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REVIEW ARTICLE

EARTHQUAKE, TSUNAMI AND CLIMATE CHANGE ON 2026

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ABSTRACT

Earthquakes and tsunamis remain among the most devastating natural hazards, and in 2026 their impacts are increasingly compounded by the accelerating effects of climate change. While earthquakes originate from tectonic plate movements, tsunamis triggered by undersea seismic activity cause widespread destruction along vulnerable coastlines. Simultaneously, rising sea levels, ocean warming, and extreme weather events linked to climate change intensify coastal exposure and magnify disaster losses. This study examines the interrelationship between earthquakes, tsunamis, and climate change in 2026, with the objective of assessing their combined environmental, socio-economic, and infrastructural impacts. Findings indicate that higher sea levels enable tsunami waves to penetrate further inland, increasing casualties, displacement, and economic damage. Climate-induced degradation of natural coastal defenses, such as mangroves and coral reefs, further reduces resilience against seismic sea waves. Additionally, densely populated coastal cities face heightened risks due to inadequate preparedness and rapid urbanization. The study concludes that although climate change does not cause earthquakes, it significantly amplifies the destructive consequences of tsunami events. An integrated disaster risk management framework is therefore essential. It is recommended that governments strengthen early warning systems, invest in climate-resilient infrastructure, restore natural coastal buffers, and enhance international cooperation to reduce vulnerability and promote sustainable development in hazard-prone regions.

KEYWORDS

Earthquake, Tsunami, Climate Change, Disaster Risk Reduction,. Coastal Vulnerability

1. INTRODUCTION

1.1 Overview of Earthquakes and Tsunamis

Earthquakes are sudden discharges of elastic strain energy stored along faults in the lithosphere of the earth mostly at the convergent plate boundaries. The subduction earthquakes are the most destructive megathrust earthquakes in the sense that they are characterised by large area of rupture and high vertical shifting of the sea floor. Rupture depth variability, slip heterogeneity, stress drop and fault geometry variability have a strong impact on seismic moment magnitude and ground shaking intensity (Lay et al., 2012). Particularly dangerous is propagation of shallow ruptures towards ocean trenches that enhance vertical uplift and subsidence of the seabed, hence, making tsunami generation potential higher. Increased seismic surveillance across tectonically active margins, in 2026, strengthens the long-term geophysical vulnerability of such high-magnitude earthquakes, especially in the heavily populated marginal coastal areas with growing infrastructure and reduced resilience capacity.

Tsunamis are excessive water waves of large scale in the ocean, which are caused mainly by underwater earthquakes that result in sudden vertical movement of columns of huge ocean water. They can travel faster than 700 km/h in the deep water, and as they approach the shallow coastal shelves, the amplification of the waves takes place because of the shoaling effect (Satake, 2015). Bathymetry, coastal geomorphology, and nearshore topography determine the inundation distance and the destructive force. As revealed in this paper, low ground levels increase the inland penetration and worsen destruction of ports, transport systems and coastal settlements. The tectonic trigger-meets-changing vulnerability of coastlines indicates the need to adopt both seismic and climate risk management in 2026.

1.2 The Growing Threat of Climate Change

Climate change is an endemic and escalating global threat that reforms the environmental foundations and exacerbates the effects of geophysical risks. Increased global mean temperatures, which have been caused by rising greenhouse gas levels, have increased thermal expansion of ocean water and melting polar ice sheets, which are major contributors of sea-level rise. Already a 1.5degC rise in global temperature has been indicated to cause significant changes in coastal ecosystems, hydrological extremes, and ocean dynamics (Hoegh-Guldberg et al., 2018). High mean sea level raises the initiating base upon which the propagation of the tsunami waves take place inland and enhances the depth of inundation, lateral displacement, and hydraulic energy. This high base in coastal megacities of high density and low-lying deltaic systems has an extreme amplification of exposure to seismic sea waves and the related impact on infrastructure collapse.

In addition, the projections in the long term indicate a steep increase in both costs of coastal flood damages and adaptive expenditures due to sustained conditions of sea-level rise, and most so in developing economies that are relatively weak in their adaptive ability (Hinkel et al., 2014). The loss of natural coastal defence systems such as mangrove forests and other coral reef systems decreases the frictional resistance to the incoming tsunami waves, raising the wave run-up heights and the distance in which the waves can penetrate the inland areas. These stressors that interact support the findings of this study that climate change is a risk multiplier and thus contributes to the socio-economic and infrastructural impacts of the earthquake-induced tsunamis in 2026.

1.3 Rationale for Integrated Hazard Assessment

The complex connexion between the geophysical and climate-driven processes makes integrated hazard assessment progressively inevitable in

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2026. Earthquakes and tsunamis do not happen in isolation but they are most of the times followed by a cascading effect on the environmental, infrastructural and socio-economic systems. When an initial earthquake sequentially creates secondary hazards, including tsunamis, coastal flooding, infrastructure malfunction, and health crises in the population, cascading disasters occur and interact dynamically with prior vulnerabilities (AghaKouchak et al., 2020). These interactions aggravate the magnitude and spatial area of disaster in coastal regions where sea-level has already risen and the ecosystem is already degrading. In the case of an example, high baseline sea levels may increase the height of the run-up of tsunamis whereas weakened coastal defences may increase erosion and structural collapse. The piecemeal hazard evaluation framework does not represent these interdependencies and this is what underestimates overall systemic risk.

Furthermore, the multi-hazard risk analysis focuses on the necessity to assess overlapping hazards in common space and time, especially in the high density coastal corridors (Kappes et al., 2012). The conventional single-hazard models do not completely deal with the risks of compounds when tectonic and climatic stressors occur simultaneously. The intensification of tsunami effects in shifting climatic conditions requires the consideration of comprehensive modelling that includes seismic, sea-level, land-use dynamics, and infrastructure resilience measures as shown in the findings of the current study. These elaborate evaluation systems play a crucial role in proper risk prediction, sustainable urban development, and disaster mitigation policies in disaster prone areas (Ussher-Eke et al, 2024).

1.4 Objective and Scope of the Study

The main purpose of this research is to observe the correlation between earthquakes, tsunamis, and climatic change in 2026, and especially the amplification of the effects of the seismic sea waves by the changes in climate due to the environmental changes. The paper aims to examine the geophysical processes in which earthquakes are produced, the mechanisms, which cause tsunamis, and how the increase in sea levels and corrosion of coastal ecosystems ultimately aggravates the effects of disasters. It also seeks to determine the socio-economic, environmental, and infrastructural effects of these combined hazards, particularly in the highly populated coastal areas. The proposed study will combine seismic risk and climate variability factors to offer a comprehensive insight on the dynamics of compound hazards and their effects on sustainable development and disaster resilience.

The area of the research is the worldwide seismic hotspots and the areas prone to tsunamis and analysed analytically are the areas that are rapidly urbanising, have high population density, and are becoming more vulnerable to climate. It takes into account not only physical effects, including inundation of coasts, destruction of infrastructure, and disappearance of an ecosystem, but also more social-economic consequences such as displacement, health risks to populations, and economic disorientation. The paper also covers the disaster risk management models, early warning signals, and climate adaptation plans as pertinent to 2026. The study addresses both the geophysical and climate aspects thus offering a combined view on hazards that can be used in policy-making and resilience planning.

1.5 Structure of the Paper

The paper has been logically organised to give an in-depth examination of the nature of interactions among earthquakes, tsunamis, and climate change. It starts with an introduction about the background, objectives, and scope of the study, and then proceeds to the literature review that looks at the tectonic processes, dynamics of tsunamis, and climate-related stressors. The later sections address global and regional trends of seismic and coastal hazards, putting emphasis on human effects, economic effects and environmental effects. The next topic that is discussed is risk mitigation strategies, such as early warning systems, climate-resilient infrastructure, and restoration of coastal ecosystems in combination with policy frameworks. Finally, the paper concludes with a synthesis of key findings, policy and institutional recommendations, and future research directions, emphasizing the need for global cooperation and multi-hazard preparedness to enhance resilience and sustainable development in hazard-prone regions.

2. CONCEPTUAL AND THEORETICAL FRAMEWORK

2.1 Tectonic Processes and Seismic Activities

The seismic activities are primarily caused by the tectonic processes, which are regulated by the relative movement of the lithospheric plates along boundaries having convergent, divergent and transform faults. Accumulation of stress in these boundaries, especially in locked parts of subduction zones and transform faults will result in sudden release of energy that is experienced as earthquakes s presented in figure 1 (Kanamori and Brodsky, 2004). The geometry and frictional properties of faults, and accrued stress affect the rupture propagation and the magnitude of the earthquake. Shallowness crustal earthquakes are more likely to produce stronger surface shaking, whereas events of deep-focus, though less harmful on the surface, may produce second geophysical effects such as landslides and seafloor movement. An illustration of this is the Sumatra-Andaman earthquake of 2004 that showed how a tsunami with disastrous effects could be caused by a 1,300km long rupture along a subduction interface, underscoring the importance of tectonic processes and hazard potential in relation to each other (Stein and Wysession, 2003).

The intraplate stress redistribution and the regional geological heterogeneities also affect seismic activities and have the ability to moderate the earthquake frequency and intensity. Historically seismically blank areas tend to store a lot of elastic energy over decades and are therefore especially vulnerable to high magnitude events. When several fault segments interact it may give rise to compound ruptures, which lead to the prolonged period of shaking and increased tsunami hazard where such interactions occur under oceanic part (Nwokocha and Okoh, 2024). Tracking and simulation of such tectonic activities are still a major concern in the determination of the pattern of occurrence of earthquakes and their cascading effects on coastal communities and structures as seen in the findings of this study in amplified tsunami susceptibility alongside climate-induced rise in sea level.

Figure 1 depicts basic tectonic processes and seismic activities that take place in the crust and otherwise upper mantle of the earth. The upper part depicts a divergent plate boundary in which the crust of continents is being pulled as a result of extensional tectonic forces. When the lithospheric plates are drifting apart, normal faults are created and a rift valley is created at the surface. Under this rifting zone, the asthenosphere ascends and decompression melting takes place as the pressure reduces producing magma that may intrude into the crust or erupt volcanically. This process undermines the crust and produces areas of instability that predispose such regions to occurrence of frequent shallow earthquakes which are related to crustal stretching and motion of faults. The bottom part illustrates the seismic movement along a fault plane where the stress bin up of tectonic forces eventually surpasses the strength of rocks causing sudden rupture. The location of the earthquake beneath the surface is where the point of the earthquake is concentrated (hypocenter) and the point directly over it on the surface of the earth is called the epicentre. The movement of the upthrown block and the descending block gives out energy as seismic waves depicted as concentric wave fronts depelling away. This is to show that tectonic stress, fault mechanics, and crustal deformation all combine to produce earthquakes and surface ground shaking.

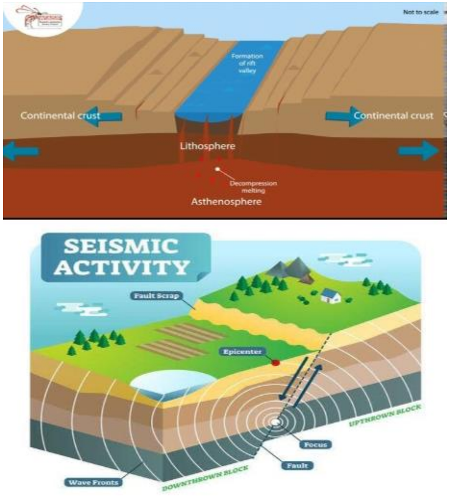

Figure 1: Diagram of Tectonic Processes and Seismic Activity (Kanamori and Brodsky, 2004).

2.2 Tsunami Formation and Propagation Dynamics

Tsunami formation starts with the rapid movement of large masses of seawater and the main causes of the above mentioned are the sudden movements of the seafloor due to the occurrence of megathrust earthquakes or submarine landslides. The amplitude and structural design of displacement of seafloor, both vertical and horizontal, determine the initial waveform of the tsunami and the amplitude of the radiation, which determines the first waveform of the tsunami and radiation pattern.

Recent research also notes that in addition to the traditional long-wave shallow water model, the propagation of tsunami must be considered in terms of a gravitationally and elastically coupled Earth-ocean system in which the deformation of the seafloor and the mass of water are dynamically coupled, which changes both the gravity and the feedback processes as the wave propagates (Watada, 2023). This type of coupling has an impact on traveltime, dispersion of the waveforms and the properties of the far-fields as can be observed by the events that happened in the 2010 maule and 2011 Tohoku-oki which were not fully accounted by the conventional models.

Complex waves Wave energy, bathymetry, and coastal morphology interaction Dynamics of propagation of tsunamis across ocean basins. The speed of the tsunami waves in deep water is close to the speed of long-gravity waves, which is generally over 700 km/h, and the bathymetric conditions refract, reflect, and concentrate the energy that may increase the wave elevation at specific coast line (Tanioka, 2023). Inferred sources processes of the tsunami waveforms data, such as timing and slip distribution of great earthquakes, have been increasingly utilised to improve the propagation models and improve the early warning systems. This thorough perception of the propagation relations is consistent with the research results that show that oceanic variations and morphological characteristics also precondition the coastal tsunami effects of 2026 not just the seismic triggers but also the oceanic and morphological conditions (Raphael et al., 2025).

2.3 Climate Change and Environmental Stress Amplification Theory

Climate change is also a stressor of the environment in terms of seismic and oceanic hazards in the sense that it can change the conditions of the base and increase the exposure and vulnerability to hazards. According to this amplification theory, global warming, caused by the anthropogenic greenhouse gas emissions, amplifies the existing environmental pressures, i.e., rising sea levels, and in such a way increases the probability and intensity of compound disasters which involve both tectonic triggers (e.g., earthquakes and tsunami generation) and climate-driven processes (e.g., rising sea levels and coastal flooding) as represented in table 1 (Long and Duan, 2025). As an example, empirical studies of the mechanisms of coastal flooding in the Gulf of Guinea reveal that the risk of exposure of coastal populations and business infrastructure to the consequences of strong floods increases substantially with rising sea levels, as well as alterations in oceanographics, without an accompanying tectonic event (Ghomsi et al., 2024). Such elevation of the seismic caused tsunami waves raises the depth and inland penetration of tsunami waves, which directly enhance human/economic damages in 2026 as per the study findings.

In addition, the dynamic modelling of the risk of compound floods in climate-strained urban environments also reveals that the interplay between population distribution, sea level rise, and storm surge extremes form a vicious cycle, which exacerbates systemic vulnerability (Long and Duan, 2025). Human mobility and demographic interactions are fundamental in hazard evaluation models, showing that the city is not only physically more vulnerable to amplified floods, but also socially more prone to this higher vulnerability in the climate pathways in the future (Ghomsi et al., 2024). This model of environmental stress amplification highlights the imperative to introduce the changing climate baselines into earthquake and tsunami risk model to adequately assess the compounded risk situations.

Table 1: Summary of Climate Change and Environmental Stress Amplification Theory

Environmental Stressor	Climate Change Influence	Amplification Mechanism	Impact on Human and Ecological Systems
Rising Sea Levels	Accelerated melting of polar ice and thermal expansion	Increases baseline water levels, enhancing storm surge and tsunami impacts	Coastal flooding, habitat loss, displacement of populations, saltwater intrusion in agriculture
Ocean Warming	Increased ocean temperatures and heat content	Intensifies storm energy, modifies ocean currents, and promotes coral bleaching	Greater frequency and severity of extreme weather events, marine biodiversity loss, disruption of fisheries
Increased Rainfall and Flooding	Shifts in precipitation patterns and extreme events	Saturates soils, increases riverine flow, and reduces absorption capacity	Infrastructure damage, urban flooding, waterborne diseases, agricultural losses
Drought and Water Scarcity	Altered hydrological cycles, reduced rainfall in arid regions	Reduces water availability, stresses agriculture, and increases wildfire risk	Food insecurity, economic losses, ecosystem degradation, migration pressures

3. EARTHQUAKES AND TSUNAMI EVENTS

3.1 Recent Global Seismic Trends

The latest trends of seismicity in the world indicate that there remains a complexity in earthquake location, frequency, and magnitude, with nuanced spatial and temporal changes in seismicity patterns in tectonic regimes. The review of 27,100 large earthquakes (Mw [?] 5.5) in 1965-March 2025 shows that the large-magnitude events still concentrate along active plate boundaries, but the spatial reporting of seismic occurrences does not align with the instrumental surveillance, which points to the lack of scientific emphasis in comparison with the empirical distribution of seismicity events as represented in table 2 (Kao, 2025). Areas like the pacific ring of fire, Mediterranean-alboran zone and Himalayan-Tibet collision front are all equally active and the mechanisms of megathrust, strike-slip and oblique faults add to a wide range of earthquake magnitudes and depths. Spatial trend analyses also indicate that patterns in seismic hazards are highly affected by redistribution of tectonic stress, crustal heterogeneities and the dynamics of fault coupling, which determine recurrent and release patterns of earthquakes all over the world.

The fine variability of earthquake occurrence in historically active and complex shear-zone illustrates case studies of seismic sequences, including the occurrence of the July 14, 2025 Mw 5.3 earthquake at the northeastern Alboran Sea (Lozano et al., 2026). Intricate fault geometries and stress orientations can be explained with events of even moderate magnitude due to the advanced relocation methods and moment-tensor inversion, which identify long clusters of hypocenters along a strike-slip fault. Such tendencies are consistent with overall findings of the world seismic catalogues that record common intermediates and shallow earthquakes that are observed in various tectonic conditions and across different subduction interfaces as well as intraplate surfaces. Taken together, these seismic trends in 2025 and early 2026 feed in to our knowledge of how the tectonic forces come in and out of phase with the production of earthquakes and allow the refinement of probabilistic models to be used in the assessment of hazards in earthquake prone regions.

Table 2: Summary of Recent Global Seismic Trends

Seismic Trend	Observed Patterns (2018–2026)	Driving Factors	Implications for Human and Environmental Systems
Increased Earthquake Frequency	Higher occurrence of shallow crustal earthquakes in tectonically active regions	Plate boundary movements, fault stress accumulation	Greater infrastructure damage, heightened risk in urban areas, disruption of essential services

Table 2 (cont): Summary of Recent Global Seismic Trends

Magnitude Variability	Rise in moderate-to-high magnitude earthquakes (>6.0 Mw)	Stress transfer along active faults, historical seismic gaps	Increased mortality, economic losses, challenges to disaster response planning
Regional Clustering	Concentration of seismic events in the Pacific “Ring of Fire,” Indonesia, Japan, and South America	Subduction zones, convergent plate boundaries, volcanic activity	Localized urban vulnerability, tsunami risk, disruption of transportation and energy networks
Seismic-Induced Secondary Hazards	Earthquakes triggering tsunamis, landslides, and soil liquefaction	Topography, coastal proximity, soil composition	Amplified human casualties, long-term displacement, environmental degradation, and infrastructure collapse

3.2 Major Tsunami-Prone Regions

Most of the major areas in the world susceptible to tsunamis are mostly linked to the active subduction zones and tectonic dynamic margins where earthquakes, submarine landslides, and volcanism activities may cause massive ocean floor movement. The most active part, in seismic and tsunamically active, is the circum-Pacific subduction belt, or the Pacific Ring of Fire, which spans the coasts of the countries of Japan, Indonesia, the Philippines, Papua New Guinea, and the west coasts of North and South America. The history shows that this area was often affected by large tsunamis, one of which was the devastating 2004 event in the Indian Ocean and several high-runup events in Indonesia which were caused by megathrust earthquakes and complicated source processes as presented in figure 2 (Reid and Mooney, 2022). Besides the Pacific Ocean, the basin of the Indian Ocean including Sunda megathrust, Andaman-Nicobar subduction and Makran margin could present a high tsunami risk because of large thrust earthquakes, which can produce trans-oceanic tsunami waves, which affect South and Southeast Asian and East African coasts.

Secondary yet still significant areas prone to tsunamis in the ocean are volcano island arcs where flank collapse and explosive eruptions may cause tsunamis in adjacent ocean basins, and inland narrow inland sea basins where local crustal faulting, as well as submarine landslides, are episodic threats to tsunamis. In Indonesia, e.g., the assessment of coastal hazards indicates the existence of spatial variations based on the exposure to tsunamis and bathymetry, coastal slope, and population density; it highlights the overlap of the geological sources and human exposure (Jumadi et al., 2025). Such a variety of source types and geomorphological environments is the reason why tsunami risk is not limited to a single ocean basin but can be observed anywhere provided that the environment permits the rapid movement of large amounts of water.

Figure 2 illustrate the devastation of a coastal settlement in the effects of the tsunami are widespread as it is depicted to be highly vulnerable to major tsunami-prone areas including Southeast Asia, Pacific Ring of Fire, and sections of the Indian Ocean basin. These areas are normally found in the active seduction areas where the oceanic plates overlap and subduct under the continental or other oceanic plates which produce very strong undersea earthquakes that can displace huge volumes of water. The resulting waves of the tsunami move quickly through ocean basins and when they arrive at shallow coastal waters, the waves grow in size and strength, and low-lying communities are covered with destructive power. The broken houses, debris, and translocated cars that are depicted in the picture indicate the great hydrodynamic energy and sediment transportation accompanying the run-up and backwash of a tsunami. These effects are amplified in densely populated coastal areas with few vertical evacuation paths or strong infrastructure, resulting in widespread loss of life, economic impact and permanent displacement. The scene highlights the high level of necessity of efficient early warning systems, zoning of coastal areas, and construction resistant to the tsunami-prone areas.

Figure 2: Picture of Tsunami Devastation in a Coastal High-Risk Region (Reid and Mooney, 2022).

3.3 Human and Economic Impacts of Recent Events

Recent earthquake and tsunami damage to humanity and economy has highlighted the complexity of disaster effects and their effects on survival, employment, health and ultimate social well-being. The earthquake and tsunami catastrophes have both short and long-term impacts on human capital, such as impairing educational pathways, physical health outcomes, and productivity of the community, especially in areas where demographic vulnerability is high (Paudel, 2025). Intense shaking of the ground, structural fracture and flooding of the coastal area cause direct and immediate mortality, massive injuries and population displacement. In addition to the loss of life, there is disruption of education, livelihoods and post-traumatic stress disorder which increase the human cost, lowering the workforce involvement and undermining the chances of recovery. Transitional displacement is frequently associated with secondary public health issues, which increase disparities among people affected and burden health services in the long term (Omachi and Okoh, 2025).

The economic effects of the current seismic activities are no exception as they include both direct losses and indirect losses which pose a challenge to the local, regional, and national economic strength. Macroeconomic impact assessments illustrate that earthquakes may lead to massive declines in the growth of the gross domestic product (GDP), employment, and sector output, particularly in construction sectors, services and agriculture (Demirdag and Nirwansyah, 2024). Damage of infrastructure, business interruption and reconstruction costs usually redirects the available public funds that could have been used in planned investments and the uninsured losses burden the entire households and small businesses in disproportionate amounts. The high costs of the long-term rehabilitation and the delaying economic activity highlight the high importance of combined disaster risk financing and resilient infrastructure planning to reduce the negative human and economic impacts of earthquakes and tsunami threats in the year 2026 and beyond.

4. CLIMATE CHANGE AS A RISK MULTIPLIER

4.1 Sea-Level Rise and Coastal Flooding

Rise of sea levels is a fundamental cause of modern and future coastal floods, which fundamentally changes the base water levels upon which extreme sea surges, tides, and storms occur. Rapid rises in mean sea level, to a large extent explained by thermal expansion of warming ocean waters, ice melting, and land hydrology changes, contribute to the occurrence of inundation events and their severity. Local rates of sea-level rise have also been reported as high as 3.89 mm/year in the Gulf of Guinea, which is higher than the rest of the world and has been adding to projected shoreline erosion, saltwater intrusion, and land permanently flooded under high-emission conditions (Ghomsi et al., 2024). The modelling work suggests that the trends can put millions of people living in the coastal areas and extensive infrastructure at the risk of constant floods, and land loss and changed nearshore processes will increase social economic and ecological risks.

Besides, topographical exposure to flooding, distribution of infrastructures and socio economic determinants contribute to the risk of flooding. Climate change, which involves sea-level rise, in the United States is estimated to expose more than 5,500 coastal facilities such as power plants, sewage treatment facilities, and industrial locations to a 1-in-100-year flood in 2100, with marginalised communities showing a higher disproportion of those at risk due to low adaptation capacity (Cushing et al., 2025). Not only do these increasing baselines elevate routine high-water flooding, but also raise the base level of tsunami wave transmission and could therefore potentially enhance the inland extent and destructive capacity of tsunami flooding in 2026 and beyond.

4.2 Ocean Warming and Ecosystem Degradation

Warming of oceans is one of the key factors contributing to the degradation of marine ecosystems, which are essentially a paradigm shift in thermal regimes, biogeochemical cycles and structure of communities in oceans globally. Marine heatwaves, which are prolonged spurts of comparatively higher ocean temperatures, have escalated in their intensity, duration, and geographical spread over the past decades and transformed trophic relations and energy circulations in marine food webs as represented in table 3 (Gomes et al., 2024). These heatwaves alter the predator-prey interactions by making heat-tolerant taxa like gelatinous zooplankton and similar dominating in the aftermath of heatwaves, taking energy out of commercially valuable species. Changing food web structure influences nutrient cycling, decreases the efficiency of biomass transfer and impairs the resilience of fisheries that support the economy of the coastal areas. Besides, high oceans temperature heightens metabolic stress, mortality rate among stenothermal organisms, and alters phenological patterns leading to sudden community restructuring.

Alongside warming, massive events of coral bleaching have become one of the most noticeable signs of ecosystem degradation, with the recent global bleaching infection of 2023-2025 covering about 84% of all coral reef systems globally (NOAA, 2025). The heat stress interferes with the symbiotic relationship between the corals and their zooxanthellae algae leading to mass coral deaths that reduce the complexity of the habitat, biodiversity and shore protection against waves. The disappearance of coral reef ecosystems destabilises important services including fisheries, tourism, and coastal buffering and enhances the susceptibility to ocean warming and adds to the environmental stressors that converge with tectonic and tsunami risks in 2026.

Table 3: Summary of Ocean Warming and Ecosystem Degradation

Oceanic Change	Climate Driver	Mechanism of Ecosystem Degradation	Impacts on Human and Ecological Systems
Rising Sea Surface Temperatures	Global warming, greenhouse gas emissions	Thermal stress leading to coral bleaching, altered species distributions, and disruption of food webs	Loss of fisheries, decreased coastal livelihoods, reduced biodiversity, and weakened reef protection
Ocean Acidification	Increased CO_2 absorption	Lowered pH affecting calcifying organisms like corals, mollusks, and plankton	Impaired shellfish production, ecosystem imbalance, reduced carbon sequestration, and economic losses for fisheries
Deoxygenation	Warmer waters reducing oxygen solubility	Expansion of hypoxic zones, fish kills, and altered marine species behavior	Decline in fish stocks, reduced marine protein availability, and habitat loss for marine fauna
Altered Ocean Currents	Climate-driven temperature and salinity changes	Disruption of nutrient transport, migration patterns, and plankton productivity	Food web destabilization, coastal ecosystem degradation, and increased vulnerability of dependent human communities

4.3 Extreme Weather Events and Compound Disasters

Anthropogenic climate change has increased the frequency and intensity of extreme weather events over the past several decades, resulting in compound disaster situations in which several hazards interact or co-exist in close time periods (Brett et al., 2025). Such compound events may include heat waves coupled with drought, heavy precipitation and flood, and tropical cyclones and storm surge, which increases the usual effects of both other hazards. As an example, recent studies indicate that compound flooding, whereby a tropical cyclone causes heavy rainfall in the same time as a coastal storm surge, causes greater flood expanse than single events, exposing a greater number of inland areas and infrastructures to deeper flooding and long-term exposure to hazards as presented in figure 3 (Grimley et al., 2024). These interactions do not only escalate physical risk, but also load the emergency response mechanisms, since these overlapping crises demand resources at the same time.

Complexity of these disasters is their compound nature that makes it more difficult to predict, prepare and respond to these disasters since conventional models of hazards rely on analysing individual extreme weather events. Compound scenarios may have non-linear effects, like the effect of a pre-existing heatwave drying soils, then increasing downstream flooding or the risk of wildfires, or the effect of multiple storms on a catchment before further rainfall events (Brett et al., 2025). This will take the form of the tsunami risk being increased in the coastal areas where heavy rain and storm surges can increase the level of water in the baselines before the arrival of seismic sea waves. The interdependence of numerous climate drivers and hazard processes hence the need of risk frameworks in an integrated approach, which would position frameworks to capture the entire range of extreme weather and compound disaster dynamics in the year 2026 and beyond.

Figure 3: Picture of Destruction from Extreme Weather and Compound Disaster (Grimley et al., 2024).

Figure 3 illustrate a massive structural devastation which is observed in line with the effects of extreme weather conditions like hurricanes or heavy storms, which show how the compound disasters increase susceptibility among the impacted communities. The damage to trees, demolished houses, the debris is evidence of strong winds, heavy rainfall and perhaps storm surges, all of which are typical of reinforced weather systems caused by climate. Extreme weathers commonly have domino effects such as flooding, infrastructure collapse, power cuts, and restriction of necessary services. When such hazards interact with underlying vulnerabilities, i.e. the poor building construction, poor drainage, or poor emergency preparedness, the compound disaster exasperates human losses, economic losses, and environmental losses. The view also shows the protracted recovery that communities have to cope with since residents are scanning through the rubble to salvage their possessions in the face of extensive damage. These incidents underscore the increasing role of the climate change in enhancing their intensity and frequency of storms, a factor that demonstrates the importance of resilient infrastructure, adaptive urban planning, and integrated disaster risk management to lessen the effects in future.

5. SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS

5.1 Infrastructure Damage and Urban Vulnerability

Citywide destruction due to earthquakes, tsunamis, and hazards aggravated by climate changes contributes greatly to the impairment of city functionality and vulnerabilities within the systems, which can increase the effects of disasters. Urban infrastructure systems consist of an interdependent network of transportation, utilities, communication, and water systems, which serve the social and economic system as lifelines. Seismic shaking in the city creates structural stresses that may cause fractures, partial collapses, and disruptions to services in the urban environment, which in turn can cause damage to the buildings, roads, and bridges, cascading through the entire urban system (Civera et al., 2025). As an illustration, elevated roads and bridges typically undergo ground shaking or collapse when reacting to intense ground vibrations, disrupting vital connectivity and emergency supply chains. In addition, high populations in cities, which are targets of exposure, facilitate the effects of asset failures, as critical infrastructure becomes inoperable, which makes it difficult to engage in rescue efforts and recovery activities following a disaster.

Climate-related threats like heavy precipitation and coastal flooding are also useful in explaining the vulnerabilities of the cities to the extent of subjecting the infrastructure to both chronic stressors and acute shocks at the same time. The main urban drainage systems, power supply systems, and transportation systems are likely to be overwhelmed and destroyed in serious flood events, affecting both utility and movement (Yang et al., 2025). Multi-hazard scenarios involving flood and seismic events indicate how climate change enhances infrastructure risk with underlying design or maintenance vulnerability situations being compounded by multi-hazards. In the case of coastal cities, the tsunami intrusions that occur after an earthquake may run into a high baseline of sea level, and the level of inundation and destruction of port facilities, sewage treatment systems and even power plants. These compounded stressors demonstrate the complexity of dependencies of urban infrastructure, in which the failure of one element of the urban infrastructure (a transportation connexion or electrical substation) can trigger a wider functional failure across the urban system. A variety of and adaptive design options such as retrofitting, network design redundancy, and multi-hazard risk modelling are thus extremely important in minimising the vulnerability of the infrastructure and increasing the resilience of the urban environment to hazard-related challenges in 2026 hazard landscapes.

5.2 Public Health and Population Displacement

The overall health care systems are often highly overstretched post-disaster due to the earthquakes, tsunamis, and displacement since the people who have been displaced have to grapple with various acute and chronic health issues. Longitudinal studies that occurred after the 2011 Japan Earthquake and Tsunami indicate that residential displacement may have long-term consequences on the physical and cognitive health of survivors such as emergence of functional limitations, depressive symptoms, and risk of cognitive decline, a number of years after the disaster as presented in figure 4 (Hikichi et al., 2021). Displacement denies one access to regular healthcare, good nutrition, and social support networks, which in combination also leads to worsening physical health and increased exposure to development of chronic diseases. As an illustration, the populations displaced to temporary housing can become less physically active and socially isolated, which increases the risk factors affecting obese and metabolic disorders even when the disaster is already over, and adds to the cumulative health burden related to exposure to the compound hazards.

At the same time, the psychological consequences of long-term evacuation and displacement are considerable, and research reports high levels of mental health disorders of anxiety, depression, and post-traumatic stress observed among those who survived the disaster and were compelled to spend most of their time in shelters (Nakai et al., 2025). Displacement can also be accompanied by disconnection with community organisations as well as environments, which further aggravates stress reactions and weakens the resilience strategies. In addition, disruption of continuity of care among already mentally ill people may contribute to symptom aggravation, which is another burden to the public health care. These issues are aggravated in the highly impacted regions where seismic activities are associated with climate pressures, and these are the reasons why combined health and displacement response strategies are necessary to take care of the short and long-term health conditions of the people affected (samuela et al., 2025).

Figure 4: Picture of Population Displacement and Public Health Challenges in a Temporary Camp (Hikichi et al., 2021).

Figure 4 shows an example of a large displacement camp which represents the extensive population and public health issues that present as a result of natural disasters, conflict, or other hazards caused by the climate. Crowded temporary housing facilities, poor sanitation facilities, and poor availability of clean water promote the risk of contracting communicable diseases like cholera, respiratory diseases and malaria. Displacement of the population usually interferes with the regular healthcare services, immunisation programmes, and consideration of the mother, which leaves weaker groups of people particularly children, the elderly and pregnant women at high risk. Mental health stress can also be triggered by being exposed to traumas and loss of livelihoods as well as being uncertain of resettlement in the long term because of the concentration of people in small areas. In addition, poor nutrition, waste disposal, and inadequate medical supplies increase health vulnerabilities that can result in the outbreak of secondary health emergencies. This scene shows the urgent necessity of organised emergency response, sustainable camp management, and long-term recovery plans which would respond to the immediate humanitarian needs and the longer-term social and health effects of displacement.

5.3 Implications for Sustainable Development Goals

The implications of compounded seismic, tsunami and climatic changes hazards on Sustainable Development Goals (SDGs) are tremendous and their impacts cut across social, economic, and environmental aspects. To promote SDGs like no poverty (SDG 1), sustainable cities and communities (SDG 11) and climate action (SDG 13), it is necessary to explicitly introduce disaster risk reduction (DRR) to development planning to protect the gains made so far. A study demonstrates how earthquakes and tsunamis pose natural hazards that may affect infrastructure, undermine economic stability and expose vulnerability in the occurrence of disaster risk and SDG plans when silos occur as represented in table 4 (Ye and Li, 2025). Additionally, the weaknesses in infrastructure and community resilience demonstrate that sustainable development will never be achieved without focusing on hazard exposure, especially in developing and hazard-prone areas where economic losses can derail the development pace towards the achievement of several SDGs at the same time.

Combining methods that incorporate climate adaptation and DRR as co-benefits of SDGs generate ecosystem, livelihood, and resilience benefits on both small and large scales. Indicatively, nature-based solution and community-based adaptation strategies mitigate hazard exposure, improve ecosystem services, and contribute to socio-economic stability, which are goals and targets of SDGs on life on land (SDG 15) and good health and well-being (SDG 3) (Majlingova, 2025). The integration of hazard risk assessment in urban planning, infrastructure investment and climate adaptation policy creation drives resiliency, which supports long term development paths. These integrative plans are quite necessary so that the gains made towards the global targets are not lost in the future disasters of compounds in 2026 and the future.

Table 4: Summary of Implications for Sustainable Development Goals

SDG Area	Hazard Exposure	Mechanism of Impact	Implications for Development and Resilience
No Poverty (SDG 1)	Earthquakes, tsunamis, and climate shocks	Destruction of livelihoods, assets, and income sources	Increased vulnerability of low-income communities, heightened risk of long-term poverty cycles
Good Health and Well-Being (SDG 3)	Population displacement and hazard-induced stress	Disruption of healthcare services, increased disease incidence, mental health stress	Reduced life expectancy, higher mortality during disasters, strain on public health systems
Sustainable Cities and Communities (SDG 11)	Urban concentration in hazard-prone areas	Infrastructure damage, urban flooding, and limited emergency access	Need for resilient urban planning, safe housing, and disaster-preparedness integration
Climate Action (SDG 13)	Sea-level rise, ocean warming, extreme weather	Amplification of environmental stresses and compound hazards	Necessitates climate adaptation policies, risk reduction strategies, and international cooperation to meet sustainability targets

6. DISASTER RISK MANAGEMENT AND RESILIENCE STRATEGIES

6.1 Early Warning Systems and Technological Innovations

Early warning has become the key to reducing the effects of earthquakes and tsunami by detecting the geophysical indicators promptly and spreading messages that can be used to save lives. ES/TS: These are hybrid earthquake and tsunami early warning systems which involve the rapid seismic source characterization in combination with oceanic monitoring systems to issue alerts in critical lead time windows before damaging waves or shaking as represented in table 5 (Rea et al., 2025). The addition of quick source parameter estimation models like QuakeUp into tsunami forecasting processes has greatly lowered the time lag between the occurrence of a seismic event and the notification of the alarm with respect to the near-coastal areas where the evacuation timeframe could be in the span of minutes. These developments enhance the effectiveness of response protocols of coastal hazards and emergency management systems by increasing the accuracy of probabilistic tsunami forecasting (PTF) with preserving its timeliness.

The early warning capabilities are also increased by technological advances in the seismic array methods which improve the precision of real-time source estimation and tsunami forecasting. Using the hybrid approaches consisting of array processing, W-phase inversion, and tsunami wave analysis, scientists have proven significant gains in the forecast timeliness, and waveforms coherence, compared to traditional systems (Naeini et al., 2026). The set of advances enables the warning systems to define the extent of earthquake rupture and provide a more accurate forecast of the tsunami signal to allow authorities to make more specific alerts and evacuation policies with less ambiguity. These innovations highlight the imperative of persistent technological development in the early warning systems, especially with the complexities of the hazard processes in 2026 due to the presence of compound hazards and climate-related stressors.

Table 5: Summary of Early Warning Systems and Technological Innovations

Technology / System	Function / Mechanism	Innovation / Advancement	Impact on Hazard Preparedness and Response
Seismic Early Warning Systems	Detect initial seismic waves and estimate earthquake parameters	Rapid source characterization, real-time alerts, array processing	Provides critical seconds to minutes for evacuation, infrastructure shutdown, and public safety measures
Tsunami Forecasting Systems	Monitor oceanic displacement and wave propagation	Integration of sea-level sensors, deep-ocean buoys, and probabilistic tsunami forecasting	Improves prediction accuracy, identifies vulnerable coastlines, and guides targeted evacuations
Remote Sensing and Satellite Monitoring	Observe environmental changes, fault movements, and coastal deformation	Use of high-resolution satellite imagery and AI algorithms	Enhances situational awareness, early detection of hazard precursors, and continuous monitoring of affected regions
Hybrid Modeling Platforms	Combine seismic, oceanographic, and climate data for hazard prediction	Coupled simulation models and machine learning algorithms	Enables scenario-based planning, reduces false alarms, and supports decision-making for emergency managers

6.2 Climate-Resilient Infrastructure Development

Climate-Resilient Infrastructure Development has become one of the key principles of adaptation and disaster management approaches, based on a necessity to design, construct, and sustain infrastructure systems that can anticipate, withstand, and recover in the wake of rising levels and frequency of climate-related hazards. The available studies indicate that the infrastructure sustainability should clearly incorporate the resiliency principles that consider climate variability and extreme weathering stressors throughout the asset lifecycle (Islam and Kabir, 2024). In transportation systems, such as increased temperature variability, rising sea level, and increased rainfall ranges put a strain on the structural stability and functionality of road systems, bridges, and rail systems, compelling them to be designed to respond to climate conditions, adopt a more selective approach to material selection, and implement active maintenance protocols that decrease their susceptibility without reducing their long-term performance. Sustainability of infrastructure when subjected to climate change requires systemic examination of the indicators of risk exposure and resilience which influence design decisions and priorities in investments.

Governance and policy-wise, the incorporation of climate resilience in national and regional infrastructure programmes has far-reaching ramifications in the development planning and regulatory framework. In high urbanisation settings like India, inculcating resilience in law and policy will mean that the infrastructure investment decisions that will be made in aid of economic development will not only promote economic growth but also help the populations with climate shocks (Irani et al., 2026). This includes mainstreaming the assessment of climate risks into engineering design codes, land-use planning, and procurement practises, as well as the equitable access to resilient infrastructure services. Additionally, resilient infrastructure investment has co-benefits on environmental sustainability and social equity through advancing inclusive and safe communal areas and continuity of vital services during and following hazards. Climate-resilient infrastructure that has been implemented strategically supports overall sustainable development trajectories and protect human health and economic sustainability in a period of increasing climate unpredictability.

6.3 Coastal Ecosystem Restoration and Policy Integration

Coastal Ecosystem Restoration and Policy Integration underscores the importance of restored and preserved coastal ecosystems (mangroves, tidal marshes, and saltmarshes) in improving the resilience to natural hazardous and climate stressors. Recovering mangrove forest cover and blue carbon ecosystems can offer a set of protective services to reduce the energy of the waves, shoreline, and storm surges and help to achieve the goals of biodiversity and carbon sequestration as presented in figure 5 (Justine and Seenath, 2025). Empirical studies show that vegetative solutions constructed on coastlines by nature can significantly decrease the wave heights and mitigate the effects of the storms, where mangroves and saltmarshes decrease the energy of waves by considerable percentages although their success varies with the composition of the species, vegetation density, and geomorphological setting. When incorporated in larger coastal management systems, such restoration activities can enhance ecological connectivity and buffer zones which decelerate inundation and erosion due to sea-level rise and extreme weather.

The combination of coastal ecosystem restoration with policy frameworks is critical to make sure that disaster risks reduction is integrated with the climate adaptation and sustainable development priorities. Emerging studies on coastal sustainability show that conserving and expanding critical mangrove habitats can help protect several ecosystem services even in the face of anticipated sea-level increase to the benefit of habitat quality, tourism, carbon storage, and shoreline protection (Stamoulis et al., 2026). Integration of policies involves mapping priority coastal areas, integrating solutions based on nature into the management plans of the coastal zones and co-existence of ecological restoration aims with economic and community development plans. These combined strategies will make sure that the restoration investments can enhance hazard protection as well as social-economic performance by entrenching ecosystem resilience within the policy tools that tackle future compound catastrophes in 2026 and beyond.

Figure 5: Picture of Integrated Strategies for Coastal Ecosystem Restoration and Policy Alignment (Justine and Seenath, 2025).

Figure 5 shows important interrelated plans of the Coastal Ecosystem Restoration and Policy Integration, which also underscores that successful restoration is not merely an ecological repair, but governance and coordinated action. The issue of multi-sector collaboration and co-production (C2-C3) depicts the significance of utilizing governments, local communities, scientists, and industry in mutual decision-making. Spatial planning (C4) combines conservation, fisheries, shipping and renewable energy development in order to minimize conflicts and the need to preserve vital habitats. Stressor reduction (C5) solves pollution, overfishing, and degraded habitat, whereas technological advances (C6) enhance the efficacy of monitoring, mapping, and restoration. Climate scenarios (C7) provide adaptive plans when sea-level is rising and oceans are warming. Facilitation (C8) contributes to natural recovery, built ecosystems (C9) e.g. artificial reefs improve the biodiversity and fisheries productivity. Everything is supported by sufficient funding (C10) which makes it sustainable in the long term. Combined, these factors represent a holistic framework of policy, representing a unified integration of ecological science, stakeholder involvement, climate adaptation, sustainable financing, to recover and sustain a resilient coastal ecosystem.

7. CONCLUSION AND RECOMMENDATIONS

7.1 Summary of Key Findings

The research paper brings out the interdependence of effects of earthquakes, tsunamis, and climate change on human societies, ecosystems, and infrastructures. It shows that tectonic activity and seismic events continue to be the main factor of sudden catastrophes, and tsunamis contribute to the devastation in the coastal belt. Climate change exerts pressure on these hazards by elevating the base level of sea level, oceans becoming warmer and more intense extreme weather events leading to compound hazards that are more frequent and severe. The results highlight that the susceptibility of the city to disasters, poor infrastructure, and density of population exacerbate the effects of disasters, and that ecosystems like coral reefs, mangroves, and saltmarshes all play an important role in mitigating the effects of environmental stress. It becomes crucial to integrate the innovations in technology, warning system, and construct resistant to climate as the means of reducing exposure and preserving life and property.

Moreover, the article demonstrates that the sustainable development goals have a close relationship with disaster risk management and climate adaptation. When hazards overlap, human health, population displacement and socio-economic stability are greatly influenced, especially in high risk areas where preparedness is less effective. The economic investments towards early warning, resilient infrastructure, and ecosystem recovery address direct impacts but also aid the sustainability of long-term sustainability and community resilience. Taken together, the results highlight the significance of multi-hazard risk assessment, policy development, and proactive planning as the key to successfully managing the atmospheric impact of the seismic and climate-related hazards in 2026 and beyond.

7.2 Policy and institutional Recommendations

Good policy and institutional structures are necessary to curb the multiplied threats of earthquakes, tsunamis and climatic change. The governments must focus on formulating and implementing multi-hazard risk management policies that combine disaster risk reduction, climate adaptation and sustainable development goals. Building code, urban planning and critical infrastructure design regulatory standards should be revised to provide the current hazard data and future climate impacts. Ensuring that the coordination among the national, regional and local authorities is strengthened would mean that the early warning systems, emergency response plans and evacuation plans are in place and tested regularly. Moreover, special funding sources and insurance policies are to be created to assist in retrofitting infrastructure, restoring ecosystems, and restoring infrastructure after the disaster to reduce the impacts of negative economic and social consequences.

Capacity building at the institutional level is also essential towards increasing resilience on all levels. To enhance quick assessment, prediction, and response agencies that handle disaster management would invest in training, the use of technologies, as well as communication across the agencies. The cooperation with the academic institutions, research centres, and international bodies can be beneficial in terms of knowledge transfer, innovation, and evidence-based decision-making. Preparedness and adaptive capacity at local level should be intensified through intensified public awareness campaigns and community engagement programmes. This can make countries less vulnerable to natural hazards and climate change by incorporating these strategies into national development plans and institutional structures as a way of safeguarding lives and property and enhancing sustainable development.

7.3 Future Research and Global Cooperation Direction

Further studies must be developed in the future centred on the development of multi-hazard risk assessment models where phenomena such as seismic, tsunami and climate are combined. This also involves the development of predictive models that reflect the compound and cascading effects and the relationship between natural hazards and the socio-economic systems. The longitudinal examination of the coastal ecosystem, urban infrastructural resilience, and population susceptibility should also be given research importance in order to produce strong datasets to be used in policy and planning. Early warning technologies, remote sensing and big data analytics are further innovations that can be used to enhance forecasting accuracy and response effectiveness. There are also interdisciplinary research that focuses on the connexions between hazard exposure, human health, and sustainable development outcomes, which are essential to the development of holistic risk management approaches.

International collaboration is necessary to combat the international character of natural hazard and climatic risks. Mutual effort among countries, regional institutions, and international bodies can help in information sharing on best practises, early notifications and technological advances. Intense capacity building initiatives and collaborative studies can increase resilience in poor resource countries, and co-ordinated funding arrangements can fund massive infrastructure adaptation and ecosystem recovery initiatives. Enhancing cross-border connexions to reduce disasters risk, adapt to climate and achieve sustainable development will lead to the development of knowledge sharing, the need to harmonise policy, and united actions in which the international community can efficiently tackle the effects of earthquakes, tsunamis, and climate change in the coming decades.

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