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Status Report

Seismological Research in India

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The recent seismological research and studies in India are dominated by 1) studies on the spatio-temporal aspects of seismogenesis and seismotectonics of the Himalaya and its adjoining regions; 2) Seismological studies on tsunamigenic earthquake and earthquake pattern of the Andaman-Nicobar subduction region of India 3) studies on seismogenesis and seismotectonics of the Stable Continental region (SCR) of India; 4) studies on site response, seismic microzonation, earthquake risk, vulnerability, disaster management and risk mitigation strategies of India; 5) studies on earthquake precursor and prediction of earthquakes in India; 6) studies on seismological issues of outside India. The extensive seismological research in India is principally aimed at understanding the intricate seismological processes beneath the study region *vis-a-vis* elsewhere in the world having analogous seismotectonic and hydrological settings. Several pieces of outstanding multi-disciplinary detailed studies on the reservoir induced earthquakes have resulted in the formulation of a comprehensive project of "Deep Crustal Drilling" (DCD) in the Koyna-Warna region by involving several institutions of India to unravel the hidden mystery involved with reservoir induced earthquake nucleation and generating processes. A series of seismological publications on challenging issues by Indian researchers in different journals of global repute during the year 2007-2011 gives enough testimony of quality-based seismological research in India, which has significant bearing on opening up of new avenues for conducting leading edge advanced seismological research in the regional and global perspectives.

Key Words: Seismotectonics; Himalaya; Subduction Region; Tsunamigenic Earthquake; Deep Crustal Drilling; Earthquake Risks & Precursors

An Overview

India has a history of pioneering seismological research in the solid earth science that resulted in the discovery of the Core of the Earth. For the first time, identification of the surface wave and its distinction from the body wave on the recorded seismogram of the 12^{th} June 1897 Shillong earthquake (Mw 8.7) led to several discoveries of the Earth System in the annals of seismological research in the world.

In recent years (2007-2011), frequent occurrences of macro to micro earthquakes in different parts of India and its adjoining regions posed a challenging task to Indian seismological community to conduct a leading edge seismological research. State-of-the-art techniques of multi-disciplinary geosciences were used to address the principal cause of earthquakes, whose after affects (tsunamis, landslides, avalanches) had major impact on both flora and faunas causing unprecedented and innumerable earthquake hazards in the region. With financial supports of Ministry of Earth Sciences (MoES) & Department of Science and Technology, Government of India to various research institutions [e.g., National Geophysical Research Institute (NGRI, Hyderabad, A.P); Institute of Seismological Research (ISR, Gandhinagar, Gujarat) [ISR 2009]; Wadia Institute of Himalayan Geology (WIHG, Dehradun, Uttrakhand); Northeast Institute of Science & Technology (NEIST, Jorhat, Assam); Centre for Mathematical Modelling and Computer Simulation (CMMACS, Bangalore); and universities [IIT Kharagpur; IIT Roorkee; IIT Kanpur; IIT Mumbai; IISc, Bangalore; University of Delhi; Jadavpur University, Jadavpur; Krukshetra University, Krukshetra; Indian Schools of Mines University, Dhanbad; Manipur University, Imphal; Osmania University, Hyderabad; Benaras Hindu University (BHU, Varanasi)] seismological research in India progressed in leap and bounds during the year 2007-2011. Different government departments (Indian Meteorological Department (IMD); Geological Survey of India (GSI)] and several other institutions of provincial governments are involved in carrying out seismological monitoring and studies as per their research programs. Seismological research in India got special impetus during this period because of great thrust given to seismological monitoring

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of seismically active regions of India in real-time mode by deploying several sets of advanced versions of seismological equipments by involving IMD, NEIST, Jorhat and WIHG, Dehradun under sponsorship programs of the Central and provincial governments. This endeavor has provided ample opportunity to generate large set of high quality seismological data as a fundamental requisite for conducting comprehensive seismological research.

The recent seismological research in India is dominated by 1) studies on the spatio-temporal aspects of seismogenesis and seismotectonics of the Himalaya and its adjoining regions; 2) Seismological studies on tsunamigenic earthquake and earthquake pattern of the Andaman-Nicobar subduction region of India 3) studies on seismogenesis and seismotectonics of the Stable Continental region (SCR) of India; 4) studies on site response, seismic microzonation, earthquake risk, vulnerability, disaster management and risk mitigation strategies of India; 5) studies on earthquake precursor and prediction of earthquakes in India; 6) studies on seismological issues outside India.

The Himalaya and its Adjoining Regions

Several geoscientists of India and abroad attempted to undertake detailed seismological studies of the Himalayan and its adjoining regions using advanced tools of seismology because of its complex geotectonic settings under which the Himalayan orogen is associated with the Indus-Tsangpo suture in the north, the left-slip Chaman fault in the west, the right-slip Sagaing fault in the east, and the Main Frontal Thrust (MFT) in the south, extending all the way from the Himalayan range to the Arabian Sea and the Bay of Bengal (Mitra *et al.*, 2008; Singh *et al.*, 2010; Khan *et al.*, 2011a). The intriguing tectonics of the region is reflected by the presence of the Shillong Plateau, which is bounded by the active south-dipping Dauki thrust as part of the broadly defined Himalayan orogen, because its bounding structure is linked with the transpressional system in the Indo-Burma Ranges. Recently, a seismotectonic overview of the Burma-Andaman-Sumatra subduction margin preceeding the 2004 off Sumatra mega-event is well illustrated by Khan *et al.* (2010a). The entire NE region adjoining Shillong Plateau is studied with new earthquake catalogue by Yadav *et al.* (2010) ana Das and Wason, (2010). Dutta *et al.* (2011) generated South Asia earthquake catalogue with refined magnitude data using regression analyses. An extensive seismicity study of NE, NW, and Western Nepal and Sikkim Garhwal Himalayan region has been made by several researchers to understand the seismic trend and the current status of stress pattern beneath the region (Thingbaijam *et al.*, 2008, 2009; Raj *et al.*, 2009; Paudyal *et al.*, 2010; Khan *et al.*, 2011). Seismological evidence on surface faulting along the northeastern Himalaya from spatial extent of great earthquakes has been put forth by Kumar *et al.* (2010). Detailed seismic structure of the under thrusting Indian plate beneath the Sikkim Himalaya has been assimilated by Singh *et al.* (2010) to better understand the nature of earthquake source zone, where recent earthquakes occurred (Raj *et al.*, 2008; Rajendran *et al.*, 2011). Recent studies made by several researchers in NE Indian region with special reference to Shillong Plateau using precisely relocated earthquakes and 3-D travel-time tomography demonstrated that the nature of crustal heterogeneities has strong bearing on seismogenesis (Bhattacharya *et al.*, 2008; 2010; Mishra, 2011). These studies also showed the uneven distribution of crustal heterogeneities in the region consists of folded and faulted Siwalik mollase sediments of Miocene age, and separated from the sprawling swampy plains of Tarai to its south by the HFT. Two main regional geological and crustal discontinuities are demarcated in terms of Main Boundary Thrust (MBT) and Main Central Thrust (MCT) and mapped by 3-D seismic tomography where a close correlation between seismicity and structural heterogeneities exists. Hidden Oldham fault is studied using integrated tools of Seismo-geophysics in the Shillong Plateau (Saha *et al.*, 2007) to understand its relationship with the 1897 earthquake (Mw 8.7). Some of researchers also estimated path attenuation of the ground motion and coda estimates using the local earthquakes in NE and NW Himalaya to understand the nature of rupture propagation and the intensity of seismic shaking during earthquakes in the region (Mohapatra *et al.*, 2011; Nayak *et al.*, 2011).

Besides use of 3-D seismic tomography method in seismological study of the Himalayan region, Indian researchers deployed several advanced seismological techniques to address the intricate geotectonic issues of the Himalaya and its adjoining regions, such as joint analyses of teleseismic receiver function and Rayleigh wave surface wave dispersion (Mitra *et al.*, 2008; Mitra *et al.*, 2011) to determine crustal and upper mantle structure of the Western Bengal Basin and the Himalayan foreland basin. Caldwell *et al.*, (2009) investigated NW Himalayan region to get deep insight into the upper middle crust of the region and they identified partial melt into the upper middle crust. Crustal structure of the Darjeeling-Sikkim Himalaya and Southern Tibet was determined using high quality seismic data by Indian seismologists in collaboration with overseas seismologists and it revealed several hidden mysteries of seismogenesis in the region (Acton *et al.*, 2011). Seismo-tectonic model of the Kangra-Chamba sector of NW Himalaya derived from the precisely relocated earthquakes using Joint Hypocenter Determination (JHD) of earthquakes suggested that complex tectonics of the region is a principal source of seismic potential of the region (Kumar *et al.*, 2009), while investigation of seismicity in the western Himalaya shed important light on the pattern of seismicity that showed good correspondence with the active tectonics of the region (Lyubushin *et al*., 2010). Seismological research in the Himalaya region during the year 2007-2011 gave special emphasis on rigorous statistical analyses of background seismicity data using techniques of earthquake swarms and clusters identification to understand the subduction kinematics and seismic potentiality of the region by demarcating seismic moment release gaps as a future potential zones for impending moderate to strong earthquakes in the Himalayan region (Mukhopadhyay et al., 2008; Mukhopadhyay et al., 2010a, b). The recent occurrence of the 8^{th} October 2008 Pakistan-Kashmir earthquake (Mw 7.9) has provided ample opportunity to study the seismogenesis of Kashmir Himalaya and future vulnerable zones beneath the region (Ghosh and Mishra, 2008a; Khan et al., 2010b), which rekindled the seismic potential of the Indus-Kohistan seismic zone and its relationship with the source zone of the past 1974 Pattan earthquake (Mw 5.9).

The Andaman-Nicobar and its Adjoining Regions

The Andaman-Nicobar region of India represents a very complex subduction tectonics among the major subduction zones of the world because of several issues related to seismotectonic settings associated beneath the Indian Ocean. A series of seismological research were carried out in the region after the 2004 mega-thrust tsunamigenic Sumatra - Andaman earthquake (Mw 9.3) because of availability of huge high-quality seismological data for the region. An extensive study from the Andaman segment was made by Andrade *et al*. (2011) to ascertain intraplate response to the great 2004 Sumatra-Andaman earthquake. Aftershocks data of the 2004 Sumatra-Andaman earthquake provided several constraints to study seismotectonics of the Andaman-Nicobar region (Dasgupta *et al*., 2007). The research in the Andaman-Nicobar region further extended by estimating Coda Q estimates using local earthquakes to understand the nature and extent of seismic wave attenuation in the area (Imtiyaz *et al*., 2007; 2008). Ghosh and Mishra (2008) analyzed a large number of moment tensor solutions of the recorded aftershocks in the Sumatra-Andaman- Nicobar region to estimate slip vector and strain partitioning and they demarcated several areas for future plausible zones of impending big earthquakes beneath the region. The subsequent occurrences of moderate to strong earthquakes in the Sumatra-Nias region were very much corroborative with these demarcated gap zones by Ghosh and Mishra (2008b). The erratic trend of aftershocks recorded during aftershock monitoring of the Andaman-Nicobar region by installing a number of 3-component digital seismographs from south to north by Indian seismologists revealed intricate pattern of seismogenesis and provided deep insight into the in-situ material heterogeneities beneath the region (Mishra *et al*., 2007a,b; Dasgupta *et al*., 2007; Bhattacharya *et al*., 2007). Kayane *et al.* (2007) in collaboration with Indian seismologists determined co-seismic and post-seismic creep in the Andaman Islands associated with the 2004 Sumatra-Andaman earthquake. Because of release of huge seismic moment during the great mega-thrust Sumatra earthquake it was realized that the subducting slab might have gone unbalanced, which was studied in detail by Khan (2011). Several studies were made to understand the fault reactivation on the subduction oceanic plate, lithospheric disposition of the subducting plate, rifting history and magmatism beneath the subduction tectonics in the Sumatra-Andaman-Nicobar region (Mukhopadhyay *et al*., 2009, 2010c; Rajendran *et al*., 2011). An extensive analyses of earthquake swarms was made to understand the nature of occurrence of shallow focus earthquakes in the Indian tropics in relation to their seasonal bias by Mukhopadhyay *et al.* (2008, 2010d).

Stable Continental Region (SCR) of India

Despite older geological age, devoid of recent magmatism, lesser seismic potential, appreciable distance of the tectonic plate boundary (> 500 km), and slow deformation rate, the stable continental region (SCR) of India witnessed several frequent strong to great earthquakes, causing a huge loss of both property and people in the region. Occurrence of the past damaging earthquakes (e.g., 1993 Latur-Killari; 1997 Jabalpur; 2001 Bhuj) in SCR are enigmatic and the exact cause of seismogenesis is not known (Mishra *et al*., 2008). By deploying relatively dense seismograph network in the western India Chopra *et al*., (2008) and Rajendran *et al*. (2008) assessed the previous activity at the source zone of the 2001 Bhuj earthquake based on the near-source and distant palaeo-seismological indicators. The seismic anisotropy of the Indian tectonic plate was made by several researchers using different techniques, including shear wave splitting to understand the continental scale mantle deformation pattern and signatures of rifts in the Indian shield region (Kumar and Singh, 2010; Kumar *et al*., 2010; Saikia *et al*., 2010). Evaluation of crustal and upper mantle structures of the eastern Indian shield has been made using seismological data recorded by the broadband stations (Kayal *et al*., 2011). Some of researchers attempted to estimate Coda-Q variations in the Kuchchh Rift Basin (KRB) and eastern Indian shield to understand its seismotectonic implications (Mandal, 2007; Khan *et al*., 2011b). To assess the cause of seismogenic potential of the region, major faults of Indian shield have been analyzed using fractal analyses with huge set of high quality of seismological data (Sengupta *et al*., 2011). The 2001 Bhuj earthquake and the Kuchchh rift basin region was studied extensively using new set of seismological data recorded by ISR, Gandhinagar, Gujarat (Sharma *et al*., 2008; Chopra *et al*., 2010, 2011; ISR 2009) and by NGRI, Hyderabad (Yadav *et al*., 2007; ISR, 2008; Mandal and Chadha, 2008; Singh *et al*., 2011). Mandal (2007) determined thickness of sedimentary layers beneath KRB using converted phase data recorded by a number of seismograph stations installed there in the region. Seismological studies revealed that occurrences of earthquakes beneath SCR of India are associated with fluid-related anomalies, which may have triggered due to the presence of fluid-filled fractured rock matrix beneath the source zone (Mandal and Chadha, 2008; Mishra *et al*., 2008; Singh *et al*., 2010, 2011).

One of the significant developments in seismology in India is the study of artificial water reservoir triggered earthquakes in well documented seismically active region of Koyna – Warna, Maharashtra, India (Gupta, 2008). Frequent occurrences of micro to moderate earthquakes in the Koyna – Warna region recorded by the seismic network consisted of advanced seismograph stations provided good quality earthquake data to undertake a comprehensive seismological analyses for better understanding of the nature of seismogenesis and nucleations of these reservoir induced seismicity in the periphery of Shivaji dam of the region (Sharma *et al*., 2007; Singh *et al*., 2008; Mishra *et al*., 2008; Singh *et al*., 2010; Gavrilenko *et al*., 2010). Several detailed studies on the reservoir induced earthquakes led to the formulation of a comprehensive project of "Deep Crustal Drilling" in the Koyna-Warna region on sponsorship by the Ministry of Earth Sciences (MoES) by involving several institutions. This research project is directed to understand the fault geometry, physical properties of rocks, fluid composition, pore fluid chemistry, heat flow, and *in-situ* stresses.

Seismic Microzonation, Earthquake Hazards and Disaster Studies

Earthquake is one of the major hazards for India. In recent years (2007-2011), seismological research in India is directed to address issues of development of tools for hazard assessment especially for earthquake and subsequently mapping the parameters necessary for long-range planning of the cities. The difficulty of this challenge is manifested in the spatially irregular patterns of damage that are typically observed after major earthquakes (Nayak, 2011). The challenge of urban hazard mapping is to predict the ground motion effects related to various sources, path and site characteristics, not just at a single site but at all the places with an acceptable level of reliability. Development of seismic microzonation of major urban centres has, therefore, been recognized as a priority area of seismic mitigation programme in India. Ministry of Earth Sciences (MoES), constituted a National Steering Committee in March 2008 to provide overall guidance to undertake seismic microzonation studies for identified cities and urban centers of the country. Geological Survey of India has successfully completed the study of generating site response map for most of important cities of India during 2007-2011. Among them are: Dehradun, Jammu, Ahmedabad, Jamnagar, Jalandhur, Bhavnagar, Bharuch, Agartala, Siliguri, Mumbai, Vizag, and Chenai, besides New Delhi, Jabalpur and Guwahati. The work has been executed by different regional offices of Geological Survey of India, located in different parts of the country. Other academic and research institutions of India, such as IIT Kharagpur, IIT Roorkee, ISR, Gandhinagar, and NEIST, Jorhat are actively involved in conducting seismic microzonation studies of Indian cities. First level seismic microzonation has already been completed for Jabalpur, Sikkim, Guwahati, Delhi, Bangalore, Ahmedabad, Dehradun, Chennai and Chandigarh. As there are no detailed guidelines for adopting appropriate investigations, all microzonation endeavors are not homogeneous. In order to fill up such gap MoES (2011b) developed a handbook on "*Seismic Microzonation*", which encapsulates detailed underlying principles and case studies on various geological, geophysical and geotechnical studies beneficial to the seismic and earthquake engineering community of India (Nayak, 2011). Extensive study on small scale zonation maps in India provided a broad picture of the levels and distribution of earthquake hazard as well as a scientific basis for earthquake resistant design codes and expected to be a manual for successful seismic microzonation study in India and the country of analogous geotectonic settings (Bansal, 2011). Gupta (2010) provided comprehensive guidelines for scientists and engineers such plans on hazard and disaster risk reduction.

Walling and Mohanty (2009) provided an overview on the seismic zonation and microzonation studies in India. Researchers adopted different methodologies of mapping seismic hazards in India. Parvez and Lyubushin (2010) generated seismic hazard map using Bayesian approach; Menon *et al*. (2010) used probabilistic seismic hazard macrozonation of Tamil Nadu, Southern India and others (Mahajan *et al*., 2010; Yadav *et al*., 2011) used similar probablistic approach to estimate earthquake hazard parameters for NW Himalaya and its adjoining regions. Raghukanth and Das (2010) applied deterministic approach to assess seismic hazard scenario for Northeast India. A holistic microzonation approach for seismic hazard assessment is put forth by Nath and Thingbaijam (2009). An extensive study on peak ground motion predictions in India has been made for different rock sites by several researchers in diverse tectonic environ of India (Nath and Thingbaijam, 2011; Parvez *et al*., 2011). Multi-criteria seismic hazard evaluation approach for different cities is applied by different researchers to estimate several sets of seismological parameters (Mohanty and Walling, 2007, 2008; Chowdhuri *et al*., 2008; Singh *et al* l., 2008; Nath *et al*., 2008a,b,c,d; Pal *et al*., 2008; Mohanty *et al*., 2009a,b,c; Nath *et al*., 2009; Walling *et al*., 2009; Nath *et al*., 2010; Nath and Thingbaijam, 2010; Anbazhagan *et al*., 2010; Rastogi *et al*., 2011; Chowdhuri *et al*., 2011; Vaccari *et al*., 2011), which helped in assessment of earthquake hazards in the region. Reassessment of earthquake hazard in Kerala state has been made by Rajendran *et al*. (2009) by analyzing historical and current seismicity trends, which showed that historical seismicity pattern has close correspondence with the present-day seismicity that can ascertain earthquake hazardous zone in the region. Several seismic parameters are estimated for Indian region using robust deterministic technique to assess seismic hazards in different parts of India (Raghukanth, 2010a,b). Recently, Srivastava *et al*. (2010) made a revelation on seismological constraints for the 1905 Kangra earthquake and associated hazards in northwest India. A classical study made by Mishra *et al*. (2010) to show the role of crustal heterogeneities beneath Andaman-Nicobar Islands in coastal hazards, which have potential to dictate the size of earthquakes. Similar approach has been applied by Singh *et al*. (2011) to assess crustal heterogeneities beneath the Kachchh, Gujarat and suggested implications of crustal heterogeneities in the earthquake hazard mitigation at the time of evolving a comprehensive hazard mitigation model for the region. Based on several studies Srikanth *et al*. (2010) made earthquake vulnerability assessment of existing buildings in Gandhidham and Adipur cities of Gujarat.

Indian coasts are vulnerable to tsunami hazards because of its nearness to the tsunamigenic earthquake prone zones of Indonesia and Makran. Rajendran *et al*. (2008) estimated tsunami hazard implications of the late arrival of the 1945 Makran tsunami. India has taken effective steps in mitigating tsunami hazard by conducting a series of research in the Indian ocean by the Indian National Centre for Ocean Information Services (INCOIS) (Gupta *et al*., 2008; 2009). A state-of the-art tsunami warning system was set up in October 2007 as outlined in the Prime Minister's twenty-six thrust areas. The system comprises a network of seismic stations including international stations to compute earthquake parameters, simulated scenarios of traveltime and run-up heights at 1800 coastal locations in the Indian Ocean, observing platforms for sea level variations, both in deep sea and coast, robust communication and dissemination system, data centre and decision support system. In last three years, many earthquakes larger than 7-magnitude, which can cause tsunami, did occur. In all such cases necessary advisories were provided to all concerned within 15 minutes. This system is recognized as the Regional Tsunami Warning System for the Indian Ocean and provided services to many countries in the Indian Ocean as well.

Seismological research on aftershock monitoring of the Andaman-Nicobar Islands after the great 2004 tsunamigenic Sumatra-Andaman earthquake (Mw 9.3) showed that public panic during and after the great tsunamigenic earthquake had aggravated the disaster scenario in the region, which could be reduced significantly by conducting systematic aftershock monitoring of the region and spreading the relevant seismological information through well planned awareness programs among the people of the affected region (Mishra *et al*., 2007b). An extensive study has been made by Jaiswal *et al*. (2011) to analyze aftershock sequence of the two great sumatra earthquakes of the year 2004 and 2005 and they simulated minor tsunami that generated on September 12, 2007 in the Indian Ocean to determine its effect on Indian coast.

Earthquake Precursor and Prediction Studies

In recent years, India has been affected frequently by moderate to large earthquakes that rocked in the Himalayan, Andaman - Nicobar and the peninsular shield region, causing sudden damage to both property and people in the region. Consequently, India has initiated a systematic research plan towards generation of long-term, comprehensive multi-parametric geophysical observations in seismically active areas, with a view to establish possible relationship between various earthquake precursor phenomenon and the earthquake generation processes using multi-disciplinary tools of study, which in turn can lead to earthquake prediction in future.

A study made by Gupta (2007) indicated that earthquake forecast appear feasible at Koyna, through rigorous monitoring of reservoir induced seismicity and its rupture nucleation, which is regarded as a milestone achievement in the field of earthquake precursor versus prediction study for the region. Several studies were carried out by Indian researchers to diagnose a suitable set of earthquake precursors for both micro and great earthquakes of India. Sinha Roy and Nath (2007) made an extensive study on precursory correlation dimension for three past great earthquakes of India, while other researchers (e.g., Dasgupta *et al*., 2010; Shanker *et al*., 2010; Singh *et al*., 2010) identified a probable precursor derived from precursory earthquake swarm, cluster analyses and from the anomalous pattern of the recorded seismicity in the region to predict next impending earthquake in the northern Burmese arc and the western Nepal Himalayan region. Panthi *et al*. (2011) developed time-predictable model applicability for earthquake occurrence in the northeast India and its vicinity to study a suitable precursor to predict earthquakes in the region. Yadav *et al*. (2010) studied regional time and magnitude predictable model for long-term earthquake prediction in the vicinity of October 8, 2005 Kashmir Himalaya earthquake and showed that intricate seismotectonic settings of the region are much more susceptible for impending moderate to strong earthquakes because of unique pattern of seismicity and earthquake clusters. Paudyal *et al*. (2010) studied characteristics of earthquake sequence in the northern Himalayan region of south central Tibet to identify earthquake precursors and locations of potential area of future earthquakes. Ministry of Earth Sciences, Government of India has initiated a flagship program on earthquake prediction study by establishing a separate division of "National Project on Earthquake Prediction (NPEP)" for India and its adjoining region to identify potential precursors for earthquake by applying integrated techniques of seismo - geological-geophysical studies in the region (MoES, 2011a). Wadia Institute of Himalayan Geology has also been involved in active seismological research since 2007 in monitoring earthquake prone zones of the north western Hiamalaya through establishments of multi-parametric geophysical observatories in real-time mode to identify precursors for earthquake, which can be used for earthquake prediction studies in the region. Geological Survey of India has indulged in studying earthquake precursory studies through continuous monitoring of seismicity by establishing three permanent seismic stations (Agartala, Adampool and Itanagar) in the northeast India.

Studies on intricate Issues of Outside India

Seismological research in India during the year 2007-2011 are found to extended beyond the Indian boundary because of occurrences of several damaging earthquakes, elsewhere in the world. Kayane *et al.* (2007) in collaboration with Indian geoscientists conducted an extensive study in the Andaman-Nicobar region to assess the co-seismic and post seismic creep in the Andaman Islands associated with the 2004 Sumatra earthquake. Researchers analyzed the 2008 Sichuan/Wenchuan earthquake (Mw 7.9) to understand what caused the genesis of such earthquake in the Sichuan basin of China (Gupta *et al*., 2008; Ghosh and Mishra, 2008). The recent 11th March 2011 Tohoku earthquake (Mw 9.0) is well studied by several Indian researchers (Rajendran *et al*., 2011; Mishra *et al*., 2011). Seismic imaging of the upper mantle under the Erebus hotspot in Antarctica has been made by Gupta *et al*. (2009); while the area in the vicinity of Aswan Reservoir Lake has been seismically imaged by Haggag *et al*. (2009) in collaboration with Indian seismologists. Rai *et al*. (2009) analyzed seismic signatures of Pan African orogeny to understand its implications for the southern Indian high-grade terranes. Detailed estimates of structural heterogeneities in the crust and upper mantle beneath Taiwan and 3-D seimic imaging of the 2004 and 2007 Niigata earthquake, Japan source zones are made by Wang *et al*. (2009a, b) in collaboration with Indian seismologist and furnished interpretation of structural heterogeneity and its bearing on seismogenesis. Indian seismologists estimated crustal heterogeneity of the source area of the Noto – Hanto earthquake (Mw 6.6), Japan to better understand the source mechanism of the earthquake (Padhy *et al*., 2011) in collaboration with Japanese researchers using high quality seismological data recorded there by dense seismic network in the Hanto region of Japan.

The extensive seismological research in India is principally aimed at understanding the intricate seismological processes beneath the study region *vis-a-vis* elsewhere in the world having analogous seismotectonic and hydrological settings. The recent trend of a series of research publications in various journals of global repute on different aspects of seismology by Indian researchers during the year 2007-2011 gives enough testimony of quality-based seismological research in India having significant bearing on opening up of new avenues for conducting advanced seismological research in the regional and global perspectives.

References

Acton, C.E., Priestley, K., Mitra, S. and Gaur, V. K., 2011. Crustal structure of the Darjeeling-Sikkim Himalaya and Southern Tibet, Geophys. Jour. Int., v.184, p.829–852, doi:10.1111/j.1365246X. 2010.04868.x.

Anbazhagan, P., Thingbaijam, K.K.S., Nath, S.K., Kumaran, J.N. and Sitharam, T.G., 2010. Multi-Criteria Seismic Hazard Evaluation for Bangalore City, India, Jour.Asian Earth Sci., v. 38, p. 186 - 198.

Andrade, V. and Rajendran, K., 2011. Intraplate response to the great 2004 Sumatra–Andaman earthquake: A study from the Andaman segment, Bull. Seismol. Soc. Amer., v. 101, no. 2, p.506-514, doi 10.1785/0120100155.

Bansal, B. K., 2011. "Preface", on Seismic Microzonation Handbook, Geoscience Division, Ministry of Earth Sciences, Government of India, p. 518.

Battacharya, P. M., Kayal, J. R, Barua, S. and Arfeiev, S. S., 2010. Earthquake source zones in NE India, Seismic tomography and fractal dimension mapping, PAGEOPH, doi: 10.1007/S00024-010-9984-2.

Battacharya, P. M., Mukhopadhya, S., Majumdar, R. K. and Kayal, J. R., 2008. 3-D Seismic structure of the N-E India region and its implications for local and regional tectonics, Jour. Asian. Earth

Sci., v. 33, no. 1-2, p. 25-41.

Bhattacharya, P. M. and Kayal, J. R., 2007. Application of fractal in marine services, Study of the Sumatra (2004) Earthquake (Mw 9.3) sequence in Andaman Nicobar Islands, Ind. Jour. Marine Sci. v. 36, n. 2, p. 136-140.

Caldwell, W.B., Klemperer, S.L., Rai, S.S. and Lawrence, J.F., 2009. Partial melt in the upper-middle crust of the northwest Himalaya revealed by Rayleigh wave dispersion, Tectonophysics, v. 477, no.1-2, p. 58-65.

Chopra, S., Yadav, R.B.S., Patel, H., Kumar, S., Rao, K.M., Rastogi, B.K., Hameed, A. and Srivastava, S., 2008. The Gujarat (India) Seismic Network, Seismol. Res. Letts., v. 79, no. 6, p. 806-815.

Chopra, S., Kumar, D. and Rastogi, B.K., 2010. Estimation of strong Ground motion for the 2001 Bhuj (Mw .6), India earthquake, Pageoph, v. 167, no. 11, p. 1317-1330.

Chopra, S., Kumar, D. and Rastogi, B.K., 2011. Attenuation of high frequency P and S waves in the Gujarat Region, India, Pageoph, v. 168, no. 5, p. 797-813.

Chowdhuri, S. N.; Singh, O. P., Mishra, O. P. and Kayal, J. R., 2008. Microzonation study from ambient noise measurement for assessing site effects in Krishnagar area and its significance with the damage pattern of Ms 4.3 of the 24th September, 1996 earthquake, Spl. Issue Indian Minerals, v. 61, no. 3-4, p.183-192.

Chowdhuri, S. N., Singh, O.P. and Majumdar, R. K., 2011. Site Response studies in Agartala Urban agglomeration, Natural Hazards, v. 59, no. 1, p. 329-345.

Das, R. and Wason, H. R., 2010. Comment on "A Homogenous and Complete Earthquake Catalog for Northeast India and the Adjoining Region" by R. B. S. Yadav, P. Bormann, B. K. Rastogi, M. C. Das, and S. Chopra, Seismol. Res. Lettrs,. v. 81, p. 235-240.

Dasgupta, S., Mukhopadhyay, B. and Mukhopadhyay, M., 2010. Next Impending Earthquake in Northern Burmese Arc - Search for A Probable Precursor, Mem.75, Geol. Soc. Ind., p. 69-80.

Dasgupta, S., Mukhopadhyay, B. and Acharyya, A., 2008. Seismotectonics of the Andaman-Nicobar Region: Constraints from Aftershocks within 24 Hours of the Great 26 December 2004 Earthquake, In: Sumatra-Andaman earthquake and Tsunami 26 December 2004 (Ed. Sujit Dasgupta), Geol. Sur. India, Spl. Pub., v. 89, p. 95-104.

Dasgupta, S., Mukhopadhyay, B. and Bhattacharya, A., 2007. Seismicity Pattern in north Sumatra- Great Nicobar Region: In Search of Precursor for the 26 December 2004 Earthquake, Jour. Earth Syst. Sci., v. 116, no. 3, p. 215-223, DOI 10.1007/s11069-010-9557-y.

Dutta, P., Naskara, M. and Mishra, O.P., 2011. South Asia Earthquake Catalogue magnitude data regression analyses, Int. Jour. Statist. and Analys., v. 1, no. 2, p.161-170.

Gavrilenko, P., Singh C. and Chadha, R. K., 2010. Modelling the hydromechanical response in the neighborhood of Koyna reservoir (India): Results of the initial filling period, Geophys. Jour. Int., v. 183, p. 461-477.

Ghosh, D. and Mishra, O.P., 2008a. Earthquake-generating Process in Pakistan-Kashmir Himalayan Front: A Tectonic Overview, Sp.Issue Indian Minerals, v. 61, v. 3-4, p. 27-40.

Ghosh, D. and Mishra, O.P. 2008b. The 2004 Sumatra-Andaman Earthquake Sequence and its Implications for Seismic Coupling: Future Vulnerability, Spl. Issue Indian Minerals, v. 61, no. 3-4, p. 93-112.

Ghosh, D. and Mishra, O.P., 2008c. Possible Causes of 12 May 2008, Wenchuan Earthquake at Longmen Shan Collision Front, Western Sichuan Province, Central China, Spl. Issue Indian Minerals, v. 61, v. 3-4, p. 213-222.

Gupta, H.K., 2007. Earthquake forecast appears feasible at Koyna, India, Curr. Sci., v. 93, no. 6, p. 843-848.

Gupta, H.K., 2008. India's Initiative in Mitigating Tsunami and Storm Surge Hazard, Jour. Earthq. Tsunami, v. 2, no. 4, p. 287-295.

Gupta, H.K., Rao, N. P, Shashidhar, D. and Mallika K., 2008. The Disastrous M 7.9 Sichuan Earthquake of 12 May 2008, Jour. Geol. Soc. Ind., v. 72, p. 325-330.

Gupta, H.K., 2008. Two Significant Developments in Seismology in India: Study of Artificial Water Reservoir Triggered Earthquakes, and Tsunami Hazard Mitigation, Mem. 68, Golden Jubilee Volume of Geol. Soc. India, p. 15-30.

Gupta, H.K. 2009. India's Initiative in Mitigating Tsunami and Storm Surge Hazard, Jour. of Earthq. and Tsunami, v. 5, p. 1-9.

Gupta, H.K. 2010. Co-operation Plan on Hazards & Disaster Risk Reduction in Asia and Pacific, Geophysical Hazards, Tom Beer (Ed), IYPE, Springer, p. 83-101.

Gupta, S., Zhao, D. and Rai, S. S., 2009. Seismic imaging of the upper mantle under the Erebus hotspot in Antarctica, Gondwana Res., v. 16, p. 109-118.

Haggag, H. M., Bhattacharya, P. M., Kamal, S. and Kayal, J. R., 2009. Seismicity and 3-D velocity structure in Aswan reservoir lake area, Egypt, Tectonophysics v. 476, p. 450-459.

Imtiyaz, A. P., Mridula, M. and Rai, S.S., 2007. Coda Q estimates in the Andaman Region using Local Earthquakes, Presented in XXIV General Assembly of the International Union of Geodesy and Geophysics (IUGG-2007) meeting held at Perugia, Italy held during July 2-13.

Imtiyaz, A. P., Sutar, A. K., Mridula, M., Mishra, S. K. and Rai, S.S., 2008. Estimation of Coda Attenuation in the Andaman Islands using Local Earthquakes, Presented in the 7th Gen. Assemb. Asian Seismol. Comm., Tsukuba, Japan, November 24-27.

ISR, 2009. Institute of Seismological Research Report, www.isr.gujarat.gov.in.

Jaiswal, R. K., Singh, A.P., Rastogi, B. K. and Murty, T.S., 2011. Aftershock Sequences of two Great Sumatra Earthquakes of 2004 and 2005 and Simulation of the Minor Tsunami Generated on September 12, 2007 in the Indian Ocean and Its Effect on Indian Coast, Natural Hazards, v. 57, no. 1, p. 7-26, DOI 10.1007/s11069-010-9637-z.

Kayal, J.R., Srivastava, V. K., Chatterjee, R., Khan, P. K., 2011. Evaluation of crustal and upper mantle structures using receiver function analysis: ISM broadband observatory data, Jour. Geol. Soc. Ind., v. 78, p.76-80.

Kayane, H., Ikeda, Y., Echigo, T., Shishikura, N., Kamataki, T., Satake, K., Mullick J. N., Basir, S. R., Chakrabortty, G. K. and Ghosh Roy, A. K., 2007. Coseismic and post seismic creep in the Andaman Islands associated with the 2004 Sumatra earthquake, Geophys. Res. Letts., v. 34.

Khan, P.K., Mukherjee, G. and Chakraborty, P. P., 2010a. Seismotectonic overview of the Burma-Andaman-Sumatra subduction margin preceding the 2004 off Sumatra mega-event, Mem., 75, Jour. Geol. Soc. Ind., p. 81-95.

Khan, P.K., Mohanty, S. and Mohanty, M., 2010b. Geodynamic implications for the 8 October 2005 North Pakistan earthquake, Surveys Geophys., DOI 10.1007/s10712-009-9083-1.

Khan, P. K., 2011. Role of unbalanced slab resistive force in the 2004 off Sumatra mega-earthquake (Mw > 9.0) event, Int. Jour. Earth Sci., v.100, p.1749–1758, DOI 10.1007/s00531-010-0576-4.

Khan, P.K., Ghosh, M., Chakraborty, P.P. and Mukherjee, D., 2011a. Seismic b-value and the assessment of ambient stress in Northeast India, PAGEOPH, v. 168, p. 1693-1706, DOI 10.1007/s00024-010-0194-x.

Khan, P.K., Biswas, B., Samdarshi, P. and Prasad, R., 2011b. Seismicity and the Coda-Q Variation in Eastern Indian Shield Region, Ind. Jour. Geosci., v. 65, p. 131-138.

Kumar N., Sharma, J., Arora, B. R. and Mukhopadhyay, S., 2009. Seismotectonic model of the Kangra-Chamba sector of NW Himalaya: Constraints from joint hypocenter determination and focal mechanism. Bull. Seism. Soc. Amer., v. 99, no.1, doi:10.1785 0120080220.

Kumar, M. R. and Singh, A., 2010. Seismic anisotropy of the Indian tectonic plate: Deciphering continental scale mantle deformation patterns, Curr. Sci., v. 99, p. 1751-1761.

Kumar, S., Wesnousky, S. G., Jayangondaperumal, R., Nakata, T., Kumahara Y. and Singh V., 2010a. Paleoseismological evidence of surface faulting along the northeastern Himalayan front, India: Timing, size, and spatial extent of great earthquakes, Jour. Geophys. Res., p.115, B12422, doi:10.1029/2009JB006789.

Kumar, N., Kumar, M. R., Singh, A., Raju, P. S. and Rao, N. P., 2010b. Shear wave anisotropy of the Godavari rift in the south Indian shield: Rift signature or APM related strain? Phys. Earth Planet Inters., doi:10.1016/j/pepi.2.

Lyubushin, A. A., Arora, B.R. and Kumar, N., 2010. Investigation of seismicity in western Himalaya. Russ. Jour. Geophys. Res., v. 11, no. 1, p. 27-34.

Mahajan, A. K., Thakur, V. C., Sharma, M. L. and Chauhan, M., 2010. Probabilistic seismic hazard map of NW Himalaya and its adjoining area, India, Natural Hazards, v. 53, no. 3, p. 443-457.

Mandal, P., 2007. Sediment thicknesses and Qs vs. Qp relations in the Kachchh Rift Basin, Gujarat, India using Sp converted phases, PAGEOPH, v. 164, p. 135-160.

Mandal, P. and Chadha, R.K., 2008. Three-dimensional velocity imaging of the Kachchh seismic zone, Gujarat, India, Tectonophysics , v. 452, p. 1-16.

Menon, A., Ornthammarath, T., Corigliano, M. and Lai, C. G., 2010. Probabilistic Seismic Hazard Macrozonation of Tamil Nadu in Southern India, Bull. Seismol. Soc. Amer., v. 100, p. 1320-1341, doi:10.1785/0120090071.

Mishra, O. P., Kayal J. R., Chakrabortty G. K., Singh, O. P. and Ghosh, D., 2007a. Aftershocks investigation in Andaman-Nicobar islands of India and its seismotectonic implications, Bull. Seism. Soc. Amer. v. 97, no. 1A, p. S71-S85.

Mishra, O. P., Singh, O. P., Chakrabortty, G. K. and Kayal, J. R., 2007b. Aftershock investigation in Andaman-Nicobar Islands: An antidote to public panic? Seismol. Res. Letts., v. 78, no. 6, p. 591-600.

Mishra, O.P., Zhao, D. and Wang, Z., 2008. The Genesis of the 2001 Bhuj, India Earthquake (Mw 7.6): A Puzzle for Peninsular India? Specl. Issue Indian Minerals. v. 61, no. 3-4, p. 149-170.

Mishra, O. P., Singh, O. P., Marathe, S., Pathak, R. C., Singh, S. K., Mishra, H. P., Saha, D. K.,Ghosh, B., Chakrabortty, G. K., Mukherjee, K. K. and Ram, S., 2009. A preliminary note on the recent (Late 2009) earthquakes around Koyna in Maharashtra and their seismogenesis, Ind. Jour. Geosci., v. 63, no. 3, p. 333-339.

Mishra, O. P., Zhao, D., Ghosh, C., Wang,Z. Singh, O. P., Ghosh, B., Mukherjee,K. K., Saha,D. K., Chakrabortty, G. K. and Gaonkar, S. G., 2010. Role of crustal heterogeneity beneath Andaman-Nicobar Islands and its implications for coastal hazards, Natural Hazards, doi: 10.1007/s11069-010-9678-3.

Mishra, O.P., 2011. Three-dimensional tomography of Northeast India and Indo-Burma region and its implications for Earthquake risks. In National Workshop on Earthquake Risk Mitigation: Strategy in Northeast, p. 40-54.

Mishra, O.P., 2011. The 11th March 2011 Tohoku earthquake (Mw 9.0): The plausible Cause of Genesis, Bull. Seism. Soc. Amer., (in Press).

Mitra S,. Kainkaryam, S. M., Padhi, A., Rai, S. S. and Bhattacharya, S. N., 2011. The Himalayan foreland basin crust and upper mantle, Phys. Earth Planet. Inters., v. 184, p. 34-40.

Mitra, S., Bhattacharya, S. N. and Nath, S. K., 2008. Crustal Structure of the Western Bengal Basin from joint analysis of Teleseismic Receiver Functions and Rayleigh wave dispersion, Bull. Seismol. Soc. Amer., v. 98, p. 2715-2723.

Mitra, S., Priestley, K., Acton, C. and Gaur, V.K., 2011. Anomalous surface wave dispersion and the enigma of "continental-like" structure for the Bay of Bengal, Jour. Asian Earth Sci., doi:10.1016/j.jseaes.2011.07.008.

MoES, 2011a. Ministry of Earth Sciences Draft Approach Paper for the 12th five year plan (2012-2017), http://dod.nic.in.

MoES, 2011b. Seismic Microzonation Handbook, Geoscience Division, Ministry of Earth Sciences, Government of India, p. 518.

Mohanty, W. K. and Walling M.Y., 2009. Seismic Hazard in mega city Kolkata, India, Natural Hazards, DOI: 10.1007/s11069.

Mohanty W.K., Walling, M.Y., Vaccari, F. and Tripathy, T. P., 2009a. G.F. Modelling of SH- and P-SV-wave fields and seismic microzonation based on response spectra for Talchir basin, India, Engg. Geol., v. 104, p. 84-97.

Mohanty, W.K., Walling, M. Y., Nath, S. K., Mitra, S. and John, A., 2009b. Microtremor survey in Talchir, india to ascertain its basin Characteristics in terms of predominant frequency by Nakamura H/V ratio technique, Engg. Geol., v. 106, p. 123-132.

Mohanty, W. K. and Walling, M. Y., 2008. First order seismic microzonation of Haldia, Bengal Basin (India) using a GIS Platform, PAGEOPH, v. 165, no. 7, p. 1325-1350.

Mohanty, W.K., Rajesh P., Suresh G., Shukla A.K., Walling M. Y. and Srivastava J.P., 2009c. Estimation of Coda wave attenuation for the National Capital Region, Delhi, India, using local earthquakes, PAGEOPH, v. 166, no. 3, p. 429-449.

Mohapatra, A. K. and Mohanty W. K., 2011. Coda Q (Qc) Estimates in the North East (NE) India using Local Earthquakes, Seismol. Res. Lettrs., v. 82, no. 1, p. 150-156.

Mukhopadhyay, B. and Dasgupta S., 2008. Swarms in Andaman Sea, India – a seismotectonic analysis, Acta Geophysica, v. 56, no. 4, p. 1000-1014, DOI: 10.2478/s11600-008-0039-5.

Mukhopadhyay, B., Acharyya A. and Dasgupta, S., 2008. Statistical Analysis on Yearly Seismic Moment Release Data to Demarcate the Source Zone for an Impending Earthquake in the Himalaya, Acta Geophysica, v. 57, no. 2, p. 387-399, DOI: 10.2478/s11600-008-0068-0.

Mukhopadhyay, B., Acharyya, A., Bhattacharya, A., Dasgupta S. and Sengupta S. R., 2009. Revisiting The Andaman Subduction Lithosphere Following The 26 December 2004 Sumatra Earthquake, Ind. Jour. Geosci., v. 63, no. 1, p. 1-10.

Mukhopadhyay, B., Fnais, M., Mukhopadhyay, M. and Dasgupta, S., 2010. Seismic cluster analysis for the Burmese-Andaman and West Sunda Arc: insight into subduction kinematics and seismic potentiality', Geomatics, Natural Hazards and Risk, DOI: 10.1080/19475705.2010.494014.

Mukhopadhyay, B., Acharyya, A. and Dasgupta S., 2010b. Potential Source Zones for Himalayan Earthquake: Constraints from Spatial -Temporal Clusters, Natural Hazards, DOI 10.1007/s11069-010-9618-2.

Mukhopadhyay, B., Acharyya,A., Mukhopadhyay M. and Dasgupta, S., 2010c. Relationship between earthquake swarm, rifting history, magmatism and pore pressure diffusion – an example from South Andaman Sea, India, Jour. Geol. Soc. Ind., v. 76, p. 164-170.

Mukhopadhyay, B., Dasgupta, S. and Acharyya, A., 2010d. Seasonal bias for the occurrence of shallow-focus earthquakes in the Indian tropics, Ind. Jour. Geosci., v. 63, no. 3, p. 327-332.

Nath, S. K., Raj, A., Sharma, J., Thingbaijam, K.K.S., Kumar, A., Nandy, D. R., Yadav, M. K., Dasgupta, S., Majumdar, K., Kayal, J. R., Shukla, A. K., Deb, S. K., Pathak, J., Hazarika, P. J., Paul, D. K. and Bansal, B. K., 2008a. Site Amplification, Qs and Source Parameterization in Guwahati Region from Seismic and Geotechnical Analysis, Seismol. Res. Letts., v. 79, p. 526-539.

Nath, S. K., Roy, D. and Thingbaijam, K. K. S., 2008b. Disaster Mitigation and Management for West Bengal, India an Appraisal, Curr. Sci., v. 94, no. 7, p. 858-866.

Nath, S. K., Shukla, K. and Vyas, 2008c. Seismic Hazard Scenario and Attenuation Model of the Garhwal Himalaya using Near Field Synthesis from Weak Motion Seismometry, Jour. Earth Syst. Sci., v. 117, p. 649-670.

Nath, S. K., Thingbaijam, K. K. Singh and Raj, A., 2008d. Earthquake Hazard in the Northeast India - A Seismic Microzonation Approach with Typical Case Studies from Sikkim Himalaya and Guwahati city, Jour. Earth Syst. Sci., v. 117, p. 809-831.

Nath, S. K. and Thingbaijam, K.K.S., 2009. Seismic hazard assessment - A holistic microzonation approach, Natural Hazds. and Earth Syst. Sci., v. 19, p. 1445-1459.

Nath, S. K., Raj, A., Kumar, A. and Thingbaijam, K. K. S., 2009. Ground Motion Synthesis and Seismic Scenario in Guwahati City : A Stochastic Approach, Seismol. Res. Letts., v. 80, p. 233-242.

Nath S. K., Thingbaijam, K.K.S., Vyas, J.C., Prakash Dev, S. M. S. and Sengupta, P., 2010. Macroseismic-driven Site Effects in the Southern Territory of West Bengal, Seismol. Res. Lettrs., v. 81, no. 3, p. 480-487.

Nath, S. K. and Thingbaijam, K.K.S., 2010. Assessment of Seismic Site Condition: a Case Study from Guwahati city, Northeast India [Online: DOI 10.1007/s00024-010-0197-7], 00024-010-0197-7.

Nath, S. K. and Thingbaijam, K.K.S., 2011. Peak Ground Motion Predictions in India: An appraisal for rock sites, Jour. Seismol., v. 15, p. 295-315.

Nayak, A., Nath, S. K., Thingbaijam, K.K.S. and Baruah, S., 2011. New Insights into Path Attenuation of Ground Motions in NE India and NW Himalayas, Bull. Seis. Soc. Amer., v. 101, no. 5, p.2550-2560.

Nayak, S. and Srinivasa Kumar, T., 2008. The First Tsunami Early Warning Centre in the Indian Ocean. In 'Risc Wise', Tudor Rose, UK. p. 175-177.

Nayak, S., 2011. "Foreword" on Seismic Microzonation Handbook, Geoscience Division, Ministry of Earth Sciences, Government of India, p. 518.

Padhy, S., Mishra, O. P., Zhao, D. and Wei, W., 2011. Crustal heterogeneity in the 2007 Noto-Hanto earthquake area and its geodynamical implications, Tectonophysics, v. 509, p. 55-68.

Pal, I., Nath, Shukla S. K., Pal, D. K., Raj, A., Thingbaijam, K. K. S. and Bansal, B. K., 2008. Earthquake Hazard Zonation of Sikkim Himalaya using a GIS Platform, Natural Hazards, v. 45, p. 333-377.

Panthi, A., Shankar, D., Singh, H. N. and Kumar, A., 2011. Time-predictable model applicability for earthquake occurrence in Northeast India and vicinity, Jour. Nat. Hazds. Earth Syst. Sci., v. 11, p., 993-1002.

Parvez, I. A. and Lyubushin, A. A., 2010. Map of seismic hazard of India using Bayesian approach, Natural Hazards, v. 55, p. 543-556.

Parvez, I. A., Romanelli, F. and Panza, G.F. 2011. Long Period Ground Motion at Bedrock Level in Delhi City from Himalayan Earthquake Scenarios, PAGEOPH, v. 168, p.409-477.

Paudyal, H., Shanker, D. and Singh, H. N., 2011. Characteristics of Earthquake Sequence in Northern Himalayan Region of South Central Tibet - Precursor Search and Location of Potential Area of future earthquake, J. Asian. Earth Sci., v. 41, no. 4-5, p. 459-466, doi:10.1016/j.jseaes.2010.11.019.

Paudyal, H., Shanker, D. Singh, H. N., Kumar, A., Panthi, A. and Singh, V. P., 2010. Current understanding of the seismotectonics of Western Nepal Himalaya and vicinity, Acta. Geod. Geophy. Hung. v. 45, no. 2, p. 195-209, DOI: 10.1556/AGeod.45.2010.2.5.

Raghukanth, S. T. G. and Dash S.K., 2010. Deterministic seismic scenarios for North East India, Jour. Seismol., v. 14, no.2, p.143-167, DOI: 10.1007/s10950-009-9158-y.

Raghukanth, S. T. G., 2010a. Estimation of Seismicity Parameters for India, Seismol. Res. Letts., v. 81 no. 2, p. 207-217.

Raghukanth, S.T.G., 2010b. Comments on Estimation of Seismicity Parameters for India (Seismol. Res. Lettrs., 2010, 81, 207- 217) by Nath, S. K. and Thingbaijam, K.K.S., Seismol. Res. Letts., v. 81, no. 6, p. 1001-1003.

Rai, A., Gaur, V. K., Rai, S. S. and Priestley, K. F., 2009. Geophy. Jour. Internat., v. 176, no. 2, p. 518-528.

Raj A., Nath, S.K., Bansal, B.K., Thingbaijam, K.K..S., Kumar, A., Thiruvengadam, N., Yadav, A. and Arrawatia, M.L., 2009. Rapid Estimation of Source Parameters using Finite Fault Modeling - A Case of Sikkim and Garhwal Himalaya, Seisol. Res. Lett., v. 80, p. 89-96.

Raj, A., Nath, S. K. and Thingbaijam, K. K.S., 2008. A Note on the Recent Earthquakes in the Bengal Basin, Curr. Sci., v. 95, p. 1127-1131.

Rajendran, K. and Rajendran, C.P., 2011. Revisiting some significant earthquake sources in the Himalaya: Perspectives on past seismicity, Tectonophysics, v. 504, p.75-88.

Rajendran, K., Andrade, V., Thulasiraman, N. and Rajendran, C. P., 2011. The 11 March 2011 Tohoku (Sendai), Japan earthquake, Curr. Sci., v. 100, no. 7, p. 966-969.

Rajendran, K., Andrade, V. and Rajendran C. P., 2011. The June 2010 Nicobar Earthquake: Fault Reactivation on the Subducting Oceanic Plate, Bull. Seismol. Soc. Amer., v. 101, no. 5, p. 2568-2577.

Rajendran, K., Rajendran, C.P., Thulasiraman, N., Andrews, R. and Sherpa, N., 2011. The 18 September 2011, North Sikkim earthquake, Curr. Sci., v. 101, p. 1475-1479.

Rajendran, C.P., John, B., Sreekumari, K. and Rajendran, K., 2009. Reassessing the earthquake hazard in Kerala based on the historical and current seismicity, Jour. Geol. Soc. Ind., v. 73, p. 785-802.

Rajendran, C.P., Rajendran, K, Thakkar, M. and Goyal, B., 2008. Assessing the previous activity at the source zone of the 2001 Bhuj earthquake based on the near-source and distant paleoseismological indicators, Jour. Geophys. Res., v. 113, B05311, doi:10.1029/2006JB004845.

Rajendran, C.P., Ramanamurthy, M.V., Reddy, N.T. and Rajendran, K., 2008. The hazard implications of the late arrival of the 1945 Makran tsunami, Curr. Sci., v. 95, p. 1739-1743.

Rastogi, B. K., Singh, A. P., Sairam, B., Jain, S. K., Kaneko, F., Segawa, S. and Matsuo, J., 2011. The Possibility of Site Effects: the Anjar Case, Following the Past Earthquakes in the Gujarat, India, Seismol. Res. Letts., v. 82, no.1, p. 692-701, DOI 10.1785/gssrl.82.1.692.

Saha D. K., Nasker, D. C., Bhattacharya, P. M. and Kayal, J. R., 2007. Geophysical and Seismological investigation for the hidden Oldham fault in Shillong plateau and Assam valley of north east India, Jour. Geol. Soc. Ind., v. 69, p.359-372.

Saikia, D., M. R. Kumar, A. Singh, G.A. Mohan and R. S. Dattatrayam, 2010. Seismic anisotropy beneath the Indian continent from splitting of direct S waves, Jour. Geoph. Res., v. 115, doi:10.1029/20.

Sengupta, P., Nath, S. K., Thingbaijam, K.K.S. and Mistri, S., 2011. Fractal Analysis of Major Faults in India on a Regional Scale, Jour. Geol. Soc. Ind., v. 78, p. 226-232.

Shanker, D., Singh, H. N., Paudyal H., Kumar A., Panthi, A. and Singh, V. P., 2010. Searching for an Earthquake Precursor- A Case Study of Precursory Swarm as a Real Seismic Pattern before Major Shocks, PAGEOPH, v. 167, no. 6-7, p. 655-666, DOI 10.1007/s00024-010-0067-3.

Sharma, Babita, Teotia, S.S. and Kumar, D., 2007. Attenuation of P- and S-waves in Koyna region, Jour. Seismol., v. 11, no. 3, p. 327-344.

Sharma, Babita, Gupta, A.K., Kameshwaridevi, D., Kumar, D., Teotia, S.S. and Rastogi, B.K., 2008. Attenuation of high frequency seismic wave in Kachchh region, Gujarat, India, Bull. Seism. Soc. Amer., v. 98, no. 5, p. 2325-2346.

Singh, A., Kumar, M. R. and Raju, P. S., 2010. Seismic structure of the underthrusting Indian crust in Sikkim Himalaya, Tectonics, v. 29, doi:10.1029/2010.

Singh, A. P., Mishra, O. P., Kumar, D., Kumar S. and Yadav, R. B. S., 2011. Spatial variation of aftershocks activity across the Kachchh rift Basin and its Seismotectonic Implications. Jour. Earth Syst. Sci., v. 121, no. 2, p. 439-451.

Singh, A.P., Mishra, O. P., Rastogi, B. K. and Kumar D., 2011. 3-D Seismic Structure of the Kachchh, Gujarat and Its Implications for the Earthquake Hazard Mitigation, Natural Hazards, v. 57, no.1, p. 83-105, DOI 10.1007/s11069-010-9707-2.

Singh, C. and Chadha, R. K., 2010. Variations in the frequency-magnitude distribution with depth in the Koyna, Reservoir site, India, Jour. Asian. Earth Sci., v. 39, p. 331-334.

Singh, C., Bhattacharya, P. M. and Chadha, R. K., 2008. Seismicity in Koyna-Warna reservoir site in the western India: Fractal and b-value mapping, Bull. Seism. Soc. Amer, doi: 1785/0120070165.

Singh, H. N., Paudyal, H., Shanker, D., Panthi, A., Kumar A. and Singh, V. P., 2010. Anomalous Seismicity and Earthquake Forecast in Western Nepal Himalaya and its Adjoining Indian Region. PAGEOPH, v. 167, no.6, p.667-684, DOI 10.1007/s00024-010-0072-6.

Singh, O. P., Chowdhuri, S. N. and Gaonkar, S. G., 2008. Site response study in the eastern part of Guwahati city (Assam), using ambient seismic noise, Specl. Issue Indian Minerals, v. 61, no. 3, p. 141-148.

Singha Roy, P. N. and Nath, S. K., 2007. Precursory Correlation Dimensions for three Great Earthquakes by Curr. Sci., v. 93, no. 11, p.1522-1529.

Srikanth, T., Pradeep, R. K., Singh A.P., Rastogi, B. K. and Kumar S., 2010. Earthquake Vulnerability Assessment of Existing Buildings in Gandhidham and Adipur Cities, Kachchh, Gujarat (India), European Journal of Scientific Research, ISSN 1450-216X, v. 41, no. 3, p. 336-353.

Srivastava, H.N., Verma, M. and Bansal, B. K., 2010. Seismological constraints for the 1905 Kangra earthquake and associated hazard in northwest India, Curr. Sci., v. 99, no. 11, p. 1549-1559.

Thingbaijam, K. K. S., Chingtham, P. and Nath, S. K., 2009. Seismicity in the Northwest Frontier Province of Indian-Eurasian Plate Convergences, Seismol. Res. Letts., v. 80, p. 599-608.

Thingbaijam, K. K. S., Nath, S. K., Yadav, A., Raj, A., Walling, M. Y. and Mohanty, W. K., 2008. Recent Seismicity in Northeast India and its Adjoining Region, Jour. Seismol., v. 12, no. 1, 107-123.

Vaccari, F., Walling , M. Y., Mohanty ,W. K., Nath, S. K., Verma, A. K., Sengupta, A. and Panza G. F., 2011. Site-specific modelling of SH and P-SV waves for microzonation study of Kolkata metropolitan city, India, PAGEOPH, v. 168, p. 67-91.

Walling, M. Y. and Mohanty, W.K., 2009. An overview on the seismic zonation and microzonation studies in India, Earth Science Reviews, v. 96, p. 67-91.

Walling, M. Y., Mohanty, W.K., Nath, S.K., Mitra, S. and John, A., 2009. Microtremor survey in Talchir India to ascertain its basin characteristics in terms of predominant frequency by Nakamura spectral ratio technique, Engg. Geol., v. 106, p. 123-13.

Wang, Z., Fukao, Y., Zhao, D., Kodiara, S., Mishra, O.P. and Yamada, A., 2009. Structural heterogeneities in the crust and upper mantle beneath Taiwan, Tectonophysics, v. 476, p. 460-477, doi:10.1016/j.tecto.2009.07.018.

Wang, Z., Zhao, D., Huang R., Tang, S. and Mishra, O.P., 2009. Structural Heterogeneity in Northeast Japan and Its Implications for the Genesis of the 2004 and 2007 Niigata Earthquakes, Bull. Seism. Soc. Amer., v. 99, no. 6, doi: 10.1785/012008281.

Yadav, R. B. S., Bayrak, T., Tripathi, J. N., Chopra, S., Singh, A. P. and Bayrak, E., 2011. A Probabilistic Assessment of Earthquake Hazard Pramaters in NW Himalaya and the Adjoining Regions, PAGEOPH, DOI:10.1007/s00024-011-0434-8.

Yadav, R. B. S., Papadimitriou, E. E., Karakostas, V. G., Shanker, D., Rastogi, B.K., Chopra, S., Singh, A.P. and Kumar S., 2011. The 2007 Talala, Saurashtra, Western India Earthquake Sequence: Tectonic Implications and Seismicity Triggering, Jour. Asian Earth Sci., v. 40, no. 10, p. 303-314, DOI:10.1016/j.jseaes.2010.07.001.

Yadav, R. B. Shankar, S. D., Chopra, S. and Singh, A.P., 2010. An Application of Regional Time and Magnitude Predictable Model for Long-Term Earthquake prediction in the vicinity of October 8, 2005 Kashmir Himalaya earthquake, Natural Hazards, v. 54, no. 3, p.985-1014, DOI 10.2007/s11069-010-9519-4.