IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

3D Modelling and photorealistic visualization of Tsunami using geospatial Techniques

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Abstract

On December 26, 2004, a tsunami triggered by a 9.2 Mw earthquake near the coast of Sumatra island in the Indian Ocean devastated more than ten countries around the ocean, including Sri Lanka, Thailand, Indonesia, and India killing at least 230,000 people, including visitors from Australia, Europe, and North America, and causing massive economic losses. The sudden tragedy, which resulted in the largest tsunami destruction in human history, shook the entire world. In terms of geographical perspectives, 3D visualisation will most likely help the public in visualising and understanding tsunami challenges. The visualisation in 3D is a nice technique because it adds some realistic elements and makes it more engaging. Anyone can benefit from watching this tsunami disaster depiction. 3D Tsunami modelling can be a very useful tool for users to have a better understanding of tsunamis and to see how they can protect themselves from being killed by tsunami big waves.

1. Introduction:

A tsunami is a succession of waves triggered by an impulsive disturbance in a body of water. In coastal locations, it causes significant damage. On the high seas, a tsunami wave might be less than 1 m tall and travel at rates of up to 800 km/h, propagating wave energy from the surface to the seafloor. As the tsunami reaches the coastline, its wave force is concentrated to a considerably shorter distance, potentially causing major damage to coastal areas [1]. A tsunami can happen when the seabed deforms quickly and a lower layer of water vertically displaces the water above it. The tectonic earthquake is a type of earthquake that occurs when the earth's crust deforms. The layer of water on the affected surface is moved from its equilibrium position when these earthquakes occur at the sea's bottom. The influence of gravity causes waves to form as a displaced body of water. When huge parts of the ocean floor sink, a tsunami can develop. The majority of tsunami visualization software is currently built in 2D. Due to the limited angle of view that people can see, it has its own set of limitations [2]. However, because it is easier to produce, many tsunami-related topics are developed in a two-dimensional perspective. Although 3D techniques are difficult to master, the end results are significantly more appealing and intriguing than 2D graphics. As a result, 3D modelling is a good idea for better visuals and visualization. In terms of substance, little graphics was made focused on what occurred beneath the sea. Mostly depicts the effects of waves and how they devastate living beings, structures, and coastal environments [3].

3D modelling is a useful tool for visualising objects that are difficult to view directly. Humans have no way of knowing how tsunamis happen down beneath the sea floor. People will struggle to comprehend how it occurs since they cannot see it. So visualising the occurrences in 3-Dimensional View is one strategy that is likely capable of providing a better insight for this topic. Each tsunami element will be depicted in a clearer and more interesting graphic viewpoint. Nobody can film a video of a tsunami by travelling to the sea floor and recording how it transpired in the actual world because they will be killed. People need to understand how tsunamis happen so they can prepare for them. Tsunamis can strike at any time and there is no way of knowing when they will strike.

The Andaman-Sumatra subduction zone in the east and the Makran subduction zone (MSZ) in the west Indian Ocean are shown in 3D modelling. The Makran subduction zone in the western Indian Ocean, off the coast of Karachi, Pakistan, has a history of tsunamis affecting the western Indian Ocean. [4] Stoneley proposed this subduction zone between the Arabian Plate and the Eurasian Plate. This is one of the world's greatest forearc regions, as well as an active accretionary wedge that is 70-100 Ma old.

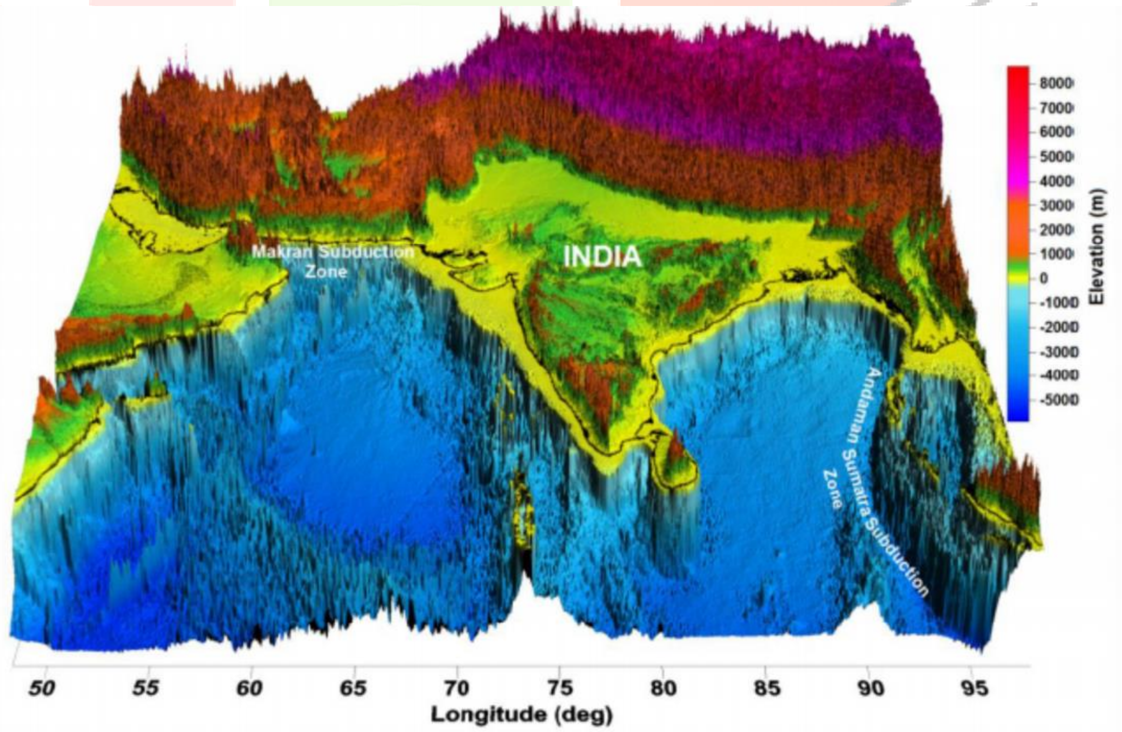

Fig.1 shows 3D Visualization of tsunamigenic sources in the Indian Ocean

The graphical image representation of information with the purpose of improving the viewer's understanding of the information contents is known as visualisation. Understanding 3D graphical models is easier and more effective than understanding 2D models. 3D visualisation models are useful tools for simulating disasters from many perspectives, allowing users to have a better understanding of the situation and assisting decision-makers in planning suitable rescue actions. 3D representations are useful tools for disaster relief, such as cyclones, tsunamis, earthquakes, flooding, and fires. 3D graphical representations greatly minimise cognitive work and increase the decision-making process' efficiency [5]. 3D visuals have the potential to be a more successful communication tool than 2D visualisations. ArcGIS pro & CAD software is used to create 3D models, primarily city and architectural models, which are scanned into computers from real-world items. 3D visualisation and animation are useful tools for transmitting information to decision-making processes in natural disaster risk assessment and management. They can be done in CAD and ArcGIS.

2. Materials and Methodology

Tsunamis are mostly measured with instruments such as tide gauges and, deep ocean bottom pressure recorders. Satellites recorded radar altimetry transects of sea-height data for the first time during the Indian Ocean Tsunami of 2004, which clearly indicated the propagation of a tsunami signal across the Indian Ocean.

The satellites crossed over the Indian Ocean at the same time as the first part of the tsunami was spreading from the Sumatra-Andaman source region by chance. Jason-1 provided the most data to give insight on tsunami generation for this event: within two hours after the earthquake, this satellite recorded practically continuous sea-height data. Five minutes later, the Topex-Poseidon satellite (which was launched in tandem with Jason-1) began collecting tsunami sea-height data. Sea-height data was obtained by the Envisat and GeoSat Follow-On (GFO) satellites 3:15 and 7:10 hours after the earthquake, respectively.

The data can be considered of as a snapshot of tsunami amplitudes along the Jason-1 trackline because the satellite's ground speed is 5.8 km/s, far quicker than tsunami propagation (red line). The wavefront of the distant (far-field) tsunami that erupted directly from the source is represented by the blue arc in the computer model of the wavefield displayed below (i.e., seafloor deformation from movement on the inter-plate thrust).

This portion of the tsunami wavefield is known as the direct arrival, and it is currently approaching India. Dispersion causes smaller amplitude waves to lag behind the blue arc, as shorter wavelength components travel at a little slower speed than the wavefront. The green arc is one of numerous tsunami reflections from coasts and underwater bathymetric features that satellite radar altimetry detects and measures. Where Jason-1's trackline intersected these arcs, it measured the height of the tsunami wave. The local tsunami is still causing strong wave activity along the Sumatran coast to the east.

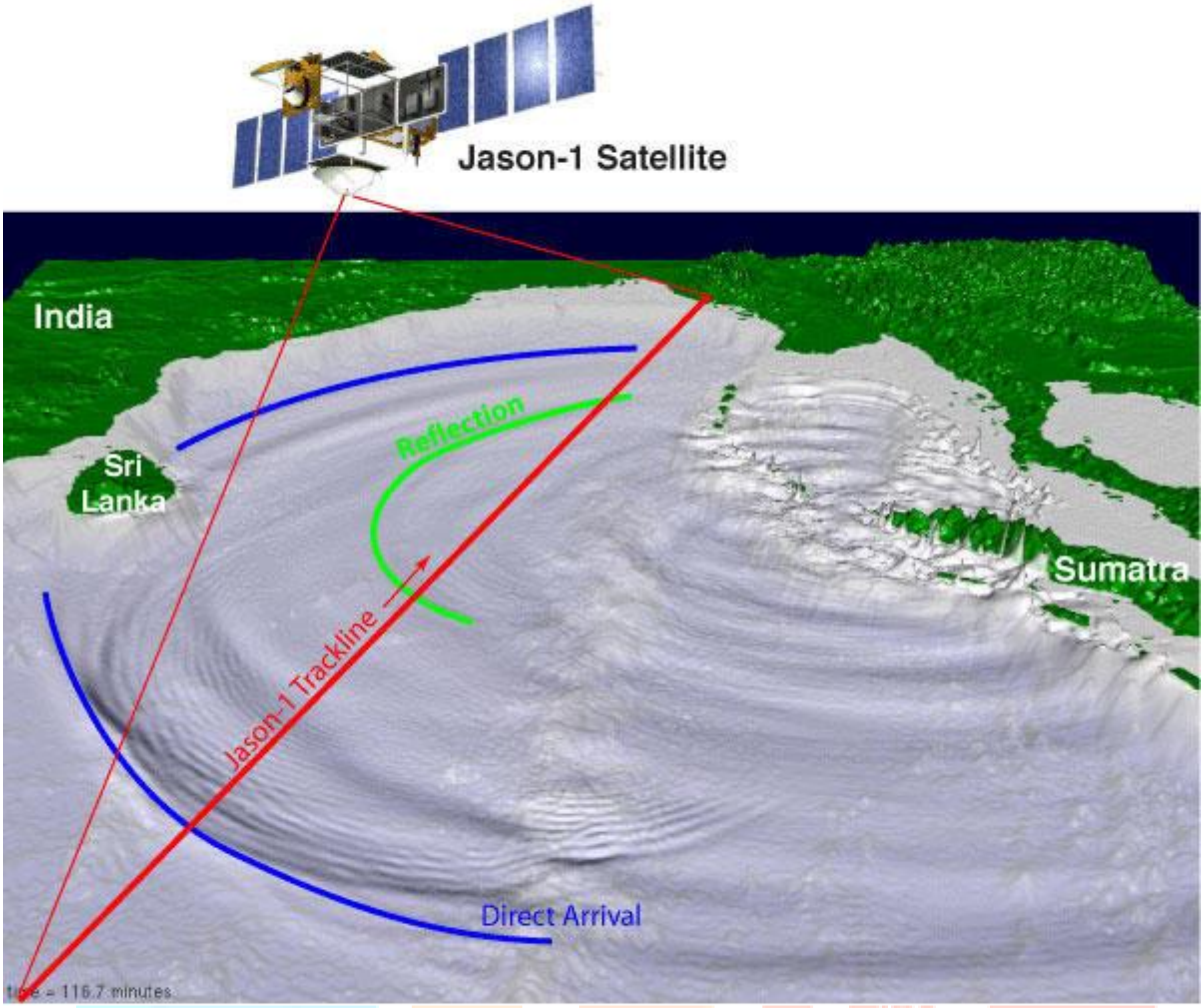

Fig.2 showing the Jason-1 rising orbit (red line) 2 hours after the 2004 Sumatra-Andaman earthquake. At an altitude of about 1300 kilometres, the spacecraft orbits the Earth. The outbound tsunami's modelled wavefront (direct arrival) from seafloor displacement produced by the earthquake is depicted in blue. One of numerous tsunami reflections is represented by the green arc. Northerly perspective. (Source: Tsunami and Earthquake Research)

Numerical Modelling

Tsunami wave propagation, run up, and inundation were studied using the TUNAMI-N2 model in a region of the Western Indian Ocean. Professor Fumihiko Imamura of Tohoku University's Disaster Control Research Center created the TUNAMI-N2 model as part of the Tsunami Inundation Modeling Exchange (TIME) programme. TUNAMI-N2 is one of the most important instruments for studying tsunami propagation and coastal amplification under various beginning conditions [6].

The earthquake source parameters, topography, and bathymetry data are the most important datasets for the TUNAMI N2 numerical model. For a given tsunamigenic earthquake, the TUNAMI N2 model uses seismic deformation as an input to estimate tsunami run-up heights and inundation levels at coastal zones. Using earthquake parameters such as location, focal depth, strike, dip, and rake angles, length, width, and slip of the fault plane, the seismic deformation for an earthquake was computed using formulation [7].

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \quad (1)$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left[\frac{M^2}{D}\right] + \frac{\partial}{\partial y}\left[\frac{MN}{D}\right] + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{7/3}} M\sqrt{M^2 + N^2} = 0 \quad (2)$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left[\frac{MN}{D}\right] + \frac{\partial}{\partial y}\left[\frac{N^2}{D}\right] + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{7/3}} N\sqrt{M^2 + N^2} = 0 \quad (3)$$

Where M and N represent the x and y directions of discharge, h represents the still water depth, is the vertical displacement of water, and D is the total depth D=h+. The primary information required for the model to capture the generation, propagation, and inundation of the tsunami wave from the source to the land are bathymetry and elevation data.

TUNAMI N2 Model

TUNAMI-N2 is a code that uses a finite difference technique based on the Leap-Frog strategy to solve the tsunami wave propagation. The central difference method is used with a second order truncation error in this formulation. The associated boundary conditions were determined using the technique and open sea boundary conditions, with the open sea boundary condition being free transmission and the land boundary condition being a perfect reflector. This study employed a frictional coefficient of 0.025. Tsunami modellers use the code extensively to measure tsunami propagation and calculate arrival timings at different places.

3. Result and Discussion

The magnitude (M) 9.1 Sumatra-Andaman earthquake struck on December 26, 2004, along a tectonic subduction zone where the India Plate, an oceanic plate, is subducting beneath the Burma micro-plate, which is part of the larger Sunda plate. Figure 1 depicts a three-dimensional view of the Andaman and Sumatra subduction zones. The Sunda Trench above marks the subduction zone's boundary between the downgoing and overriding plates.

We present a brief review of the earthquake's geological setting and seismological characteristics, as well as a summary of tsunami generation modelling for this event and the M=9.3 northern Sumatra earthquake on December 26, 2004.

The fault that erupted during this earthquake was enormous, extending from northwest Sumatra to the Andaman Islands. We have to add the time it takes for the 2004 earthquake to unzip along the fault in tsunami simulations because of its enormity. The rupture front for this earthquake travelled at a high pace of around 2.5 km/s, which is characteristic for subduction zone earthquakes, like a propagating crack in a frozen lake. The rupture front propagated for nearly 8 minutes from the hypocentre to the end of its 1200 km excursion (almost the length of California!). Because tsunami waves move more slowly than fault rupture, in tsunami models for lesser magnitude earthquakes, the displacement of the seafloor generated by an earthquake is considered to occur instantly [8] [9].

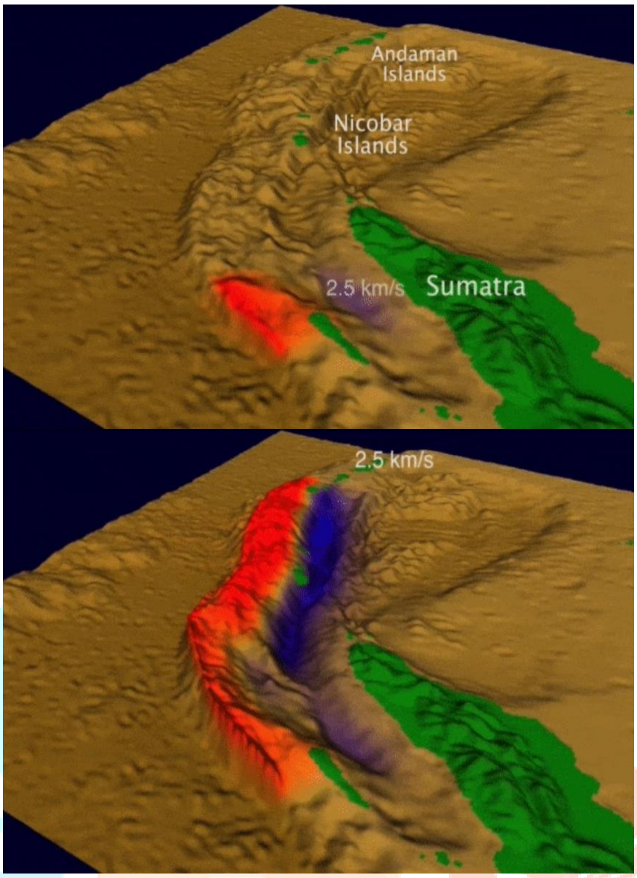

Fig-3 This 3D image depicts a model of vertical seafloor displacement produced by the Sumatra-Andaman earthquake on December 26, 2004. The rupture front's northward propagation is depicted, as well as an exaggeration of the seafloor's vertical movement. In this 3D image, the water has been eliminated. When the seabed goes upward, it is coloured red, and when it moves downward, it is coloured blue. (Image courtesy of Tsunami Generation from the M=9.1 Sumatra-Andaman Earthquake in 2004.)

We can now add water to this 3D model to demonstrate how tsunami waves migrate away from the earthquake source. The tsunami waves generated at the onset of the earthquake rupture have travelled part way into the Bay of Bengal by the time the earthquake rupture reaches the Andaman Islands, as depicted in the image below.

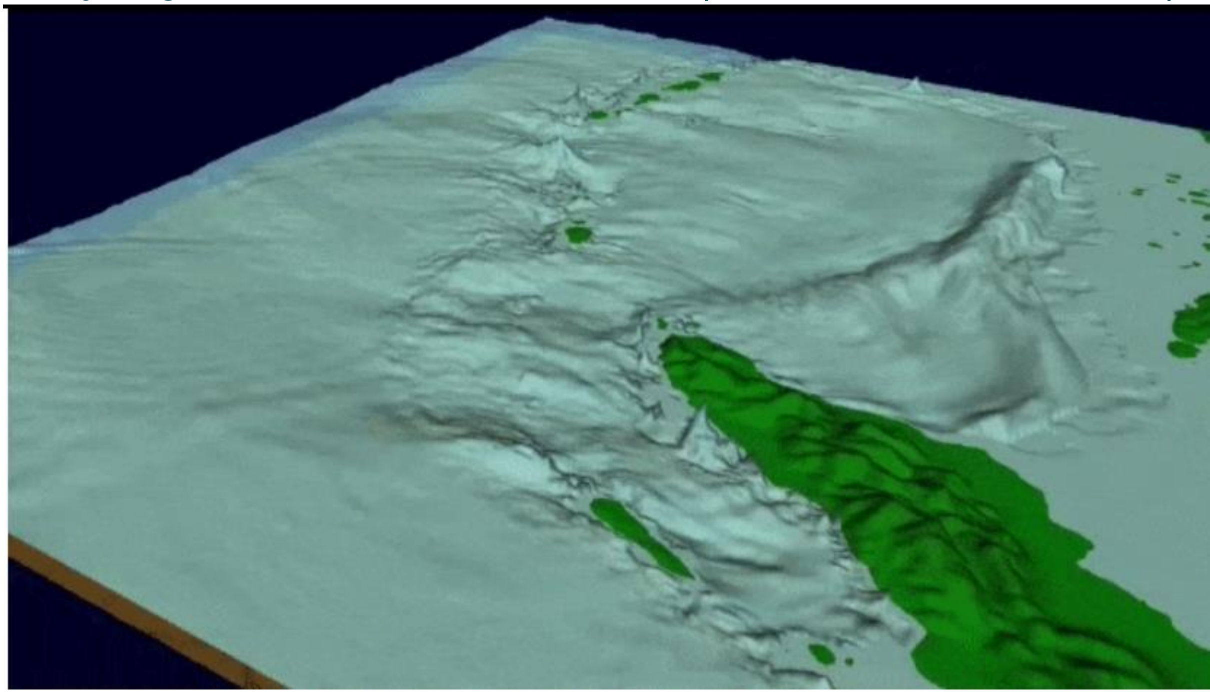

Fig-4 The progression of tsunami waves triggered by the December 26, 2004 Sumatra-Andaman earthquake is depicted in this 3D image. Because the entire fault takes around 8 minutes to break, tsunami waves generated near the epicentre have already made their way halfway into the Bay of Bengal by the time the earthquake has just started to generate more tsunami waves near the Andaman Islands. These waves then travel to Thailand across the Andaman Sea. (Photo courtesy of Eric Geist, USGS Pacific Coastal and Marine Science Center geophysicist)

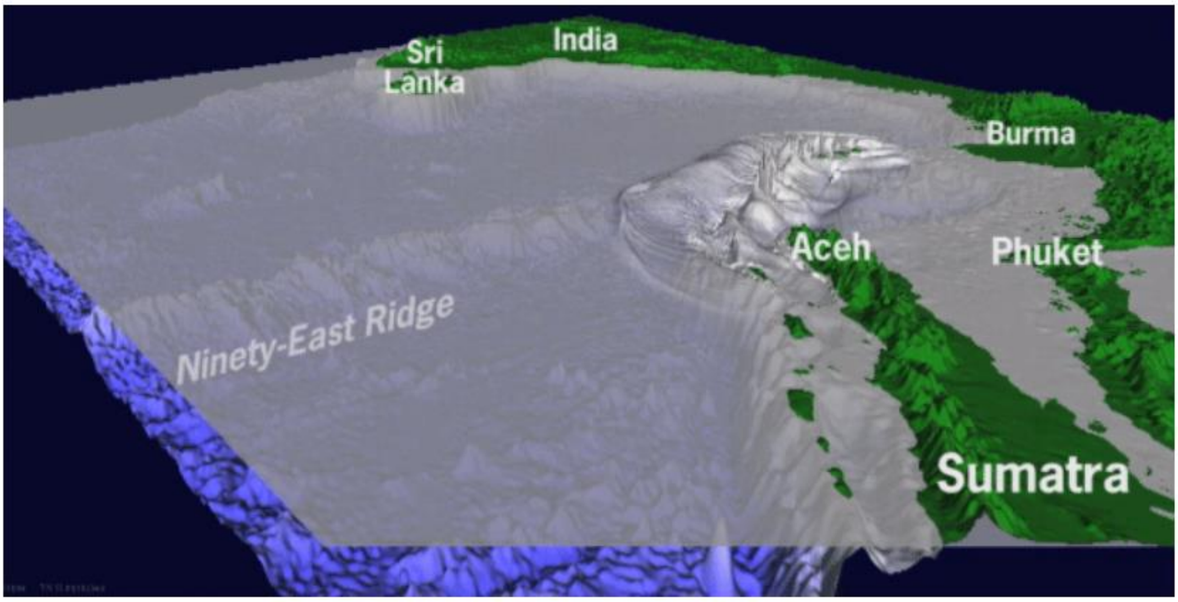

Fig-5 Tsunami waves between the island of Sumatra and the Sunda Trench are depicted in this 3D image. It then spreads eastward into the Bay of Bengal, toward Sri Lanka and India, then outward into the Indian Ocean, toward Sumatra and Thailand. The Banda Aceh region of northern Sumatra has the largest offshore tsunami amplitudes. (Photo courtesy of Eric Geist, USGS Pacific Coastal and Marine Science Center geophysicist)

High-resolution satellite photography is used to detect tsunami-induced changes in 3D.

The usefulness of remotely sensed data was demonstrated by the spectacular 3D digital globe's Quick Bird satellite images captured before and during the Sumatra tsunami (figure 6). Such data would be useful for rescue and recovery operations if it were provided in near real time. These data might also be utilised to create before and after damage imagery to swiftly assess the degree of the tsunami's and other natural disasters' impact. we can clear see the damage due to Andaman-Sumatra tsunami 2004.

(a)

(b)

Fig-6 Natural colour photographs of the Banda Aceh coastline taken by Digital Globe's Quick Bird (a) before and (b) after the tsunami of December 26, 2004. (Geology Today, Vol. 21, No. 1, January-February 2005, Blackwell Publishing Ltd)

4. **Conclusion**:

The present study showing 3D visualization images of 26 December 2004 Andaman-Sumatra tsunami. This image will most likely aid the public in visualising and comprehending tsunami challenges from a geographical perspective. The visualisation in 3D is a nice technique because it adds some realistic elements and makes it more engaging. Anyone can benefit from watching this tsunami disaster depiction. The 3D visualisation can be used as a teaching tool to help students envision the notion of a tsunami and understand how it occurs and impacts them. When people grasp the concept of a tsunami. They will never experience simple phobia once the topic has been discussed because they understand how it occurs and the consequences of it.

People will be able to create a self-alert to this disaster once they understand the concept of a tsunami and its effects. They will never choose to live in areas where tsunami waves have a high risk of collapsing since they are aware of the devastation that tsunami waves may cause. Because kids are familiar with tsunami characters, this will serve as a reminder to them of the importance of eliminating this phenomenon by relocating to safer areas; as the saying goes, "prevention is better than cure." 3D Tsunami modelling can be a very useful tool for users to have a better understanding of tsunamis and to see how they can protect themselves from being killed by tsunami big waves.

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