17] A. Katzenberger, J. Schewe, J. Pongratz, A. Levermann, Robust increase of Indian monsoon rainfall and its variability under future warming in CMIP6 models, *Earth Syst. Dynam*. **12** (2021) 367–386.
[18] M. van der Mheen, E. Sebille, C. Pattiaratchi, Beaching patterns of plastic debris along the Indian Ocean rim, *Ocean Sci*. **16** (2020) 1317–1336.
[19] A.V. Duhec, R.F. Jeanne, N. Maximenko, J. Hafner, Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles, *Mar. Pollut. Bull*. **96** (2015) 76–86.
[20] M. Mugilarasan, R.R.S. Karthik, B. Subbareddy, G. Hariharan, I. Anandavelu, T.P.S. Jinoj, R. Purvaja, R. Ramesh, Anthropogenic marine litter: an approach to environmental quality for India's southeastern Arabian Sea coast, *Sci. Total Environ*. **866** (2023) 161363.
[21] J.R. Jambeck, R. Geyer, C. Wilcox, T.R. Siegler, M. Perryman, A. Andrady, K.L. Law, Plastic waste inputs from land into the ocean, *Science* **347** (2015) 768–771.
[22] D.B. Daniel, M.P. Ashraf, S.N. Thomas, Abundance, characteristics and seasonal variation of microplastics in Indian white shrimps (*Fenneropenaeus indicus*) from coastal waters off Kochi, Kerala, India, *Sci. Total Environ*. **737** (2020) 139839.
[23] CPCB, Annual Report on Solid Waste Management (2020 - 21), Central Pollution Control Board, Delhi, India (2021) p. 156 pp.
[24] L. Lebreton, J. Van Der Zwet, J.W. Damsteeg, B. Slat, A. Andrady, J. Reisser, River plastic emissions to the world's oceans, *Nat. Commun*. **8** (2017) 1–10.
[25] DoECC, Kerala State Action Plan on Climate Change 2.0 (2023 - 2030), Directorate of Environment and Climate Change (DoECC), Department of Environment, Government of Kerala (2022).
[26] R. Smithers, SPLICE Phase 1, A Methodology for Rapid Evidence Assessments, Report for Defra. Ricardo-AEA (2015) p. 36.
[27] V. Hatje, M. Sarin, S.G. Sander, D. Omanovi´c, P. Ramachandran, C. Volker, R.O Barra, A. Tagliabue, Emergent interactive effects of climate change and contaminants in coastal and ocean ecosystems, *Front. Mar. Sci*. **9** (2022) 936109.
[28] H. Cabral, V. Fonseca, T. Sousa, M. Costa Leal, Synergistic effects of climate change and marine pollution: an overlooked interaction in coastal and estuarine areas, *Int. J. Environ. Res. Public Health* **16** (2019) 2737.
[29] E.H. Bates, L. Alma, T. Ugrai, A. Gagnon, M. Maher, P. McElhany, J.L. Padilla-Gamino, Evaluation of the effect of local water chemistry on trace metal accumulation in puget sound shellfish shows that concentration varies with species, size, and location, *Front. Mar. Sci*. **8** (2021) 636170.
[30] Z. Wang, J.P. Meador, K.M. Leung, Metal toxicity to freshwater organisms as a function of pH: a meta-analysis, *Chemosphere* **144** (2016) 1544–1552.
[31] A. Stockdale, E. Tipping, S. Lofts, R.J.G. Mortimer, The effect of ocean acidification on organic and inorganic speciation of trace metals, *Environ. Sci. Technol*. **50** (2016) 1906–1913.
[32] L.M. Charrieau, H.L. Filipsson, Y. Nagai, S. Kawada, K. Ljung, E. Kritzberg, T. Toyofuku, Decalcification and survival of benthic foraminifera under the combined impacts of varying pH and salinity, *Mar. Environ. Res*. **138** (2018) 36–45.
[33] G. Kibria, D. Nugegoda, G. Rose, A.K.Y. Haroon, Climate change impacts on pollutants mobilization and interactive effects of climate change and pollutants on toxicity and bioaccumulation of pollutants in estuarine and marine biota and linkage to seafood security, *Mar. Pollut. Bull*. **167** (2021) 112364.
[34] M. Connan, V. Perold, B.J. Dilley, C. Barbraud, Y. Cherel, P.G. Ryan, The Indian Ocean 'garbage patch': empirical evidence from floating macro-litter, *Mar. Pollut. Bull*. **169** (2021) 112559.
[35] C. Li, X. Wang, K. Liu, L. Zhu, N. Wei, C. Zong, D. Li, Pelagic microplastics in surface water of the Eastern Indian Ocean during monsoon transition period: abundance, distribution, and characteristics, *Sci. Total Environ*. **755** (2021) 142629.
[36] M. Ranjani, S. Veerasingam, R. Venkatachalapathy, T.P.S. Jinoj, L. Guganathan, M. Mugilarasan, P. Vethamony, Seasonal variation, polymer hazard risk and controlling factors of microplastics in beach sediments along the southeast coast of India, *Environ. Pollut*. **305** (2022) 119315.
[37] S.K. Sivadas, K. Ramu, P. Mishra, M.V. Ramana Murhty, Potential plastic accumulation zones in the Indian coastal seas, *Front. Mar. Sci*. **8** (2021) 1801.
[38] R. Kiruba-Sankar, K. Saravanan, S. Adamala, K. Selvam, K. Lohith Kumar, J. Praveenraj, First report of marine debris in Car Nicobar, a remote oceanic Island in the Nicobar archipelago, Bay of Bengal, *Reg. Stud. Mar. Sci*. (2023) 102845.
[39] N.L. Bindoff, W.W.L. Cheung, J.G. Kairo, J. Arístegui, V.A. Guinder, et al. (Eds.), IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 447–587.
[40] P. Chowdhury, M.R. Behera, A study on regional sea level variation along the Indian coast, *Procedia Eng*. **116** (2015) 1078–1084.
[41] J.A. Church, J.M. Gregory, P. Huybrechts, M. Kuhn, K. Lambeck, et al. (Eds.), Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 639–693.
[42] P. Chowdhury, M.R. Behera, D.E. Reeve, Future wave-climate driven longshore sediment transport along the Indian coast, *Clim. Chang*. **162** (2020) 405–424.
[43] P. Chowdhury, M.R. Behera, Effect of long-term wave climate variability on longshore sediment transport along regional coastlines, *Prog. Oceanogr*. **156** (2017) 145–153.
[44] S. Fetisov, I. Chubarenko, Marine litter stormy wash-outs: developing the neural network to predict them, *Pollutants* **1** (2021) 156–168.
[45] M.A. Browne, M.G. Chapman, R.C. Thompson, L.A. Amaral Zettler, J. Jambeck, N.J. Mallos, Spatial and temporal patterns of stranded intertidal marine debris: is there a picture of global change? *Environ. Sci. Technol*. **49** (2015) 7082–7094.
[46] U. Andriolo, G. Gonçalves, Is coastal erosion a source of marine litter pollution? Evidence of coastal dunes being a reservoir of plastics, *Mar. Pollut. Bull*. **174** (2022) 113307.
[47] M. Bełdowska, A. Jędruch, L. Łęczy´nski, D. Saniewska, U. Kwasigroch, Coastal erosion as a source of mercury into the marine environment along the Polish Baltic shore, *Environ. Sci. Pollut. Res*. **23** (2016) 16372–16382.
[48] M. Deshpande, V.K. Singh, M.K. Ganadhi, M.K. Roxy, R. Emmanuel, Changing status of tropical cyclones over the north Indian Ocean, *Clim. Dyn*. **57** (2021) 3545–3567.

[49] M. Mondal, A. Biswas, S. Haldar, S. Mandal, S. Bhattacharya, S. Paul, Spatio-temporal behaviours of tropical cyclones over the Bay of Bengal Basin in last five decades. Trop, *Cyclone Res. Rev*. **11** (2022) 1–15.
[50] K.S. Gandhi, D. Pradhap, G. Prabaharan, S.H. Singh, S. Krishnakumar, Distribution of plastic litter in beach sediments of Silver beach, Cuddalore, during Nivar Cyclone – a first report, *Mar. Pollut. Bull*. **172** (2021) 112904.
[51] H.S. Lo, Y.K. Lee, B.H.K. Po, L.C. Wong, X. Xu, C.F. Wong, C.Y. Wong, N.F. Tam, S.G. Cheung, Impacts of typhoon Mangkhut in 2018 on the deposition of marine debris and microplastics on beaches in Hong Kong, *Sci. Total Environ*. **716** (2020) 137172.
[52] S. Veerasingam, M. Mugilarasan, R. Venkatachalapathy, P. Vethamony, Influence of 2015 flood on the distribution and occurrence of microplastic pellets along the Chennai coast, India, *Mar. Pollut. Bull*. **109** (2016) 196–204.
[53] A.G. Turner, J.M. Slingo, Subseasonal extremes of precipitation and active break cycles of the Indian summer monsoon in a climate-change scenario, *Q. J. R. Meteorol. Soc*. **135** (2009) 549–567.
[54] C.K.B. Krishnamurthy, U. Lall, H.H. Kwon, Changing frequency and intensity of rainfall extremes over India from 1951 to 2003, *J. Clim*. **22** (2009) 4737–4746.
[55] D.R. Pattanaik, M. Rajeevan, Variability of extreme rainfall events over India during southwest monsoon season, *Meteorol. Appl*. **17** (2010) 88–104.
[56] H. Ali, V. Mishra, Contributions of dynamic and thermodynamic scaling in subdaily precipitation extremes in India, *Geophys. Res. Lett*. **45** (2018) 2352–2361.
[57] M. Mujumdar, P. Bhaskar, M.V.S. Ramarao, U. Uppara, M. Goswami, et al. Droughts and floods; In: *Assessment of Climate Change Over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India*, R. Krishnan, J. Sanjay, C. Gnanaseelan (Eds.), Springer, Singapore, Singapore (2020) pp. 117–141.
[58] C.T.J. Roebroek, S. Harrigan, T.H.M. van Emmerik, C. Baugh, D. Eilander, C. Prudhomme, F. Pappenberger, Plastic in global rivers: are floods making it worse? *Environ. Res. Lett*. **16** (2021) 025003.
[59] R. Karthik, R.S. Robin, P. Ramachandran, D. Ganguly, I. Anandavelu, R. Raghuraman, G. Hariharan, A. Ramakrishna, R. Ramesh, Microplastics along the beaches of southeast coast of India, *Sci. Total Environ*. **645** (2018) 1388–1399.
[60] R. Karthik, R.S. Robin, P. Ramachandran, V. Karthikeyan, B. Subbareddy, K. Balachandar, G. Hariharan, D. Ganguly, V.D. Samuel, T.P.S. Jinoj, R. Ramesh, Microplastic pollution in fragile coastal ecosystems with special reference to the X-Press Pearl maritime disaster, southeast coast of India, *Environ. Pollut*. **305** (2022) 119297.
[61] R.S. Robin, P. Ramachandran, D. Ganguly, G. Hariharan, A. Paneerselvam, R.T. Sundari, R. Karthik, C.S. Neethu, C. Saravanakumar, P. Semanti, M.H.K. Prasad, M. Mugilarasan, S. Rohan, K. Arumugam, V.D. Samuel, R. Ramesh, COVID- 19 restrictions and their influences on ambient air, surface water and plastic waste in a coastal megacity, Chennai, India, *Mar. Pollut. Bull*. **171** (2021) 112739.
[62] A. Aiyappan, Tamil Nadu. Encyclopaedia Britannica. Available online from: https://www.britannica.com/place/Tamil-Nadu (accessed November 2022).
[63] S. Mondal, M.A. Lee, Long-term observations of sea surface temperature variability in the Gulf of Mannar, *J. Mar. Sci. Eng*. **11** (2023) 102.
[64] K.D. Raj, G. Mathews, D.O. Obura, R.L. Laju, M.S. Bharath, P.D. Kumar, A. Arasamuthu, T.K.A. Kumar, J.K.P. Edward, Low oxygen levels caused by *Noctiluca scintillans* bloom kills corals in Gulf of Mannar, India, *Sci. Rep*. **10** (2020) 22133.
[65] S. Miththapala, The Gulf of Mannar and Its Surroundings: A Resource Book for Teachers in the Mannar District, IUCN Sri Lanka Office, Colombo (2012) p. 64.
[66] S. Miththapala, The Gulf of Mannar and Its Surroundings: A Resource Book for Teachers in the Mannar District, IUCN Sri Lanka Office, Colombo (2012) p. 64.
[67] NABARD, State Focus Paper. National Bank for Agriculture and Rural Development (NABARD), State: Kerala (2020) p. 132.
[68] DoF, Integrated fisheries development plan for coastal zone management plan 2019, Kerala, Department of Fisheries (DoF), Government of Kerala (2021).
[69] L.S. Nair, V. Sundar, N.P. Kurian, Longshore sediment transport along the coast of Kerala in southwest India, *Procedia Eng*. **116** (2015) 40–46.
[70] DoF, Kerala fisheries statistics at a glance 2021, Directorate of Fisheries (DoF), Government of Kerala (2021).
[71] A. Parthasarathy, U. Natesan, Coastal vulnerability assessment: a case study on erosion and coastal change along Tuticorin, Gulf of Mannar, *Nat. Hazards* **75** (2015) 1713–1729.
[72] UNISDR, Global Assessment Report on Disaster Risk Reduction - Risk and Poverty in a Changing Climate: Invest Today for a Safer Tomorrow, United Nations International Strategy for Disaster Reduction, Geneva, Switzerland (2009) p. 207.
[73] U. Pradhan, S. Naik, M. Begum, S.S. Kumar, U.S. Panda, P. Mishra, M.V.R. Murthy, Marine litter: post-flood nuisance for Chennai beaches, *Curr. Sci*. **115** (2018) 1454–1455.
[74] S.K. Sivadas, P. Mishra, T. Kaviarasan, M. Sambandam, K. Dhineka, M.V. Ramana Murthy, S. Nayak, D. Sivyer, D. Hoehn, Litter and plastic monitoring in the Indian marine environment: a review of current research, policies, waste management, and a roadmap for multidisciplinary action, *Mar. Pollut. Bull*. **176** (2022) 113424.
[75] P. Kaladharan, K. Vijayakumaran, V. Singh, D.P.S. Prema, Asha, S. Sulochanan, P. Hemasankari, L. Edward, S. Padua, V. Shettigar, A. Anasukoya, H. Bhint, Prevalence of marine litter along the Indian beaches: a preliminary account on its status and composition, *J. Mar. Biol. Assoc. India* **59** (2017) 19–24.
[76] T. Kaviarasan, K. Dhineka, M. Sambandam, S.K. Sivadas, D. Sivyer, D. Hoehn, U. Pradhan, P. Mishra, M.V. Ramana Murthy, Impact of multiple beach activities on litter and microplastic composition, distribution, and characterization along the southeast coast of India, *Ocean Coast. Manag*. **223** (2022) 106177.
[77] M. Sambandam, K. Dhineka, S.K. Sivadas, T. Kaviarasan, M. Begum, D. Hoehn, D. Sivyer, P. Mishra, M.V. Ramana Murthy, Occurrence, characterization, and source delineation of microplastics in the coastal waters and shelf sediments of the central east coast of India, Bay of Bengal, *Chemosphere* **303** (2022) 135135.
[78] J. Patterson, K.I. Jeyasanta, R.L. Laju, A.M. Booth, N. Sathish, J.K.P. Edward, Microplastic in the coral reef environments of the Gulf of Mannar, India - characteristics, distributions, sources and ecological risks, *Environ. Pollut*. **298** (2022) 118848.
[79] S. Krishnakumar, S. Srinivasalu, P. Saravanan, A. Vidyasakar, N.S. Magesh, A preliminary study on coastal debris in Nallathanni Island, Gulf of Mannar Biosphere Reserve, Southeast coast of India, *Mar. Pollut. Bull*. **131** (2018) 547–551.
[80] K.D. Raj, G. Mathews, P.D. Kumar, Tiger cowrie *Cypraeatigris*feeds on coral-competing sponge *Rhabdastrellaglobostellata*in an *Acropora* dominated reef of Gulf of Mannar, India, *Mar. Freshw. Behav. Physiol*. **52** (2019) 101–105.
[81] K.D. Raj, G.S. Aeby, G. Mathews, G.J. Williams, J.M. Caldwell, R.L. Laju, M.S. Bharath, P.D. Kumar, A. Arasamuthu, N.G.G. Asir, L.M. Wedding, A.J. Davies, M.M. Moritsch, J.K. Patterson Edward, Coral reef resilience differs among islands within the Gulf of Mannar, southeast India, following successive coral bleaching events, *Coral Reefs* **40** (2021) 1029–1044.
[82] G. Gopakumar, B. Sulochanan, V. Venkatesan, Bloom of *Noctiluca scintillans* (Macartney) in Gulf of Mannar, southeast coast of India, *J. Mar. Biol. Assoc. India* **51** (2009) 75–80.
[83] H. Gomes, R. do, K. McKee, A. Mile, S. Thandapu, K. Al-Hashmi, X. Jiang, J.I. Goes, Influence of light availability and

prey type on the growth and photo-physiological rates of the mixotroph *Noctiluca scintillans*, *Front. Mar. Sci*. **5** (2018) 374.
[84] H.R. Nelson, A.H. Altieri, Oxygen: the universal currency on coral reefs, *Coral Reefs* **38** (2019) 177–198.
[85] R. Alderdice, D.J. Suggett, A. C´ardenas, D.J. Hughes, M. Kühl, M. Pernice, C.R. Voolstra, Divergent expression of hypoxia response systems under deoxygenation in reef-forming corals aligns with bleaching susceptibility, *Glob. Chang. Biol*. **27** (2020) 312–326.
[86] P. Harrison, K. Furuya, P. Glibert, J. Xu, H. Liu, K.D. Yin, J.H.W. Lee, D. Anderson, R. Gowen, A. Al-Azri, A. Ho, Geographical distribution of red and green *Noctiluca scintillans*, *Chin. J. Oceanol. Limnol*. **29** (2011) 807–831.
[87] L.V. Ballesteros, J.L. Matthews, B.W. Hoeksema, Pollution and coral damage caused by derelict fishing gear on coral reefs around Koh Tao, Gulf of Thailand, *Mar. Pollut. Bull*. **135** (2018) 1107–1116.
[88] S.C. Painter, Y. Artioli, F.H. Amir, J. Arnull, R.S. Ganeshram, N. Ibrahim, V.D. Samuel, R.S. Robin, R. Raghuraman, R. Purvaja, R. Ramesh, Anthropogenic nitrogen pollution threats and challenges to the health of South Asian coral reefs, *Front. Mar. Sci*. **10** (2023) 1187804.
[89] C.E.J. van Bijsterveldt, B.K. van Wesenbeck, S. Ramadhani, O.V. Raven, F.E. van Gool, R. Pribadi, T.J. Bouma, Does plastic waste kill mangroves? A field experiment to assess the impact of macro plastics on mangrove growth, stress response and survival, *Sci. Total Environ*. **756** (2021) 143826.
[90] ISFR, Forest Survey of India. Ministry of Environment, Forest Climate Change, State of India Forest Report, Government of India, 16th edition, Vol. I, Forest Survey of India, Uttarakhand, India (2019).
[91] UNEP and OCHA, X-Press Pearl Maritime Disaster: Sri Lanka - Report of the UN Environmental Advisory Mission (2021) pp 70. Available online from: https://wedocs.unep.org/20.500.11822/36608 (accessed February 2023).
[92] K. Balachandar, C. Viswanathan, R.S. Robin, K.R. Abhilash, R. Sankar, V.D. Samuel, R. Purvaja, R. Ramesh, Benthic foraminifera as an environmental proxy for pollutants along the coast of Chennai, India, *Chemosphere* **310** (2023) 136824.
[93] C.S. Neethu, C. Saravanakumar, R. Purvaja, R.S. Robin, R. Ramesh, Oil-spill triggered shift in indigenous microbial structure and functional dynamics in different marine environmental matrices, *Sci. Rep*. **9** (2019) 1354.
[94] S.V. Samiksha, P. Vethamony, W.E. Rogers, P.S. Pednekar, M.T. Babu, P.K. Dineshkumar, Wave energy dissipation due to mudbanks formed off southwest coast of India, *Estuar. Coast. Shelf Sci*. **196** (2017) 387–398.
[95] N.K.M. Valappil, V. Hamza, J.F. de Oliveira Júnior, Evaluation of daily average temperature trends in Kerala, India, using MERRA-2 reanalysis data: a climate change perspective, *Environ. Sci. Pollut. Res*. (2022) 1–24.
[96] P. Lehodey, J. Alheit, M. Barange, T. Baumgartner, G. Beaugrand, K. Drinkwater, J.-M. Fromentin, S.R. Hare, G. Ottersen, R.I. Perry, C. Roy, C.D. van der Lingen, F. Werner, Climate variability, fish, and fisheries, *J. Clim*. **19** (2006) 5009–5030.
[97] S.S. Shaju, R.R. Akula, T. Jabir, Characterization of light absorption coefficient of red *Noctiluca scintillans* bloom in the South Eastern Arabian Sea, *Oceanologia* **60** (2018) 419–425.
[98] R. Jyothibabu, K.K. Balachandran, L. Jagadeesan, C. Karnan, N. Arunpandi, S.W.A. Naqvi, R.S. Pandiyarajan, Mudbanks along the southwest coast of India are not too muddy for plankton, *Sci. Rep*. **8** (2018) 1–13.
[99] M. Madhupratap, T.C. Gopalakrishnan, P. Haridas, K.K.C. Nair, Mesozooplankton biomass, composition and distribution in the Arabian Sea during the fall intermonsoon: implications of oxygen gradients, *Deep-Sea Res. II Top. Stud. Oceanogr*. **48** (2001) 1345–1368.
[100] K. James, V. Kripa, G. Vineetha, S. Padua, D. Prema, A. Babu, S. John, S. John, R. Lavanya, R.V. Joseph, Microplastics in the environment and in commercially significant fishes of mud banks, an ephemeral ecosystem formed along the southwest coast of India, *Environ. Res*. **204** (2022) 112351.
[101] Y.V. Saprykina, S.V. Samiksha, S.Y. Kuznetsov, Wave climate variability and occurrence of mudbanks along the southwest coast of India, *Front. Mar. Sci*. **8** (2021) 671379.
[102] A. Biju Kumar, V. Bhagyalekshmi, A. Riyas, Climate change, fisheries and coastal ecosystems in India, *J. Aquat. Biol. Fish*. **5** (2017) 7–17.
[103] A. Nair, V.G. Nair, K.S. Nair, The role of North West Equatorial Indian Ocean in modulating the variability of southwest monsoon rainfall over Kerala in a climate change perspective, *Theor. Appl. Climatol*. **146** (2021) 39–154.
[104] A. Nair, K.A. Joseph, K.S. Nair, Spatio-temporal analysis of rainfall trends over a maritime state (Kerala) of India during the last 100 years, *Atmos. Environ*. **88** (2014) 123–132.
[105] J. Thomas, V. Prasannakumar, Temporal analysis of rainfall (1871–2012) and drought characteristics over a tropical monsoon-dominated state (Kerala) of India, *J. Hydrol*. **534** (2016) 266–280.
[106] M. Santos-Andrade, V. Hatje, A. Arias-Ortiz, V.F. Patire, L.A. da Silva, Human disturbance drives loss of soil organic matter and changes its stability and sources in mangroves, *Environ. Res*. **202** (2021) 111663.
[107] C.E. Lovelock, R. Reef, Variable impacts of climate change on blue carbon, *One Earth* **3** (2020) 195–211.
[108] IPCC; In: Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, H.-O. Portner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Loschke, V. Moller, A. Okem, B. Rama, (Eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA (2022).
[109] M.O. Soares, C.C. Campos, P.B.M. Carneiro, H.S. Barroso, R.V. Marins, C.E.P. Teixeira, M.O.B. Menezes, L.S. Pinheiro, M.B. Viana, C.V. Feitosa, J.I. Sanchez-Botero, L.E.A. Bezerra, C.A. Rocha-Barreira, H. Matthews-Cascon, F.O. Matos, A. Gorayeb, M.S. Cavalcante, M.F. Moro, S. Rossi, G. Belmonte, V.M.M. Melo, A.S. Rosado, G. Ramires, T.C.L. Tavares, T.M. Garcia, Challenges and perspectives for the Brazilian semi-arid coast under global environmental changes, *Perspect. Ecol. Conserv*. **19** (2021) 267–278.
[110] E.H. De Carlo, D.J. Hoover, C.W. Young, R.S. Hoover, F.T. Mackenzie, Impact of storm runoff from tropical watersheds on coastal water quality and productivity, *Appl. Geochem*. **22** (2007) 1777–1797.
[111] R.S. Robin, R. Karthik, R. Purvaja, D. Ganguly, I. Anandavelu, M. Mugilarasan, R. Ramesh, Holistic assessment of microplastics in various coastal environmental matrices, southwest coast of India, *Sci. Total Environ*. **703** (2020) 134947.
[112] J.L. Lavers, J. Rivers-Auty, A.L. Bond, Plastic debris increases circadian temperature extremes in beach sediments, *J. Hazard. Mater*. **416** (2021) 126140.
[113] F. Faure, C. Saini, G. Potter, F. Galgani, L.F. de Alencastro, P. Hagmann, An evaluation of surface micro- and mesoplastic pollution in pelagic ecosystems of the Western Mediterranean Sea, *Environ. Sci. Pollut. Res*. **22** (2015) 12190–12197.
[114] B. Gewert, M. Ogonowski, A. Barth, M. MacLeod, Abundance and composition of near surface microplastics and plastic debris in the Stockholm archipelago, Baltic Sea, *Mar. Pollut. Bull*. **120** (2017) 292–302.
[115] W. Zhang, S. Zhang, J. Wang, Y. Wang, J. Mu, P. Wang, X. Lin, D. Ma, Microplastic pollution in the surface waters of the Bohai Sea, China, *Environ. Pollut*. **231** (2017) 541–548.
[116] C.C. Wessel, G.R. Lockridge, D. Battiste, J. Cebrian, Abundance and characteristics of microplastics in beach

sediments: insights into microplastic accumulation in northern Gulf of Mexico estuaries, *Mar. Pollut. Bull*. **109** (2016) 178–183.

[117] J. Martins, P. Sobral, Plastic marine debris on the Portuguese coastline: a matter of size? *Mar. Pollut. Bull*. **62** (2011) 2649–2653.

[118] A.L. Andrady, Microplastics in the marine environment, *Mar. Pollut. Bull*. **62** (2011) 1596–1605.

[119] A. Isobe, K. Kubo, Y. Tamura, E. Nakashima, N. Fujii, Selective transport of microplastics and mesoplastics by drifting in coastal waters, *Mar. Pollut. Bull*. **89** (2014) 324–330.

[120] P. Possatto, M. Barletta, M. Costa, J. Ivar do Sul, D. Dantas, Plastic debris ingestion by marine catfish: an unexpected fisheries impact, *Mar. Pollut. Bull*. **62** (2011) 1098–1102.

[121] A.L. Lusher, M. McHugh, R.C. Thompson, Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel, *Mar. Pollut. Bull*. **67** (2013) 94–99.

[122] G. Seena, K.R. Muraleedharan, C. Revichandran, S.A. Azeez, S. John, Seasonal spreading and transport of buoyant plumes in the shelf off Kochi, southwest coast of India-a modeling approach, *Sci. Rep*. **9** (2019) 19956.

[123] G. Hariharan, P. Ramachandran, I. Anandavelu, R.S. Robin, R. Ramesh, Ingestion and toxic impacts of weathered polyethylene (wPE) microplastics and stress defensive responses in whiteleg shrimp (*Penaeus vannamei*), *Chemosphere* **300** (2022) 134487.

[124] G. Hariharan, P. Ramachandran, I. Anandavelu, R.S. Robin, R. Ramesh, Accumulation and ecotoxicological risk of weathered polyethylene (wPE) microplastics on green mussel (*Pernaviridis*), *Ecotoxicol. Environ. Saf.* **208** (2021) 111765.

[125] N. Ranger, S. Hallegatte, S. Bhattacharya, M. Bachu, S. Priya, et al. An assessment of the potential impact of climate change on flood risk in Mumbai, *Clim. Chang*. **104** (2011) 139–167.

[126] D. Honingh, T. van Emmerik, W. Uijttewaal, H. Kardhana, O. Hoes, N. van de Giesen, Urban river water level increase through plastic waste accumulation at a rack structure, *Front. Earth Sci*. **8** (2020) 28.

[127] A. Bratovcic, Available recycling solutions for increased personal protective equipment in the environment due to the COVID-19 pandemic, *Aswan Univ. J. Environ. Stud*. **2** (2021) 1–10.

[128] A. Bhattacharya, S.K. Khare, Ecological and toxicological manifestations of microplastics: current scenario, research gaps, and possible alleviation measures, *J. Environ. Sci. Health C* **38** (2022) 1–20.

[129] DoE, Coastal zone management, Department of Environment, Government of Tamil Nadu (2023). https://www.environment.tn.gov.in/crz (accessed February 2023).

[130] DoE, Draft Tamil Nadu State Action Plan on Climate Change - 2.0 Department of Environment (DoE), Government of Tamilnadu (2023). https://www.environment.tn.gov.in/tnsapcc-draft (accessed February 2023).

[131] K.K. Balachandran, G.S. Reddy, C. Revichandran, K. Srinivas, P.R. Vijayan, T.J. Thottam, Modelling of tidal hydrodynamics for a tropical ecosystem with implications for pollutant dispersion (Cohin Estuary, Southwest India), *Ocean Dyn*. **58** (2008) 259–273.

[132] J. Maynard, J. Byrne, K. Kerrigan, D. Tracey, K. Bohnsack, F. Pagan, J. Walczak, G.J. Williams, J. Waddell, Coral reef resilience to climate change in the Florida Reef Tract; In: Florida Department of Environmental Protection Technical Report (2017) p. 23.

[133] M. Mugilarasan, R. Karthik, R. Purvaja, R.S. Robin, B. Subbareddy, G. Hariharan, S. Rohan, T.P.S. Jinoj, I. Anandavelu, P. Pugalenthi, R. Ramesh, Spatiotemporal variations in anthropogenic marine litter pollution along the northeast beaches of India, *Environ. Pollut*. **280** (2021) 116954.

[134] O.O. Fadare, E.D. Okoffo, COVID-19 face masks: a potential source of microplastic fibers in the environment, *Sci. Total Environ*. **737** (2020) 140279.

[135] The Hindu, Chennai-based environmental group seeks more norms for disposal of COVID-19 medical waste in Tamil Nadu (2020).

[136] T.R. Walker, (Micro)plastics and the UN sustainable development goals, *Curr. Opin. Green Sustain. Chem*. **30** (2021) 100497.

[137] M. de Oliveira Soares, Climate change and regional human pressures as challenges for management in oceanic islands, South Atlantic, *Mar. Pollut. Bull*. **131** (2018) 347–355.