Abstract

Seismicity along the Himalayan front is mostly attributed to the processes of collision between the Indian and the Eurasian plates, which results towards the under-thrusting of the Indian Peninsula underneath the Himalaya. The dynamics of the region bears very complex components which require in-depth understanding. The region experienced a large number of great earthquakes for the last 100 – 120 years causing massive destruction. The present scenario depicts that large size magnitude earthquakes which have not occurred for quite long time are expected to hit in the three seismic gaps. These seismic gaps are identified as the Kashmir gap, Central gap and the Assam gap. But the central seismic gap lying between the 1905 Kangra and 1934 Bihar-Nepal earthquakes has high probability for one or more M >8 Himalayan earthquakes in this century. So the study for the future large size earthquake estimation is of great importance in this very region of central seismic gap. The present study area of the thesis extends from Latitude 28°N- 33°N and Longitude 76°E-82°E which lies in the central seismic gap. The proposed work of this thesis is to estimate the large earthquake potential in Kumaun Himalaya and its adjacent Fault zone using the GPS strain measurements and multi-seismotectonic parameters study. The application and the complete investigation of fractal capacity dimension ($D_0$) value of structural elements, spatial fractal dimension ($D_C$) value of past seismicity, correlation of b-value with $D_C$ value, multifractal dimension $D_q$, temporal fractal correlation dimension ($D_2(t)$) and GPS strain measurements of three years of field data of the region has been utilized for the identification of hazardous zones for large size earthquake in the region. Faults and spatial distribution of earthquakes epicentres, statistically obey a power law distribution which is quantified by the fractal dimension for the distribution of the structural elements and earthquake events. Fractal analysis of fault system and spatial distribution of epicenters of past seismicity will help in understanding the dynamic process of future large earthquakes occurrence. Fractal analysis of complex fault system of the region was studied through the box counting method. This technique helped in the characterization of the fault system present in the area where the area was subdivided into 25 blocks of $1^\circ \times 1^\circ$. The determination of fractal capacity dimension ($D_0$) of each block provided the different numerical values of low and high. The indication of minimum or maximum coverage of structural
elements in a region was identified with lower to higher capacity dimension value. The $D_0$ value was found to vary from 0.812 to 1.866. The study of entire blocks reveals that four blocks are having very high value of $D_0$ (1.866, 1.818, 1.616 and 1.475). Among these four blocks, two are characterized by intense clustering of earthquakes indicated by low value of correlation fractal dimension ($D_C$) (0.245, 0.836 and 0.946). Further, these two blocks are categorized as highly stressed zones and the remaining two are characterized by maximum coverage of structural elements in the study area. The information regarding main features of seismicity and inner dynamics of seismotectonic activity can be analyzed through the spatio-temporal variation of earthquakes. Spatial correlation dimension ($D_2 = D_C$) is a measure of spatial clustering and also indicate about the seismicity of the region. The fractal dimension of the spatial distribution was calculated from the correlation integral approach. A number of subsets (say 50 or 100 or 200 events windows) of earthquakes were considered and $D_C$ values were determined. This leads to a number of $D_C$ value ranging from low to high. The lower values are the highly clustered seismicity that indicates about the highly stressed zones. The variation of $D_C$ value of fifty, hundred and two hundred with respect to time were plotted and the lowest $D_C$ values were observed in the year 2005. The $D_C$ value of fifty events windows was noticed to change from 0.285 to 1.824. The study of fifty events windows gave three low $D_C$ value with specific mean time, ($D_C$ value = 0.836 with mean time 308.21 months), ($D_C$ value = 0.946 with mean time 389.02 months) and ($D_C$ value 0.285 with mean time 391.29 months). These were used for the $D_C$ patches plot indicating the highly stressed zones. Similar low $D_C$ values were observed before some of the large earthquakes globally in different tectonic setting of a region. So the study of $D_C$ value plot with respect to time is an important parameter to understand the future large earthquake. These highly stressed zones are the expected areas where nucleation for large earthquake may finally appear. A unique property of $D_C$ value fluctuation has already been noticed before the large earthquake globally. Another important seismotectonic parameter i.e. $b$-value variation derived from Guttenberg Richter frequency of earthquakes-magnitude relation of hundred events earthquake windows was analyzed. The $b$-value for hundred events windows changes from 0.40 to 1.05. The variation of $D_C$ and $b$ value with time was observed to be positive correlation. The drop in $b$-value was noticed along with the $D_C$ value of hundred events windows.
In understanding the large earthquake mechanism, it was earlier indicated that b value drops before a large size earthquake. Thus correlation of parameters b-value and $D_C$ gives positive indication of impending large earthquake. To understand the complexity of the earthquakes behavior, multifractal analysis of the events is very necessary. Multifractal characterization is achieved by measuring the so-called generalized dimensions $D_q$. The multifractal index gives us a quantitative measure of irregularities (or regularities) in the spatial distribution patterns. The results obtained allow me to classify different elements based on their multifractal indices. The multifractal dimension $D_q$ is a parameter representing the complicated fractal structure or multi-scaling nature. Multifractal study was also carried out with the correlation integral approach in order to quantify the further complex spatial distribution of events. Multifractal study is very important to understand the heterogeneous characteristics of seismicity in a region. Spatial multifractal study carried out with the help of correlation integral approach gave $D_q$ versus $q$ variation plot or $D_q$ – spectrum for hundred and fifty events windows. The plot shows the multifractal nature indicating the events are distributed in clusters. The clustering and diffuse seismicity in a multifractal structure is associated with the decrease and then increase of $D_q$ values respectively. The temporal variation of $D_q$ reflects the accumulation and release of strain energy within the tectonic stress field. Changes between the fractal dimension $D_C$ or $D_2$ and multifractal ($q=3-22$) measures illustrate the sensitivity of the multifractal characterization which changes with respect to local complexity. The large difference between $D_2$ and $D_{22}$ suggests the presence of significant ‘fractal heterogeneity’ within the epicentre distribution of shallow seismicity due to differences in fault complexity at local scales. The generalized dimension $D_q$ and $D_q$ spectra of the seismicity reflects the change in seismicity pattern for the region. Therefore, the study of temporal variation $D_q$ and $D_q$ spectra may be used to study the changes in the seismicity structure before the occurrence of large earthquake, which may be very helpful in understanding the preparation zone of large size earthquakes. The present work of the thesis of the study region show multifractal behavior of the seismicity. Such study may become important in understanding the preparation zone of large size earthquake in various tectonic regions. Further the investigation of the time series of inter-occurrence of earthquakes of hundred events window, analyzed with the help of temporal fractal correlation dimension ($D_2(t)$) was performed. The
variation of $D_2(t)$ values was noticed in the range of 0.19 to 0.68 in the study region. The value of $D_q$ at positive $q$ is measured to establish the relation between $D_q$ versus $q$ for investigating the multifractal behavior of time series of the earthquakes. The result shows the lower fractal dimension is associated with higher clustering of events. The lowest value is observed in the 2005 and is marked with densely clustered. The relation $D_q$ versus $q$ is obtained for investigating multifractal behavior of the time series of the data set. The $D_q(t)$ obtained for different values of $q$ shows the $D_q(t)$ versus $q$ or $D_q(t)$ spectra. The sharp change of $D_q$ is noticed for the value $q = 2...7$, where we see cluster within cluster pattern indicating the heterogeneity of the structure. As the earthquake occurrence is the process of release of energy, understanding the development of stress and strain is important. The present scenario of strain accumulation in the Kumaun Himalayan region was further investigated with the GPS measurements. The three years campaign mode GPS study reveals that the horizontal motion of the station are in the range of 35-50 mm/yr. The strain rate was determined from the velocity vectors of the site stations. The strain rate so obtained, indicates some interesting relation with the highest capacity dimension value of block- “S”. The block “S” was identified with high $D_0$ value where extensive convergence is noticed. Hence this block may be estimated as the seismically hazard zone for future event. The study of fractal capacity dimension, fractal correlation dimension, $b$ value analysis, multifractal analysis (spatial and temporal) and strain rate measurement from the field data suggest to identify the four blocks – i) “Block-A” with latitude 32º N-33º N ;longitude 76ºE- 77ºE, ii) “Block-N” with latitude 30ºN -31ºN ; longitude 79 ºE -80 ºE, iii) “Block-L” latitude 30ºN -31ºN ; longitude 77 ºE -78 ºE and iv) “Block-S” with latitude 29ºN -30ºN ; longitude 79 ºE -80 ºE as the zones for high seismic risk for future large earthquake. So the complete study of all the above said parameters will be of great importance in understanding the complex nature of earthquake occurrence in any part of the world which is seismically active region. The output of the thesis entitled “Evaluation of Large Earthquake Potential in Kumaun Himalaya and its adjacent Fault Zone using GPS strain and Seismicity Analysis” demarcates the importance of proper hazard estimation and provides crucial information for government to plan to save property and life.