# CHAPTER 2
# LITERATURE REVIEW

## 2.1 GENERAL

This chapter introduces an overview of research literatures and articles on various techniques for the tsunami detection and its investigation of the early detection using remote sensing tools and techniques. In particular, the literature survey fulfills two important tasks related to the computational and algorithmic analysis of Tsunami wave parameters and remote sensing approach to detect the tsunami signal for the investigation of its early warnings.

## 2.2 REVIEW ON TSUNAMI WAVE PARAMETERS

Most of the current tsunami under water seismological algorithms has been developed since the 1960s when the giant Chilean earthquake generated in Pacific Ocean. Plate tectonic theory was also introduced in the same year, numerous mathematical models of earthquake source were developed to relate the seismic moment and size of the fault. For an observational sides, various tide gauge sensors, seismic networks was also deployed in 1960s. In 1970s, using the obtained theories and observed datasets, fault attributes of the larger or smaller earthquake studies have been carried out. The magnitude moment scale which is well known as Richter scale was also introduced. Theoretical and computational developments made to estimate and compute the seafloor shift, fault sizes and tsunami wave propagations models on the actual bathymetry. In 1980s, seismograms have been recorded digitally, which improved the data quality and reduces the processing times. The large scale tsunami propagation models were also employed and studied in this decade and it became more popular. The developments and advancements of computer networking have made it possible and reliable to carry out the researches in seismic wave analysis and real time measurements of the tsunami wave parameters. Furthermore, the tsunami hazard development tools have also been implemented and discovered to analyze the seismic activities using satellite altimetry. Using these datasets and information's, more tsunami studies could be carried out in a very short duration of time. Numerous scientific reports and research articles have been published regarding the 2004 tsunami earthquake. Here, we only refer the special issues of some of the reputed scientific journals in which most of the seismological aspects of tsunami and earthquakes are explained. Since the earthquake action of tectonic plates cause tsunami, they are frequently initiate in the Earth's utmost restless turfs around the Pacific Rim along the "Pacific Ring of Fire", a section of tall tectonic action. According to statistics, 17 tsunamis occurred, in the Pacific, in between the year 1992 and 1996, taking nearly 1,700 lives.

The tsunami events are normally explained by means of the solitary wave theory based on the classical approach. The profile of N-waves is defined by the water depth *d* and non-dimensional wave height *H/d*. In general, the initial surface displacement induced by the earthquake provides the high probability impact due to the seismic activity. Under these conditions the N-waves have longer wavelength and smaller amplitude. For these kinds of waves the dispersion is the significant parameters because the dispersive number *kd* varies from 0.01 to 0.1. For the Indian ocean *kd* is measured in between 0.026 to 0.25 (Ward, 1980). In the Pacific Ocean, a basin-wide tsunami occurred in 1960. The main cause of this generation was by the gain Chilean earthquake, which was recorded as magnitude of 9.5 over the Richter scale. Tsunami caused more than 1500 casuals over the Chilean coast. Following this mega disaster, a team has formed known as Tsunami commission by IUGG and they develop tsunami warning system for the scientific studies and investigation of the tsunamis by means of the underwater explosions (Smith *et.al.*, 1997).

Geist (1998) investigate the generation stage of the tsunami that includes the formation and evolution of initial ocean surface displacements due to the large earthquake triggered at the bottom of seafloor. The generated water surface is transformed to the long gravity waves which radiates from the earthquake source where it occurred at the time of evolution. The modeling of the tsunami is closely linked with the further studies on the earthquake mechanisms.

Billiam (2005) and Chang (2006) proposed techniques for globally observed seismological and sea-level datasets which are available within the minutes through the internet. Tsunami travels with concurrently in the outwards directions from the generating region. Since its generation is due to the underwater explosion, hence, energy movements also take place in the direction of the propagation. The speed of the propagation depends on the depth of ocean. In deep and exposed ocean, they travel at the speed of 500-1000*km/h*. The change occurrences take place for the tsunamis propagations from the deep water to the coastline due to the nearshore bathymetry and shoreline morphology. The most undeveloped part of the tsunami modeling is the run-up of the tsunami currents onto the land area.

Numerous reports of newspaper along with various movies about submarine quakes and imposed tsunamis have bestowed to public cognizance of the risk. The outcomes of tsunami can be catastrophic at times, for example, 2004 tsunami in Indian Ocean, the entire Indian Ocean was propagated and caused immense destruction to at least 12 countries. They have the strength to knock down infrastructures, crush and flip vehicles, lift giant rocks, demolish houses and cause failures of local/regional/international communication network and emergency response systems, causing damage worth of millions or even billions of dollars. Some of which could not even be addressed for months (Cheng-Seng, 2006). They result in decline of any economy. In order for detecting the tsunamis there is a need to determine the magnitude and epicenter of the earthquake. According to statistics, 17 tsunamis occurred, in the Pacific, in between the year 1992 and 1996, taking nearly 1,700 lives.

Presently, tsunami watch systems are built on computer programs of modeling which notify against the likelihood of the impacts of earthquake-originated tsunami, and try to forecast their strength along with their onset times verses location depends on the quake properties. These models of computer consists ocean bathymetry and geometries of coastline, with the onset criterions modernized by base ocean pressure as the tsunami wave moves over after a possibly threatening quake. A procedure lives for the quick distribution of quake data and tsunami mathematical model notifications amongst alien administrations but there is no such scheme for native discovery of a real incoming tsunami wave having a valuable alerting power (Iwan, 2006, Rabinovich, 2007).

Another process describes the sea level tide-gauges at coastal positions, nearer to the epicenter, able to convey vital quantitative data for locations further downstream, as in the year 2011, in Japan, the tsunami signals were detected through numerous High Frequency radars all around the Pacific zone with correct outcomes from location in Japan pennisula, United States and Chile. An observed way for the involuntary notification of a tsunami founded on pattern recognition in period series of tsunami generated current speeds, using information occupied by fourteen radars on the coasts of Japan and USA. Presently the high frequency radar systems works without break from many coastal locations around the globe, observing the currents on the surface of the ocean and tsunami waves to displacements up to 500*Km* from shore (Horsburgh *et.al.*, 2010, Daba *et.al.*,2003 and Dubois *et.al.*, 2005). Basically, the tsunami arrival and detection researches are limited but the post processing has been carried in some of the literatures using satellite image analysis for the affected area, tsunami damage level classification using image processing and manual techniques.

The main components for an endwise system of tsunami are to yield near-real-time surveying, seismic activities alert, punctual conclusion production and advisories, and broadcasting of early warnings and evidence Here, we only refer the special issues of some of the reputed scientific journals in which most of the seismological aspects of tsunami and earthquakes are explained (Stien, 2005). However, the large scale of tsunami destruction makes it hard to comprehend total tsunami impact in the whole Ocean. Latest developments of technologies of remote sensing crush many problems and guides to detecting the elaborated characteristics of tsunami detriment. Another way to do so, as many researches propose, is an overview in developing a way to look for and discover the impact of tsunami damage by integrating numerical modeling, technologies of GIS and remote sensing. Section of this method is carried out to few tsunami event, such as, in the year 2007, on Solomon Island, tsunami caused by earthquake, to find the affected regions and know the structural destruction, using the above method and the analysis of satellite imagery with high-resolution optical.

In general, the earthquakes generate tsunamis as a type of N-wave, the consistency of the analytical and numerical models are first applied to the deep and exposed ocean then runs up to the beaches. International coordination group was initiated and formed by Intergovernmental Oceanographic Commission (IOC) under United Nations Educational (UNE), Scientific and Cultural Organization (UNESCO) after the huge 1960 Chilean Tsunami in 1960. Again in 1965, another coordination group which is known as International Tsunami Information Centre (ITIC) with the support from United States of America, National Oceanographic and Atmospheric Administration (USA-NOAA). The International Coordination Group for Tsunami Warning Systems (ITSU) in Pacific was also formed and established under IOC [World Disaster Report, 2005].

Furthermore, December 26, 2004 Indian Ocean tsunamis was again the worst disaster in the history and was caused by giant Sumatra-Andaman earthquake with magnitude of 9.3 devastated the shores of Indian Ocean (Abe,2007, and Rabinovich *et. al*.,2007).

Once the tsunami waves generated from the deep water and runs up towards the coastal regions, it's a difficult task to prevent the life. In order to resolve these kinds of problems, early warning systems are implemented in operation to analyze and produce the results to disaster team. The basic concepts of such systems is to detect any kind of unusual seismic activities under water and automatically judge weather the seismic activity has been generated from the cause of earthquake or some other reason. After this process, bulletins must be issues to the disaster's authority in order to take up the appropriate action (Bugharello, 2005 and DART report, 2007).

Tsunamis, a critical natural menace, have the power to source great destructions with damage of lives within moments on shores. Any place having a huge water bodies, large lakes even, can cause a tsunami. From sources of history and scientific observations, the occurrence of Tsunamis can be in any large seas of the world, with almost 85% of tsunamis happening in the Pacific region, causing damage within hours across a complete ocean basin. Thereby, devastating tsunamis happen in geologically less lively oceans like the Atlantic, the Indian Ocean or the Mediterranean (Teshirogi *et.al.*, 2009).

Tsunami detection warning system consists of (Envirtech, 2011):

1. Seismic data, marine data collection using in-situ method or satellite remote sensing imageries.
2. A secured sea to ground surface and space based telecommunication network.
3. GSN station to monitor the waves
4. Regional satellite or other telecommunication based network to provide efficient budget link analysis.
5. Additional notification system through mobile based dissemination technique to support the government for the quick action.

Table 2.1 indicates the bulletin content based upon the decision about tsunami generation risks, In general it depicts that the local tsunamis effects are within 100*Km* of the epicenter, regional tsunamis are limited to 100*Km* of epicenter and ocean-wide tsunamis are across the entire ocean basin.

**Table 2.1** Tsunami generation risk bulletin (NOAA Forecast manual, 2011)

| Earth-quake depth | Location | Magnitude | Tsunami Potential |
|---|---|---|---|
| <100Km | Very near sea | >7.9 | Ocean Wide destruction |
| | | 7.6 to 7.8 | Regional Destruction |
| | | 7.0 to 7.5 | Local destruction |
| | | 6.5 to 7.0 | Very small scale |
| | Inland | >6.5 | No tsunami potential |
| >100Km | Inland | >6.5 | No tsunami potential |

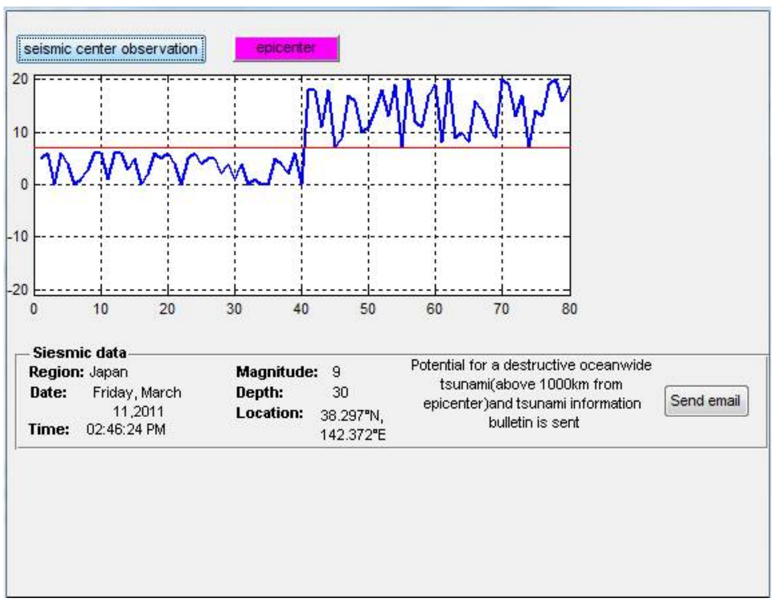


**Figure 2.1** Acquired datasets for the tsunami detection and arrival monitoring [Bingham, 2002]

The further step of the detection process is to obtain Bottom Pressure Recorder (BPR) Measurement $h_{d.}$ This information is required to measure the expected run-up of the tsunami waves towards the coast from deep water. Furthermore, depends on the flow chart mentioned in Figure 2.2, the bulletins are generated and sent the warning to the concerned authorities using e-mail for emergency purpose. The measurement is used to estimate the expected run-up as per the equation provided in equation 2.1

$$\frac{h_s}{h_d} = \left(\frac{H_d}{H_s}\right)^{1/4} \qquad (2.1)$$

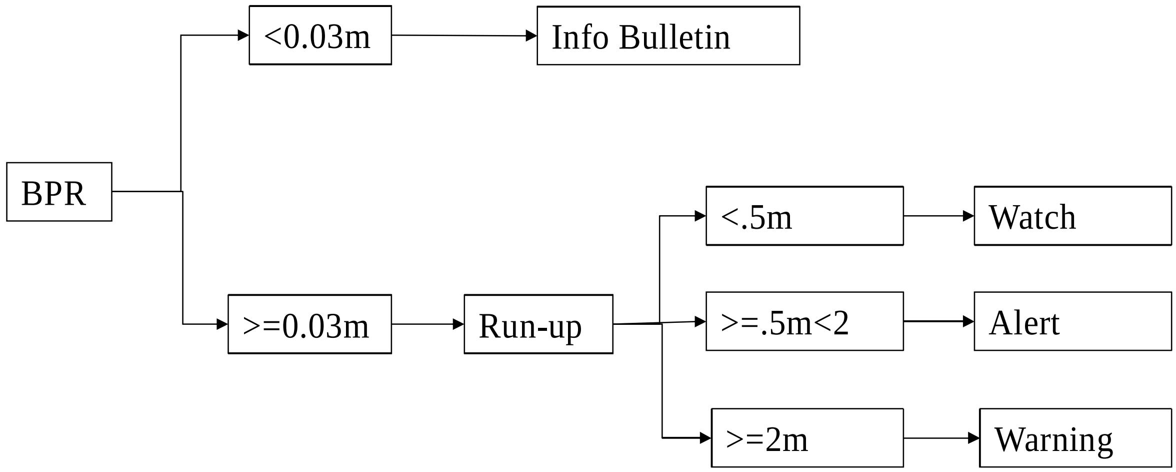


**Figure 2.2** Decision for monitoring using BPR measurement [Bingham, 2002].

The bottom pressure recorders play the important role to find and detect the actual cause of the tsunami generation point. It can be seen that if BPR is greater or equal to 0.03*m*, the tsunami run-up starts. If the magnitude reaches more than 2*m*, the warning is to be issued to the concerned authority for the further action. Hence, if BPR design should be so accurate in such a way that it should provide the accurate threshold command values so that the quick action can be taken. The last and final step of the tsunami detection is to obtain the sea level fluctuation recorded by the tide gages located at the shore line and the actual run-up and the maximum wave run-up inundation can further be estimated using the mathematical relationship as mentioned in equation 2.2.

$$H_{\max} = 2.83 h_s^{1.25} \cot B \quad (2.2)$$

*B* is the slope of the seabed (in degrees)

Finally, the bulletin is to be circulated depends on the decision provided. The actual and acquired run-up values should be matched for the further validation. The updates about the confirmation or cancellation are done based on the chart as illustrated in Figure 2.3 [Bugharello, 2005]

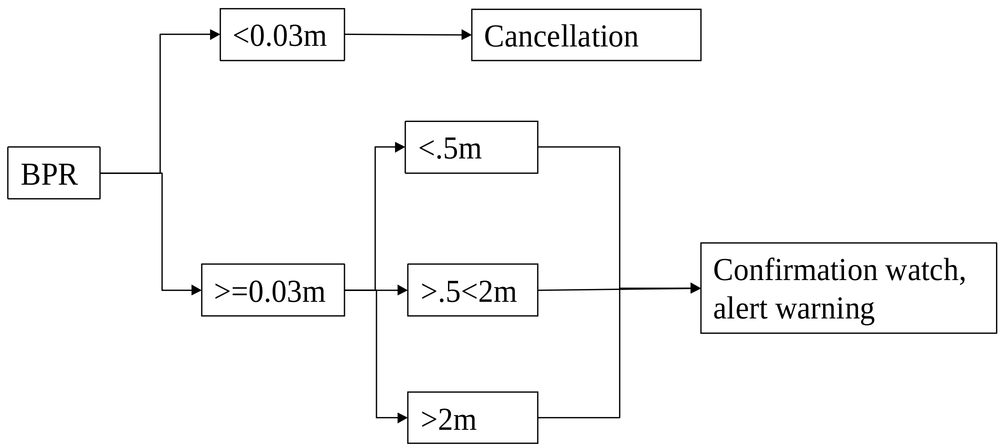


**Figure 2.3** Decision tree for confirmation, cancellation and update the database [Bugharello, 2005]

## 2.3 REVIEWS OF REMOTE SENSING OF OCEAN

Most of the current tsunami under water seismological algorithms has been developed since the 1960s when the giant Chilean earthquake generated in Pacific Ocean. Plate tectonic theory was also introduced in the same year, numerous mathematical models of earthquake source were developed to relate the seismic moment and size of the fault. For an observational sides, various tide gauge sensors, seismic networks was also deployed in 1960s. In 1970s, using the obtained theories and observed datasets, fault attributes of the larger or smaller earthquake studies have been carried out. In 1980s, seismograms have been recorded digitally, which improved the data quality and reduces the processing times. The large scale tsunami propagation models were also employed and studied in this decade and it became more popular. The developments and advancements of computer networking have made it possible and reliable to carry out the researches in seismic wave analysis and real time measurements of the tsunami wave parameters. Furthermore, the tsunami hazard development tools have also been implemented and discovered to analyze the seismic activities (Okal, 2007 and Abey, 2007).

In the present era, the globally observed seismological and sea-level datasets are available within the minutes through the internet (Bilham, 2005). Using these datasets and information's, more tsunami studies could be carried out in a very short duration of time. Numerous scientific reports and research articles have been published regarding the 2004 tsunami earthquake (Iwan, 2006).

As under the discussion and part of the tsunami working group, the tide gauge data was collected and compiled about40-50 tide gauge records in to region of Indian Ocean to analyze maximum amplitude and spectral components**.** Sea-level monitoring of the oceanographic activities have been developed known as Global Sea Level Observation System (GLOSS) and is located in Australia, The pacific and Atlantic oceans recorded the 2004 tsunami (Okal, 2007).

Tsunami execution and propagation was also measured on hydrophones or seismometers in which the analysis have been carried out to provide a wide range of time of arrival about 90 to 3000*s*. The aspect of Global Positioning Systems (GPS) measurements of tsunamis and its surveys have also been carried out this research categories based on the societal responses (Fujji *et.al*., 2007, Stosius,2010).

The real-time justifications and monitoring of the tsunami have been incomplete to deep-water bottom pressure instrument interpretations of variation in sea level changes. The coastal based radar monitoring systems are implemented in various countries to detect the tsunami wave's arrival near to the coast and to analyze and present the report to the disaster management team for the quick and sudden action to save various lives.

Numerous models have been proposed in order to retrieve the wave parameters either in exposed sea or in coastal sea waters. The sea state can be completely characterized by the directional wave spectrum, which describes the distribution of wave energy with respect to the wave propagation and wave numbers. Retrieval of the ocean wave parameters by SAR depends on sea state conditions.

Beckmann, and Spizzichino, (1963) discussed the idea of electromagnetic waves interaction with ocean waves with the use of Maxwell's equation and they intimate the theory of Kirchhoff's approximation which was valid for longwave. Elachi, and Brown, (1977) described some of the mechanism of SAR-ocean interaction with the development of linear transform equation. The detailed study about the sea scattering mechanism can be found in Valenzuela (1978). Sea surface back scattering response sensed by the sensors are more dominantly affected by the surface scattering phenomenon between the interactions of electromagnetic and sea surface waves.

Alpers (1983) provided the basis for a procedure to derive the wave height spectra from SAR intensity images. The effectiveness of a linear system approach to SAR wave imaging can be explored through the numerical simulation study. These simulations begin with the input ocean spectrum in order to estimate the height topography, and use of models based on the backscattered signals are the function of wave height which includes the mapping of intensity levels depending on the duration of wind blow over the sea surface.

Apel and Gonzalez, (1983) investigated the ocean wave detection capability using the SEASAT SAR sensor. It has been found that the images of ocean waves can be enhanced by applying a defocused azimuth reference signal, *i.e.*, the images are defocused if the references signal is matched to a stationary object. A question then follows of what causes defocusing. Alpers *et. al*. (1981) suggested that defocusing is due to the slant-range acceleration associated with the orbital motions of a longwaves. Ouchi (1984) and Irvin and Tilley (1988) have independently reached the same conclusion that the amount of defocusing of the references signal for optimum images depends only on the phase velocity of a long wave and its propagation direction.

Hasselmann *et. al*., (1985) and Frank and David, (1986) focused on the SAR image spectrum obtained through the Modulation Transfer Function (MTF), which produced the accurate estimate of the slope-and height-variance spectrum. Hasselmann *et. al*., (1991, 1996) described the statistical properties of the ocean wave field at any given location and time, and the SAR technology is only the measurement to estimate the directional ocean wave spectrum globally and continuously, but some limitations still exist, like the azimuth high wave number cut-off and the need for the prior information in retrieval procedures. The standard estimation of the normalized radar cross-section (NRCS) for the case of flat sea surface shows negative values more than -10 dBs. In addition, it also depends on the SAR imaging mechanisms such as velocity bunching, tilt and hydrodynamic modulations.

Krogstad (1992) derived an analytical expression for the non-linear ocean-to-SAR spectral transform which describes the SAR image spectrum as a function of ocean wave fields. It shows the relation for ocean wave spectra derived from the SAR signal spectra. The main drawbacks in these algorithms are the need of a wave spectrum in order to solve the propagation ambiguity and finding a unique solution to the wave system. Vachon *et. al*., (1994) found that the copolarization (HH/VV) datasets are less affected by wind and sea states and they showed a better response for the wave parameter estimation as compared to the cross-polarization (HV/VH) image data. Leo (2007) has developed an equation for the ocean wave slopes under the various water/wave conditions. Yang and Ouchi (2010) suggested a method to retrieve the ocean wave height based on the polarimetric ratio of radar cross sections for HH- and VV- polarization images for the purpose to estimate the wave slopes by means of pixel based analysis.

Motoyuki *et.al.*, (2012) proposed a very few examples of detection, determination, and evaluation of the damaged areas affected by the March 11, 2011 earthquake and tsunami in east Japan. Due to very limited time and resources, we used only conventional analysis methodologies; in spite of this limitation, They have been able to show the very promising potential of PolSAR in disaster observation, especially for scattering mechanism analysis, compared to conventional single polarization SAR and optical remote sensing detection of damaged areas after a disaster can be done using only a single PolSAR observation.

Dubois *et.al.,* (2014) proposed a novel technique for the tsunami detection. Arrival times computed by radars headed those at adjacent tide gauges by median values of 19 minutes (Japan) and 15 minutes (USA). The early water wave-height rises due to the tsunami as calculated using tide gauges was moderate, ranging from 0.4 to 3 *m*. Hence, it seems conceivable to detect the reasonable tsunamis using this method.

The remote sensing tools are now a day on demand to analyze the tsunami affected regions. One of the important and sophisticated well known SAR sensors can be used to observe the datasets. SAR images are basically suffers from speckle noise. The filtering scheme is the necessity to obtain the clear information which could further be detected at user end. At present due to lack of the datasets, we could not able to show how the SAR images appear for tsunami affected region. The simulation has been carried out in MATLAB interface (Dubois *et.al.*,2005 and Daba *et.al.*, 2003). A Wiener filters can be used to enhance SAR image by removing the speckles and further post tsunami analysis can be carried out using image processing technique. A pixel differential rule can be applied between final obtained image and enhanced image, resultant of both provides the black region which indicates unaffected fields. Once these images re resulted out, percentage damage can be determined (Horsburgh *et.al.*, 2010 and Stosius *et.al.*, 2010).

Tsunamis, a critical natural menace, have the power to source great destructions with damage of lives within moments on shores. Any place having a huge water bodies, large lakes even, can cause a tsunami. From sources of history and scientific observations, the occurrence of Tsunamis can be in any large seas of the world, with almost 85% part of the tsunamis happening in Pacific region, affecting damage within an hour through a complete ocean basin. Thereby, devastating tsunamis happen in the geologically less lively oceans like the Atlantic, the Indian Ocean or the sea of Mediterranean (Teshirogi *et. al*., 2009).

SAR satellite sensor has been designed and, partially, put into operation, leading to an important breakthrough in Earth Science studies. The common characteristics of such new systems are, indeed, a reduced revisit time (as short as a few days) and, in most cases, an improved spatial resolution (as small as a few meters), providing scientists with unprecedented data for the mapping and monitoring of natural and human-induced hazards (Dubois *et al.,* 2005, Daba *et al.,* 2003, Fuji *et al.,* 2007).

The early detection and warning systems have shown and proven an ultimate importance, especially after the destructive tsunami that hit Japan in March 2011. The purpose of this research is to notify and enhance the existing tsunami results for the detection and early warning prediction with the suitable accuracy (Morissay, 2005).

Lipa *et. al*., (2012) have suggested the realistic model for discovery of the early arrival of the tsunami, and validate its utilization with results from information dignified by various different high frequency radar sites in Japan and USA following the *M* 9.0 quake, Japan, March,11,2011.

The great earthquake and tsunami occurred in March 2011 at Japan. Earthquake & Tsunami of 2011, the number of confirmed deaths is 15,891 as of April 10, 2015, according to Japan's National Police Agency. Most people died by drowning. More than 2,500 people are still reported missing.

The various parameters have been analyzed and resulted out such as the marine debris in the region of japan coastal area which contains the post analysis activity using SAR datasets over the various processing cycle of the satellite movements. The purpose of this research is to notify and enhance the existing tsunami results for the detection and early warning prediction with the suitable accuracy. The real-time interpretations and monitoring of a tsunami have been narrow to deep water pressure sensor interpretations of variation in the sea-level deviations. The coastal based radar monitoring systems are implemented in various countries to detect the tsunami wave's arrival near to the coast and to analyze and present the report to the disaster management team for the quick and sudden action to save various lives. An empirical model for the recognition of the early influx of a tsunami, and validate its use with outcomes from data restrained by fourteen high frequency radar sites in Japan and USA following the $M$ 9.0 earthquakes off Sendai, Japan, on 11 March 2011 [Arii. *et. al.*,2014].

## 2.4 OUTLINE OF RESEARCH PROBLEM

Numerous methods and techniques have been presented in various literatures for the tasks of our research. For the first task of the computational and algorithmic analysis of tsunami wave parameters, the Eigen function studies can be done and simulate on the MATLAB interface to calculate the tsunami wave parameters in deep, intermediate and shallower region of ocean.

Regarding the second task which is concerned with the detection tsunami early warning, most of the published methods are based on comparing the intensity of the image pixels of pre and post analysis datasets of SAR images. Here we implemented only to the case study to develop the novel technique to detect the tsunami signal arrival near to coast of Japan using coastal based radar remote sensing technique.

## 2.5 SUMMARY

The various literatures have been studied and analyzed in this chapter to understand the problem concerned with the tsunami modeling, detection and the prediction of its early warning using the remote sensing techniques along with the post analysis. Although there are several approaches, models, techniques and concepts reported for detection of tsunamis using radar and SAR datsets. A very few research work were found for the modeling of tsunami Eigen function and the detection using RADAR dataset for the tsunami arrival to its coast. The radar imaging mechanisms and retrieval of wave parameters have also been studied to propose a new technique for the retrieval of wave parameters using SAR. Most of the approaches have been based on the tsunami wave parameters using the remote sensing techniques. The problem concerned with the early warning detection of tsunami signals using the remote sensing is cumbersome due to the unavailability of datasets and synchronization of the various satellites in satellite to monitor the earth vibrations The previously developed models, techniques, and approaches are more appreciable in order to fulfill the research objectives.