

Need of a disaster alert system for India through a network of real-time monitoring of sea-level and other meteorological events

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Need of a disaster alert system (DAS) capable of online transmission of real-time integrated sea-level and surface meteorological data is discussed. In addition to INSAT platform transmit terminal, VHF, etc., the ubiquitous cellular phone network would be an important option that can be effectively utilized to provide the crucial communication capability to DAS. Such a system would also provide a sufficiently large near-real-time database for running storm-surge models and prediction of any suspected destructive surge events at vulnerable coastal belts as well as complement any deep ocean tsunami warning system that India might put in place. Web-enabled DAS network with authorized access would facilitate viewing real-time/near-real-time coastal sea-level and surface meteorological events, ensuring data security and confidentiality.

Keywords: Alert systems, sea level, storm surge, tsunami, wireless network.

THE recent monster tsunamis that struck the South Asian countries, including India, and the severe destruction and devastation brought by them, have triggered serious deliberations from many quarters on the urgent need for versatile disaster warning systems in place for India. Immediate alert and related information bulletins disseminated to appropriate local and central disaster management cells and the people by public communication channels such as commercial radio, television and marine radio system available in the country, would have saved many lives. It is indeed essential to establish efficient means to alert local authorities to put into action the appropriate emergency measures. Another necessity is 'capacity building' to manage emergency situations. Thus, what India lacks the most at the moment is an instrumented wireless network of mechanisms in place for quick dissemination of disaster alert information to the coastal communities. The suggested network, i.e. Disaster Alert System (DAS) will complement the early warning system for tsunamis that has been proposed by the Department of Ocean Development¹, by providing the crucial *in situ* real-time/near-real-time integrated coastal sea-level and surface meteorological data input to storm-surge models and ocean disaster simulation and prediction models. In this context, it would be worthwhile to carefully examine

the natural disasters that have already struck India in the past, locations that have been vulnerable to disasters and the quantum of human lives lost (let alone the colossal damage and property loss caused by them). Such an exercise would serve to educate the people, and would perhaps be a vital input to the decision-makers and the concerned scientific communities to arrive at some useful measures that could be economically implemented to issue timely alert and warning to the people of India and its neighbours.

Tsunami is a special type of long wave (solitary wave) that is generated in the sea following a large-scale impulsive disturbance (for example, earthquake). In contrast, storm-surge is a localized disturbance of sea-level resulting from the action of a cyclone. Tsunamis and storm-surges are the two natural calamities that have hit India; they have taken a heavy toll of lives and inflicted colossal damage to property. Underwater earthquakes (seaquakes), which are the most potent cause for tsunamis, have been monitored successfully in limited areas of certain countries (e.g. California, southwest Iceland) based on noticeable increase in the background seismic activities². However, with the present scientific knowledge and technology available even with the most advanced nations, reliability of seaquake prediction for warning purposes is considered to be rather poor.

Before discussing the types of disaster alert and warning systems for India, it would be prudent to examine the impact of tsunami and storm-surge events that have hit our nation in the past. Table 1 provides an indication of the frequency of occurrence of tsunami episodes in India and the losses incurred. The tsunami, which was generated in the Pacific Ocean in 1883, struck Calcutta harbour and smashed 300 river-boats in the Hoogly river. During this period, Madras coast recorded 2 m tsunami waves. According to historical records, during the trough phase of this tsunami, the sea receded all of a sudden that the ruins of old buildings with brazen gates and other accompaniments were seen in Chennai. The tsunami of 1945, which was triggered by an earthquake near Karachi, Pakistan, submerged Pingleswar temple situated close to the mouth of the Gulf of Kutch. The large tsunami waves destroyed many coastal dwellings as well. However, no major destructions were reported. It is evident that the most severe tsunami hit India on 26 December 2004.

Storm-surge is another type of disaster that occurs in India; the '1999 super cyclone' being the one which triggered the severest storm-surges along the coast of Orissa. This disaster affected 13 coastal districts of Orissa and claimed more than 20,000 lives. In addition, it affected more than 15 million people. Sea water that entered a few kilometres from the coast, made the land unfit for cultivation. Similarly, the cyclone that hit Kakinada in 1996 caused 2 to 3 m surge, killing 978 people (1375 persons were reported missing). The devastation damaged 647,554 houses and 174,000 ha of crops. Figure 1a provides a quarter century-wise distribution of storm-surge induced loss of human lives in India during the last three and a quarter centuries (1681–2004).

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Table 1. Tsunami episodes that have occurred in India in the past

Year of occurrence	Location	Loss of human lives
19 August 1868	Andaman Islands	Data not available
31 December 1881	Andaman Islands, Nagapattinam	Data not available
August 1883	Calcutta harbour and Madras coast	Nil
26 June 1941	East coast of India	Nil
27 November 1945	Gulf of Kutch, Mumbai and Karwar	A few (exact figure not available).
26 December 2004	Andaman and Nicobar Islands and east and southwest coasts of India	10,136 (official) 16,000 (estimated) (~ 7000 people missing in Andaman and Nicobar Islands)

Source: National Geophysical Data Center; Van Dorn⁵.

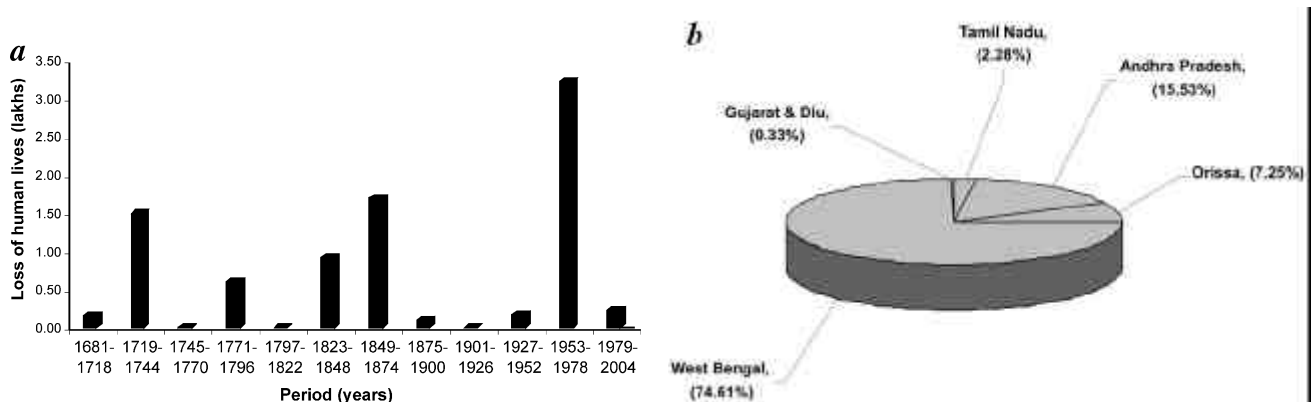


Figure 1. *a*, Quarter century-wise distribution of storm surge-induced loss of human lives in India during the last three and a quarter centuries. *b*, Percentage distribution of storm surge-induced loss of human lives in India during the same period. (Source: Intergovernmental Oceanographic Commission, in part.)

Figure 1 *b* illustrates percentage distribution of storm-surge-induced loss of human lives in India during this period. Figure 2 *a* indicates state-wise time series distribution of storm-surge-induced loss of human lives in India during the period 1681–2004. Figure 2 *b* provides state-wise percentage distribution of storm-surge occurrences in India during the above period. Figure 3 illustrates state-wise time series distribution of storm-surge occurrences in India during the last three and a quarter centuries. Figure 4 *a-f* shows Indian coastal locations (state-wise information) that are vulnerable to storm-surges and the number of storm-surge occurrences during the period 1681–2004. From the above statistics on tsunamis and storm-surges, it is worthwhile to ask the question whether India should go solely for a tsunami alert and warning system or a combined system for storm-surges and tsunamis. Although the frequency of occurrence of tsunamis in India is far less than that of storm-surges (so also the relative severity of these two disasters), the 26 December 2004 disaster has come as a reminder that tsunamis can no longer be overlooked. Thus, India could think of opting for alert systems for both disasters.

Although the main causative factors for tsunami and storm-surge are earthquake and storm winds respectively, the com-

mon factor that gives rise to the disaster is an appreciable anomaly in the coastal sea-level (both high and low frequency components). Coastal sea-level is, therefore, one essential common parameter to be monitored closely to examine the development and progress of the effect of the approaching/prevaling danger. However, strong wind is an additional factor in the case of storm-surge. Thus, there are a few commonalities in the nature of alert and warning systems that have to be implemented to tackle these two natural disasters together. Close real-time monitoring of these two signals might provide the input useful for running predictive models and issuing warning for immediate and region-specific selective evacuation.

Since the propagation speed of earthquake-generated shock waves (which propagate through the solid earth) is approximately 70 to 100 times larger than that of the tsunami waves (which propagate through water bodies), there would be some time available to warn the coastal communities about an oncoming possible tsunami disaster. The important features of tsunami warning systems are: (i) rapid and accurate detection of location of earthquake epicentre, (ii) determination of actual existence of a tsunami, and (iii) accurate calculation of expected time-of-arrival of tsunami

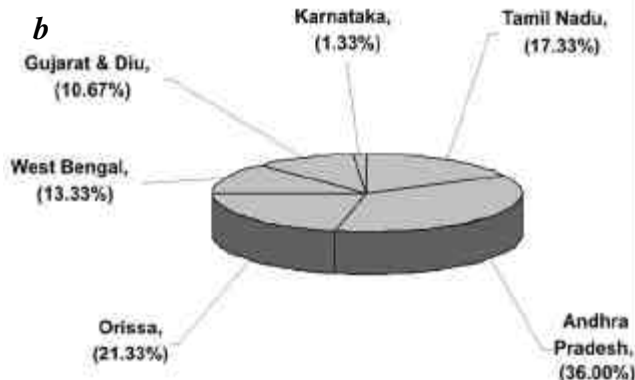
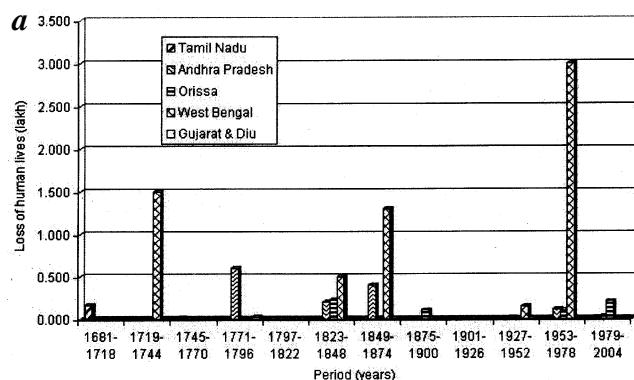


Figure 2. *a*, State-wise time series distribution of storm surge-induced loss of human lives in India during the last three and a quarter centuries. *b*, State-wise percentage distribution of storm-surge occurrences in India during the same period. (Source: Intergovernmental Oceanographic Commission, in part.)

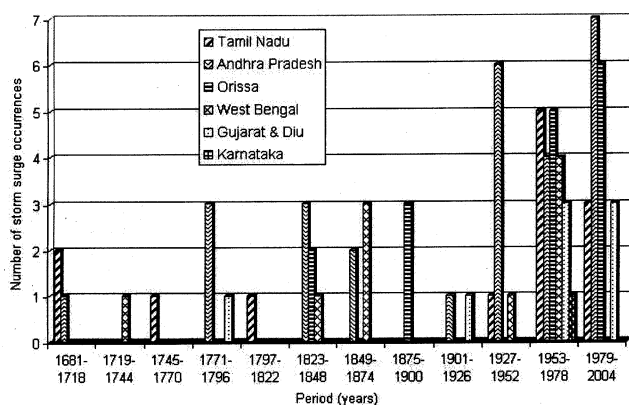


Figure 3. State-wise time series distribution of storm-surge occurrences in India during the last three and a quarter centuries. (Source: Intergovernmental Oceanographic Commission, in part.)

at given coastal locations and issue of warning via the fastest possible communication channels.

It has been feasible to deploy seafloor-mounted tsunami detection sensors in the Pacific Ocean rim regions with the support of instrumented deep-water moored buoys in the vicinity of seafloor spreading centres. The primary sensors are seismic probes imbedded in the seafloor at varying depths². High-precision pressure sensors that are located on the seafloor are also providing important data on the propagation of tsunamis in deep water^{3,4}. In moored buoy systems, acoustic modems attached to the moorings transmit event-detection data (i.e. seismic and bottom pressure data) to a module attached to a surface buoy. This surface-module, in turn, relays the data to several land-based disaster warning centres via satellite transmission network. The tsunami buoy systems are aimed at quickly confirming the existence of potentially destructive tsunamis and reducing the incidence of false alarms. It is expected that a series of instrumented deep ocean buoys might provide the much needed and reliable early warning. Where the source motion is known, computer

simulations have been found to agree quite accurately with observations⁵.

Although offshore instrumented buoys are important devices and can be used for detection of both tsunami and storm-surge events far away from land, they are expensive and might pose logistical challenges. Thus, an alternate complementary, coastal-based system that provides real-time or near-real-time data to authorized agency/agencies can be thought of.

A suitable network for real-time monitoring of storm-surge and running of operational storm-surge models for predictive purposes must consist of real-time transmitting sea-level and surface meteorological monitoring systems. A great advantage of the storm-surge model is its usefulness in predicting the anticipated flooding at selected locations. The storm-surge model that is established on a geographical information system (GIS) platform would allow a realistic assessment of the impact of elevated/depressed water-levels on the regions covered by the storm-surge model. The prediction will enable the local administrators/planners to issue periodic warning of maximum likely flooding at a given location in a given coastal/estuarine region for a specific meteorological event.

At present, in India, storm-surge models for Indian coasts are run based on past historical datasets that have been archived from a network of coastal sea-level gauges (tide gauges) maintained by the Survey of India (SOI) and meteorological datasets that have been archived from a network of meteorological stations maintained by India Meteorological Department (IMD). The proposed DAS network consists of a combination of digital sea-level gauges and digital surface meteorological instruments. The present network of tide gauges that are operational in India are primarily mechanical or quasi-mechanical float-driven gauges. In recent times, some electronic gauges have also been introduced at a few locations. In the ubiquitous float-driven gauge, the tidal curve is traced using an ink-pen that moves freely along the Y-axis over a graduated paper chart

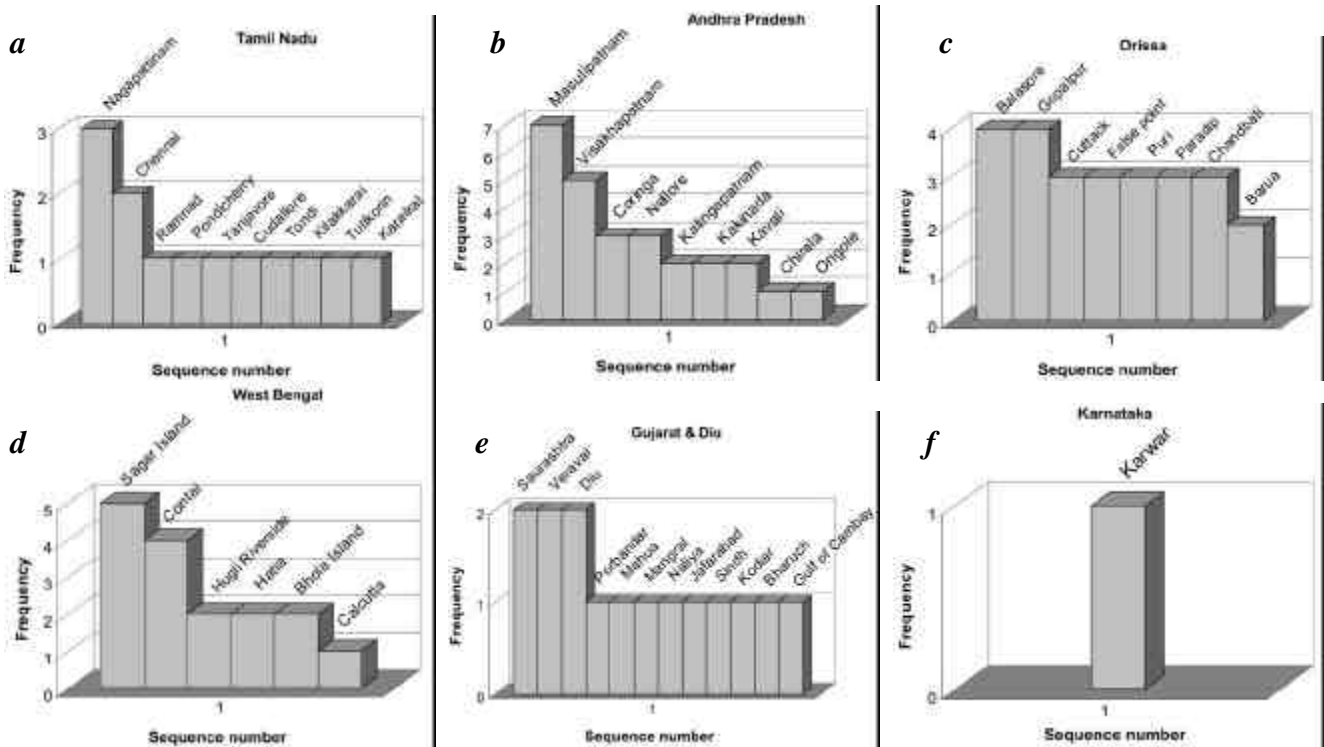


Figure 4. Number of storm-surge occurrences in Tamil Nadu (a), Andhra Pradesh (b), Orissa (c), West Bengal (d), Gujarat (e), and Karnataka (f) during the last three and a quarter centuries. (Source: Intergovernmental Oceanographic Commission, in part.)

that is rolled over a cylindrical drum, whose motion along the X-axis is controlled by a fine-resolution mechanical clock. Depending on the type of float gauge deployed at a given tidal station, the chart paper is removed daily, weekly, or at some other suitable interval. The graphical trace thus registered on the paper chart is subsequently digitized at a convenient time and the data are posted to the headquarters of SOI for archival, preparation of Tide Table, and various scientific and operational applications. Most of the currently existing meteorological instruments are also mechanical in nature, and the meteorological observations are noted and registered at certain selected times only. Thus, at present, *in situ* real-time integrated sea-level and meteorological data are not available for any real-time operational tasks, such as running predictive models for warning purposes. Thus, the first step towards implementation of real-time reception of coastal sea-level and surface meteorological dataset is modernization of mechanical instrumentation to add the requisite capability for obtaining digital data output, preferably in computer-compatible format. The next step is to incorporate real-time transmission capability through the existing wireless communication network, leading to availability of *in situ* digital dataset for predictive models and visual graphical representation of the current coastal sea-level and other relevant meteorological events for viewing by designated personnel (and by authorized consent, also the general public during occasions of expected or currently occurring anomalous coastal sea-level scenarios).

As storm-surge is a manifestation of the action of a violent gust of wind and atmospheric pressure gradient over a large water body, deployment of a network of wireless transmitting water-level loggers (tide gauges) and meteorological monitoring systems (weather stations) would provide a sufficiently large real-time database for running predictive models for storm-surge forecasting, if ancillary database on the bathymetry and topography of the region of interest is available. Real-time database of water-level oscillations obtained from a network of spatially distributed wireless-transmitting water-level gauges can also be used for real-time validation of the storm-surge model. In India, practically all the populated areas are networked to cellular transmitting stations and, therefore, the required dataset can be made available on-line for real-time model-running applications. The monitored information and forecast can be disseminated to the coastal communities and the general public through a variety of electronic media already available in India.

Based on the above discussions, it would be desirable to opt for development and deployment of a network of web-enabled wireless-transmitting real-time integrated coastal sea-level and surface meteorological monitoring systems incorporating the state-of-the-art wireless technology (Figure 5). The ubiquitous cellular phone network coverage that is presently available in India is one of the options that can be effectively used to provide the much needed wireless communication capability to the proposed DAS network. Additionally, VHF, INSAT platform transmit terminal,

etc. can also be incorporated to facilitate robust communication and redundancy. Such a system would also provide a sufficiently large real-time database for prediction of storm-surge events (and the quasi-periodic resurgence that often follows the primary forced surge). The DAS network would complement the national efforts towards the development of early warning systems for disaster management.

There exist various types of sea-level gauges⁶ and because of the dynamic nature of the sea, coastal sea-level measurements by most of the devices evaluated thus far are subject to varying levels of site-specific inaccuracies. For example, accuracy of all in-water systems such as the conventional float-driven gauges, guided air acoustic gauges, bubbler gauges, and pressure transducers deteriorate under the influence of flows, waves, and a combination of flows and waves (drawdown of a few centimetres). However, such deterioration of performance can be significantly minimized with the incorporation of suitable hydro-mechanical front ends at their inlets⁷. However, performance of guided air acoustic gauge is severely influenced by another site-specific factor, namely temperature gradient in its sounding tube⁸, up to a maximum of 6 cm observed at Zuary estuary, Goa for a short duration in the morning and afternoon⁹. Further, any well-based gauges (e.g. conventional float-driven gauges, guided air acoustic gauges) suffer from an inherent problem of trapping of low density water during the post monsoon season, thereby introducing over-estimation of a few centimetres in sea-level measurements, especially so in estuarine sites¹⁰. Pressure transducer does not require stilling-wells for deployment and, therefore, the above-cited error is absent in pressure transducer-based gauges, if they are not deployed within stilling-wells. Another advantage of pressure transducer based sea-level gauges, in contrast to float-driven and air acoustic gauges, is the absence of saturation at extraordinarily large elevation of sea-levels,

such as those occurring during storm-surges and the crest phase of tsunamis. However, sea-level measurement accuracy of pressure transducers deteriorates under suspended sediment-laden turbulent water bodies¹¹. Such deterioration has been observed from fairly large turbid water bodies (e.g. Hugli estuary, India; Humber estuary, UK) and also constricted turbid water bodies (e.g. concrete well at Apollo Bunder, Mumbai, which is hydraulically connected to the sea via a pair of ducts). In view of this, use of pressure transducers under such conditions may preferably be discouraged. Recent studies¹² have suggested that microwave radar gauge has to be given strong consideration at locations where variations in water density preclude the effective use of pressure systems. It must, however, be noted that, unlike in sea-level measurements for studies of climate change, error of a few centimetres in sea-level measurements is tolerable in the context of sea-level measurements for monitoring large elevations such as those encountered during storm-surges or tsunamis. A limitation of the conventional float-driven gauge is that its inherent low-pass filtering characteristics prevent it from providing a complete picture of the high-frequency constituents of the disastrous storm-surge and tsunami events (especially the range, period and number of constituent waves in the wave-packet known as soliton that crowns the crest phase of the tsunami waves). Further, a variety of errors, including the nonlinear response of stilling-well-based gauges to large amplitude waves¹³ such as those present during tsunami and storm-surge episodes renders detailed post-disaster analysis of the nature of such events difficult. It would, therefore, be advisable to have in place, additional bottom pressure-based sea-level gauges because they would register low-pass filtered sea-level as usual, and additional capability could be built to register the high frequency extreme surge levels encountered during tsunami and storm-surge events. The bottom pressure based gauge would measure water pressure at a sufficiently quick rate. If these on-line transmitted measurements indicate the presence of some unusual waves or the low-pass filtered sea-level measurements indicate drawdown or set-up signals that are associated with storm-surge or tsunami, the authorized agencies that monitor the integrated coastal sea-level and surface meteorological events can issue periodic alerts to the concerned local and central officials and the coastal communities.

Float-driven gauge was the first device developed to provide a graphical record of the low-frequency sea-level oscillations, primarily tides. This is also the oldest and ubiquitous device in the world that provided most of the available records pertaining to tides, storm-surges, and even tsunamis. The tide station at Mumbai is perhaps one of the oldest in the world and the fascinating tide-curves registered by the float gauge at Mumbai as early as 1884 were reported by Darwin in his celebrated treatise on tides¹⁴. In view of these, while incorporating any new device as part of any modernization efforts, it might be worthwhile to retain the age-old float gauges which have served the Indian

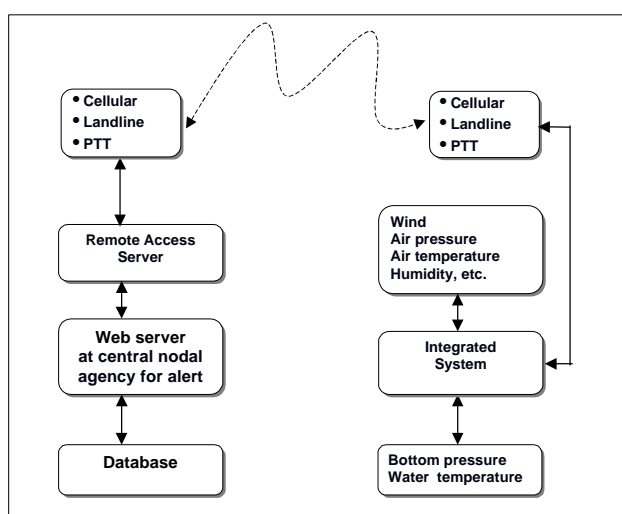


Figure 5. Illustration of suggested disaster alert system for India, comprising a network of wireless-transmitting integrated sea-level and surface meteorological monitoring systems incorporating the state-of-the-art wireless technology.

harbours for centuries. These gauges have been routinely maintained by SOI – an agency entrusted with the responsibility of the general superintendence and control of systematic sea-level observations in India, according to a resolution passed by the Government of India. However, necessary improvements need to be incorporated into the existing float gauges to minimize the reported drawbacks and add real-time data transmission capability. Use of pressure gauge will enable registering high-frequency constituents of the sea-level oscillation. A cost-effective pressure transducer that has been evaluated¹⁵ and found to be suitable for the present application is silicon piezoresistive pressure transducer, which has been successfully used by NIO in the establishment of a global sea-level observing system (GLOSS) in Ghana, West Africa, for the Intergovernmental Oceanographic Commission of UNESCO. Uninterrupted sea-level and water temperature data recorded by this gauge from the Ghanaian boundary at the Gulf of Guinea since 1 July 2004, are available for use by the world community. Under GLOSS, NIO has also established an autonomous electronic weather station at Tema harbour, Ghana and it is functional.

One might legitimately question the survivability of any instrumentation in coastal waters during a disaster event. While probabilities do exist of damages to instrumentation, there are ample instances where such instrumentation has survived the disaster. For example, sea-level data from many recent (26 December 2004) tsunami-hit locations have been recorded by SOI gauges and displayed on the NIO website with permission from SOI. Similarly, the tide gauges designed and deployed by NIO survived the notorious 'super-cyclone' that hit Orissa coast in 1999. Thus, while a certain element of risk and damage to any coastal-based instrumentation cannot be ruled out, it is necessary to go for integrated coastal sea-level and meteorological monitoring systems for disaster warning pertaining to storm-surges and tsunamis.

There appears to be a consensus in India on the urgent need for establishment of a disaster warning system. A network capable of on-line transmission of integrated sea-level and surface meteorological events from coastal tide gauges and weather stations is an important ingredient to complement the deep ocean systems that are currently contemplated for providing timely alerts of an imminent disaster. With the expertise and experience already available in the country, implementation of an effective warning system is just a matter of time. In this effort, the existing float-driven gauges can be modernized and pressure gauges can be added to provide the capability for measurement of the high-frequency components associated with storm-surge and tsunami events and the feature of non-saturation under extreme events.

While implementation of DAS is one aspect, an equally important requirement is preparedness against natural oceanogenic disasters and cost-effective mitigation measures to face the natural disaster. Strict implementation of coastal

zone regulation guidelines, development of environment-friendly schemes such as 'bio-shields' (e.g. plantation of mangroves and other suitable plants), disaster awareness programmes to the coastal communities, inclusion of topics on natural disasters and effective ways of facing them, etc. in school and college syllabi would be valuable means of preparedness against future coastal disasters.

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