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Seismic Hazard Computation of Central Chhattisgarh (India) Using Probabilistic Approach

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In the central part of India a state Chhattisgarh, is undergoing a speedy stage of infrastructure development. The vulnerability of a limited region is increased by the dense population and infrastructure, which creates an enormous potential loss. Due to increased seismic activity in thickly populated areas, seismic hazard analysis is becoming a need of the hour. Six district headquarters namely Raipur, Mahasamund, Kawardha, Bilaspur, Janjgir, and Raigarh have been selected in Central Chhattisgarh region as the study area. For the assessment of the seismic behavior of the selected district headquarters, Probabilistic Seismic Hazard Analysis has been carried out. The study considered a catalog of earthquakes that occurred between latitudes 18° and 25° North and longitudes 79° and 87° East, with active seismic sources within 300 km of the study region. Statistics were utilized to evaluate the seismic data, and the Gutenberg-Richter (G-R) connection was used to establish a recurrence relationship. The region-specific attenuation relationships for Peninsular India have been used for shallow crustal earthquakes. The peril curves of the mean annual rate of exceedance for PGA at the bedrock level have been generated by the MATLAB program for all identified seismic sources for the study area. According to the research, PGA values were calculated for 50 years with a 10% chance and a return duration of 475 years, as well as a 2% probability and a return period of 2475 years. Among the 6 district headquarters, the maximum PGA values obtained are for Raipur as 0.0155g and 0.0325g, and minimum PGA values for Janjgir as 0.0102g and 0.0165g respectively, for the same probabilities and return periods. The study reveals that the central part of Chhattisgarh is seismically safe and it comes in seismic Zone II and its seismicity is low.

Keywords: District Headquarters, Seismic Sources, Seismic Parameters, Peak Ground Acceleration, PSHA, Probability of Exceedance.

1. Introduction

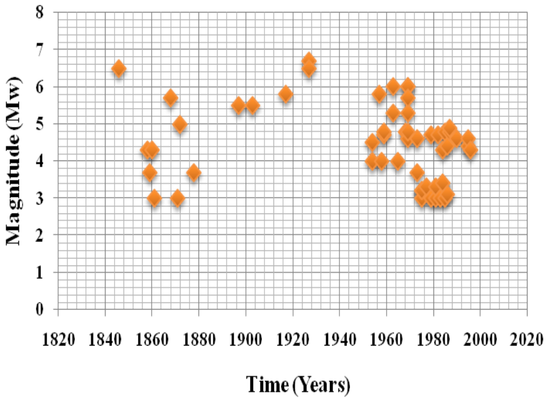
Tremor is one of the natural calamities that cannot be predicted. The primary cause of earthquake destruction is the breaking down of structures caused by the movement of the ground.The danger of earthquakes is the potential for seismic activity to cause natural events like shaking ground, fault lines breaking, landslides, and tsunamis that can harm people and structures in a particular location. The risk that comes with shaking of the ground during a specific timeframe is what seismic hazard means.Peak Ground Acceleration (PGA) is a frequently utilized measure to express effective earth motion. The evaluation can be conducted through either a predetermined or probabilistic method. The seismic hazard at a location is primarily influenced by three factors: earthquake magnitude, the distance between the source and the site, and the duration of ground trembling. The researchers devised a procedure for probabilistic seismic hazard analysis (PSHA), which begins with the development of a detailed list of earthquakes, continues with the processing of the list's data, and chooses an attenuation relation particular to each location. In PSHA, the uncertainty about the place, magnitude & shaking vastness of future tremors are involved. PSHA intends to enumerate these uncertainties and, when combined, generate a clear description of the potential distribution of future earthquakes in an area. PSHA's primary outputs are seismic peril curves depicting the disparity between certain ground-motion parameters, including PGA, and the mean annual rate of exceedance (or return time). Probabilistic seismic analysis is commonly utilized to determine the potential susceptibility of a designated location withgroundmotion parameters. The main district headquarters of Central Chhattisgarh is located in peninsular India's stable continental area.The seismicity of peninsular India is increasing day by day. In Chhattisgarh, the seismic activity increased in the year 2020 and 2021 and it is reported around Central district headquarters. So the present study is focused on seismic hazard assessment of Central Chhattisgarh, adopting a probabilistic approach and assessing Peak Ground Acceleration for six district headquarters: Raipur, Mahasamund, Kawardha, Bilaspur, Janjgir, and Raigarh.

EARLIER STUDY

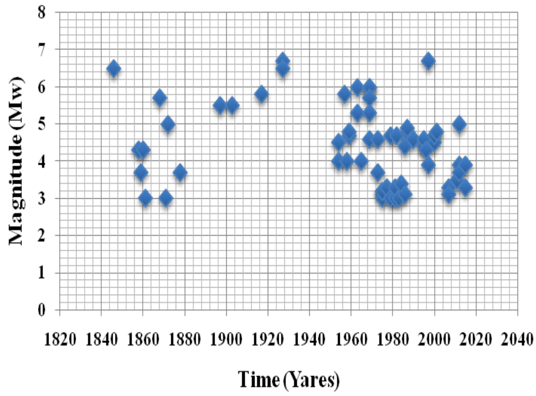
Despite the fact that in probabilistic analysis, arithmetic probabilities correspond to the occurrence of earthquakes and their effects during a particular time frame, such as the lifespan of a designated design framework. The indispensable object of the probabilistic seismic risk evaluation approach was overlain by Cornell and McGuire. Various Indian researchers have performed PSHA namely, for India, for the Northeast Region of India, for peninsular India, for Bangalore city, for northwestern Himalayas region, for Manipur, for India, for Himachal Pradesh and adjoining regions, for Kashmir Valley, for smart city Jalandhar, for Gujarat region, for Kashmir basin and for Patna district.

HISTORICAL SEISMICITY OF STUDY REGION

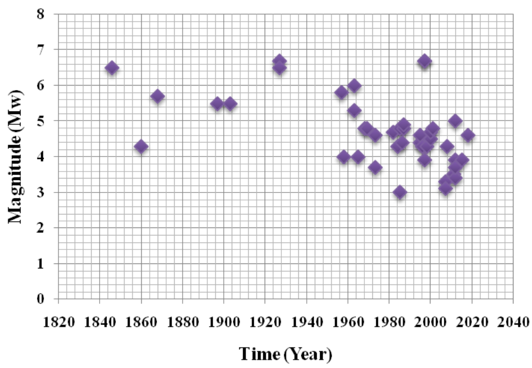
Seismic activity is rare in Chhattisgarh. In present days the collected past earthquake data around the district headquarters: Raipur, Mahasamund, Kawardha, Bilaspur, Janjgir, and Raigarh, the seismic activity has increased and it is depicted in Figure. 1.



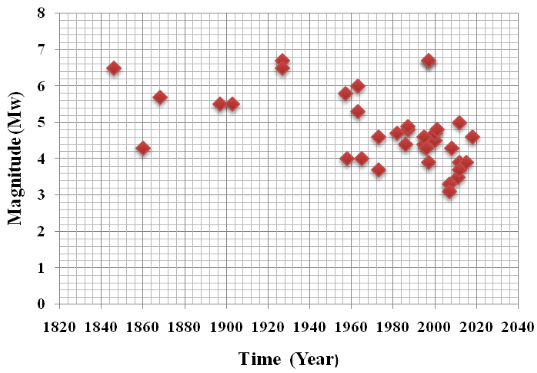
(a) Raipur



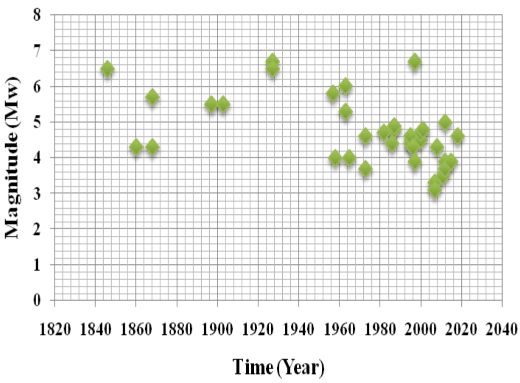
(b) Mahasamund



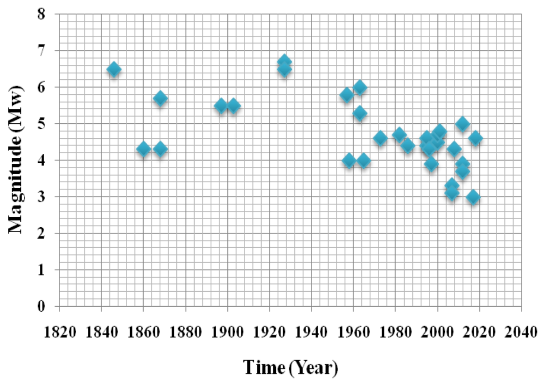
(c) Kawardha



(d) Bilaspur



(e) Janjgir



(f) Raigarh

Figure 1.Past Earthquake Round District Headquarters

All past earthquakes data were collected from reliable agencies e.g. IMD and USGS website from 1846 to 2018. The scenario clearly reflects that the earthquake activity has increased from 1960 to 2018. It generates an essential need for earthquake hazard analysis for the central Chhattisgarh region.

PSHA

The seismic probabilities evaluation offers a structure that allows for the recognition, measurement, and integration of uncertainties related to earthquake magnitude, location, and recurrence rate. This approach provides a comprehensive understanding of seismic risk. The current study is limited to assessing the risk of peak ground motion. The initial step involves analyzing the historical data sources such as fault lines and magnitudes to determine the pattern of earthquake occurrence. The seismotectonic model is formed by combining data on seismic shaking transmission (known as attenuation) with occurrence information. It is important to take into account the unique characteristics of the location when analyzing the outcomes. When conducting seismic hazard analysis, it is crucial to recognize the origins that caused danger at specific locations and have knowledge of their attributes. The examination involved the subsequent essential stages[Figure. 2]:

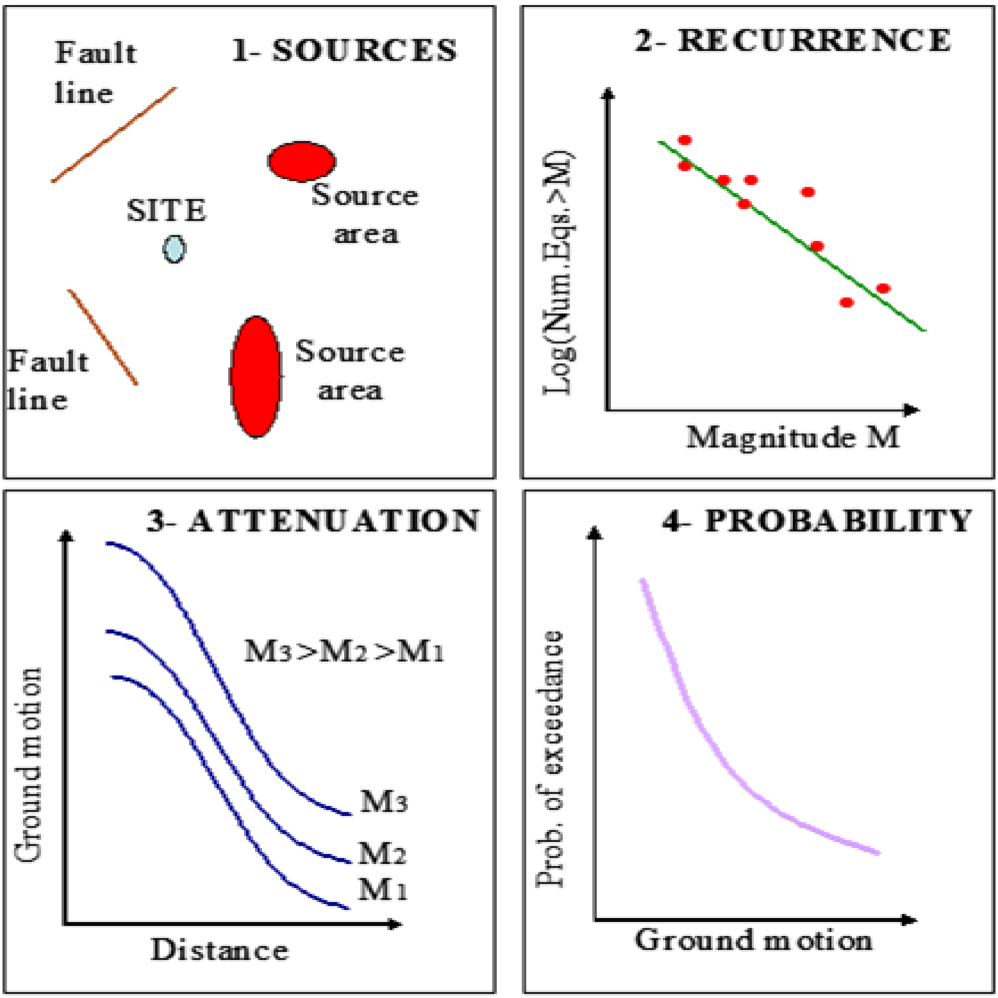


Figure2.PSHA Methodology Steps

- Characterizing All Sources: Characterize all seismic sources that could affect the seismic hazard at the terminal site, including key characteristics such as location, geometry, faulting mechanism, the spatial distribution of seismicity, maximum magnitude, and earthquake recurrence.

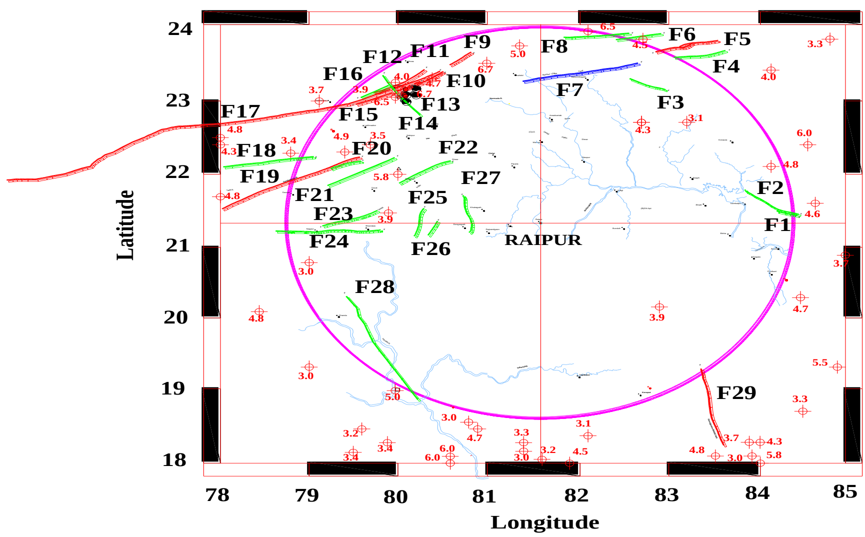
- Characterization of each source's seismicity: It is necessary to determine the level of seismic activity or the time frame in which the tremors reappear. Each source's seismicity is determined by using a reappearance relationship, which specifies the frequency at which an earthquake of a particular magnitude may be exceeded. While the recurrence relationship can account for the largest tremor, it doesn't restrict the analysis to only the particular earthquake.

- Determination of Ground Motions from Each Source: To predict the ground movement caused by earthquakes of various magnitudes at different locations, it is necessary to employ forecasting models. It also takes into account the unpredictability involved in the predictive correlation. In available earthquake ground motion attenuation relationships, an appropriate relationship is selected for the tectonic environment, source characteristics, magnitude, distance ranges, and terminal site conditions.

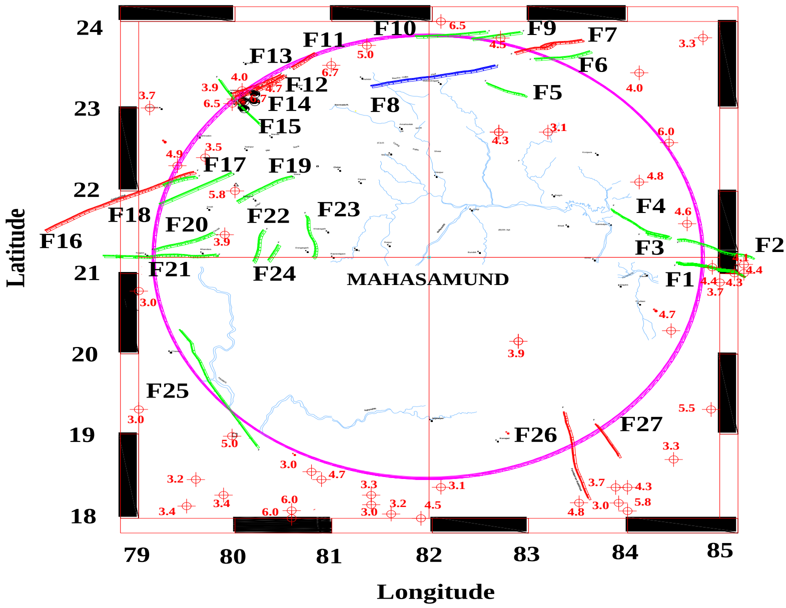
- Probabilistic Calculations: Finally, the variations in identifying tremor location, magnitude, and ground motion parameters are integrated to determine the possibility of exceeding the earth motion parameter within a given timeframe.

5. SEISMOGENIC SOURCES OF THE REGION

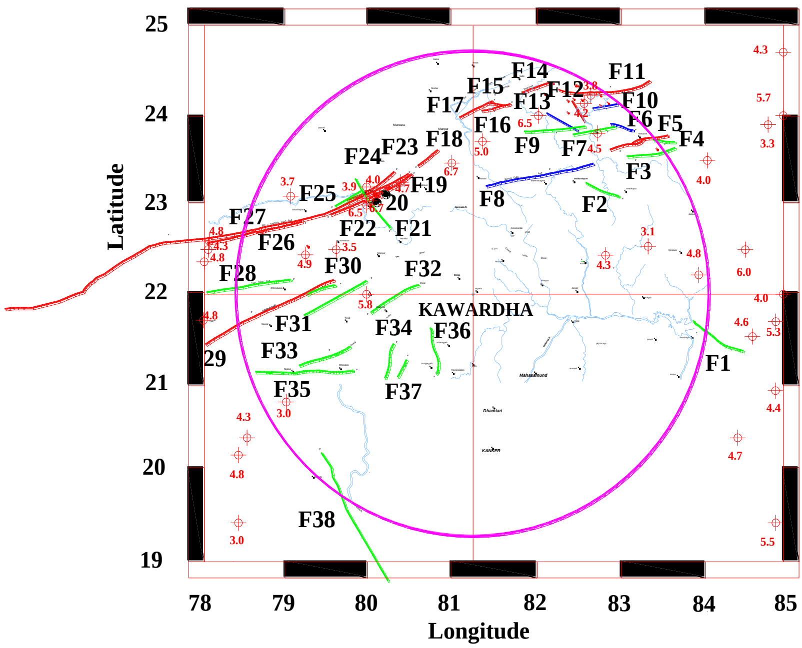
The linear seismogenic sources as a fault, having fault length (Li) ≥ 25 kM, within a radius of 300 kM around the major district headquarters, have been identified and numbered using Seismotectonic Atlas. The parameters which need to be defined for fault sources are location, fault length, and shortest magnitude (S_{max}).



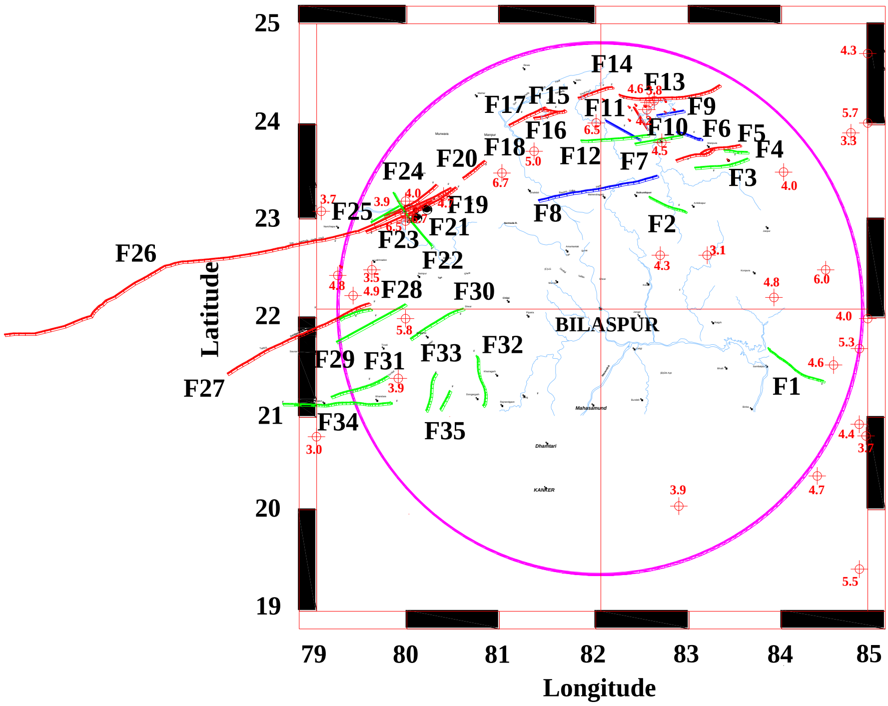
(a) Raipur



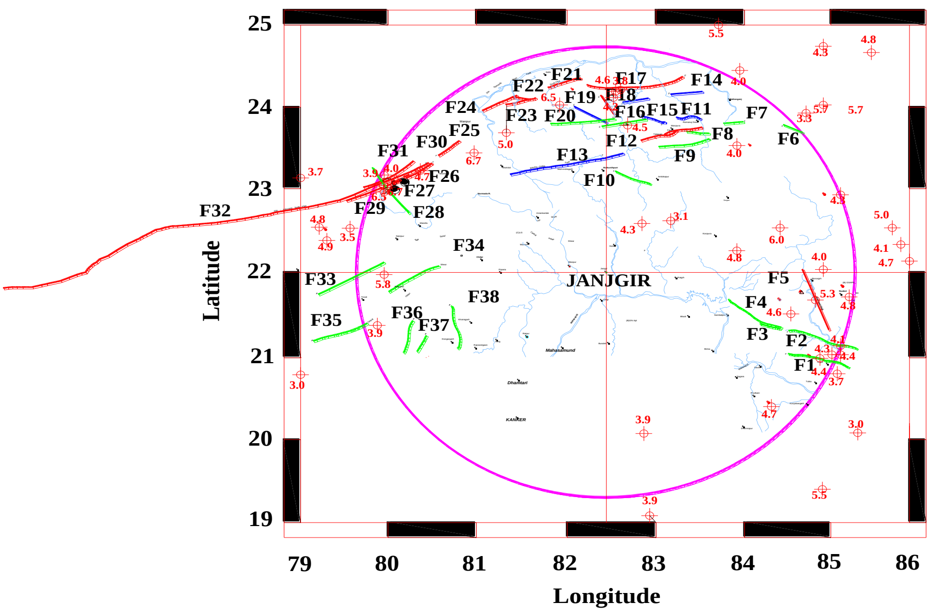
(b) Mahasamund



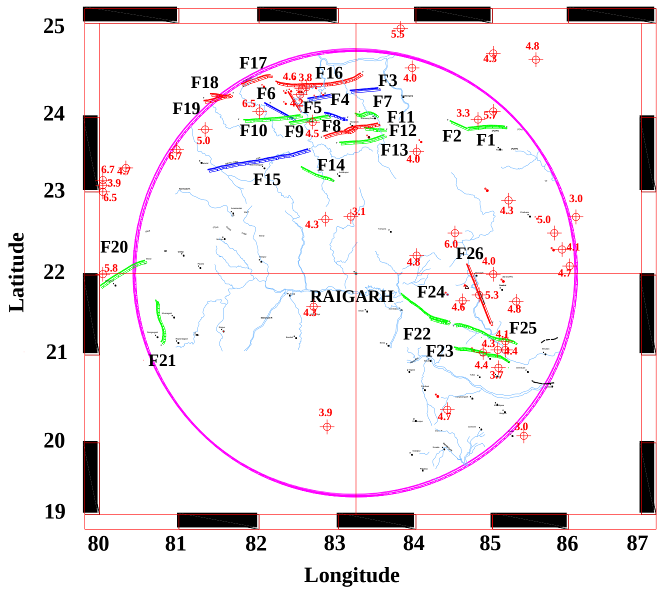
(c) Kawardha



(d) Bilaspur



(e) Janjgir



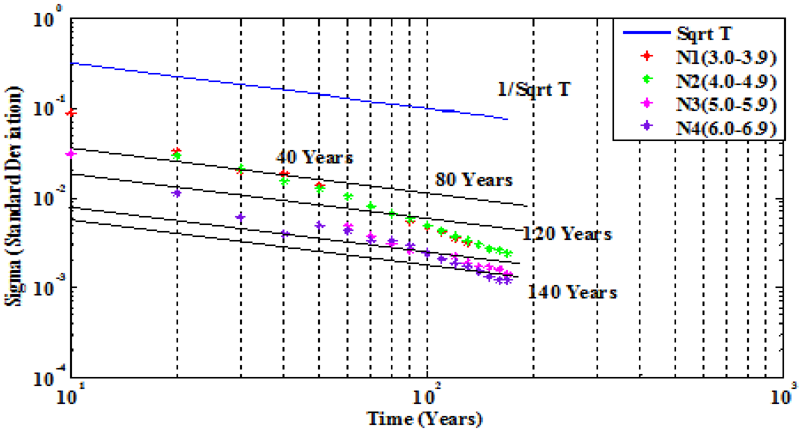
(f) Raigarh

Figure 3.Faults Map of District Headquarters of Central Chhattisgarh

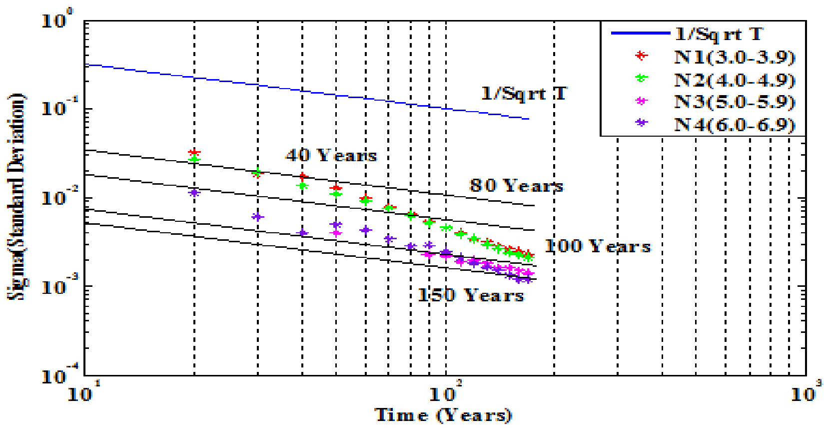
The potential seismic sources in numbers for Raipur are twenty-nine, for Mahasamund is twenty-seven, for Kawardha is thirty–eight, for Bilaspur is thirty–five, for Janjgir thirty–eight and for Raigarh is twenty–six have been identified. Around the major district headquarters, key faults are Gavilgarh Fault (182 km), Bamhni - Chilpa Fault (140 km), Narmada South Fault (477 km), Tapti North Fault (109 km) and Brahmani Fault (87 km). The Auto-cad map has been utilized to combine earthquake data obtained from multiple agencies and literature sources, in addition to displaying all tectonic sources as depicted in Figure 3. The minimum source-to-site distance for all seismic sources of district headquarters has been tabulated as in Appendix Table. 1 &Table 2

6. DATA COMPLETENESS AND RECURRENCE RELATIONSHIP

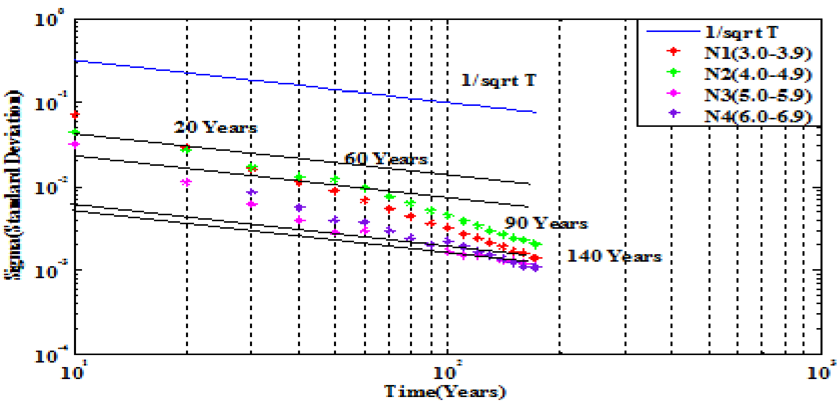
The study area analyzed historical earthquake events between 1846 and 2018, with magnitudes ranging from 3.0 Mw to 6.7 Mw. The accuracy of the data was verified using the Stepp [20] method. Figure 4. illustrates the temporal variation of Mw for the data set obtained from GSI, USGS, andIMD, with magnitude levels N1, N2, N3, and N4.



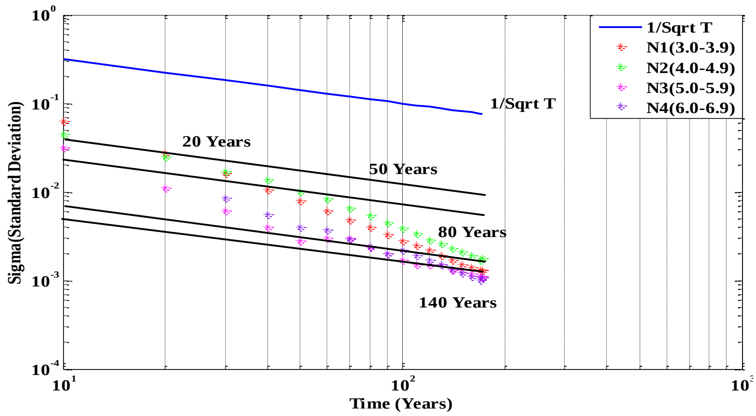
(a) Raipur



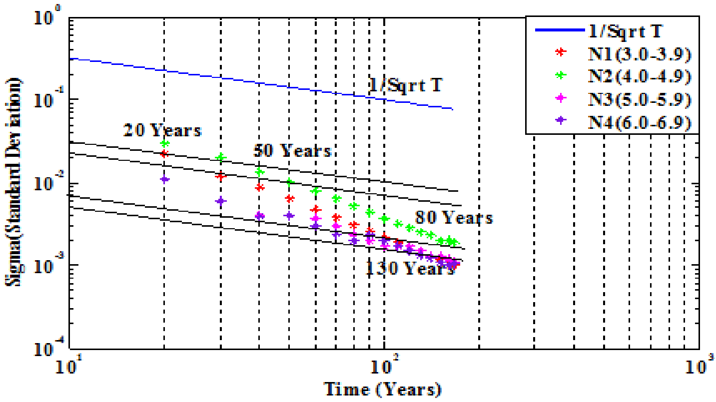
(b) Mahasamund



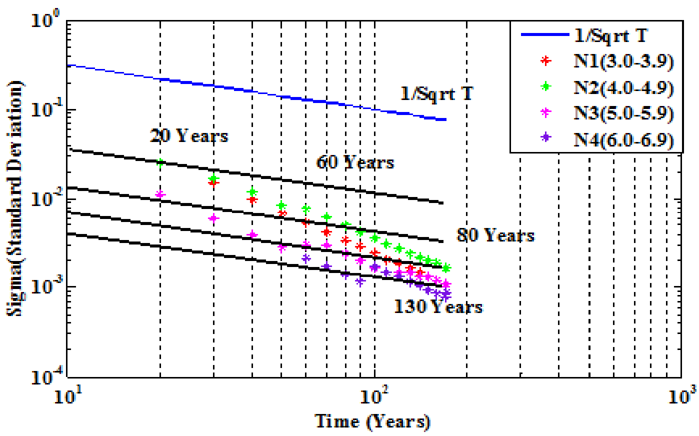
(c) Kawardha



(d) Bilaspur



(e) Janjgir



(f) Raigarh

Figure 4. Data Completeness Test for District Headquarters of Central Chhattisgarh.

[Variation of SD (σ) versus time interval and magnitude and line with slope (1/√T)]

The Gutenberg-Richter recurrence law governs the occurrence of earthquakes in all regions of the globe. Also following the G-R recurrence law are shakes of significant depth. Equation (1) demonstrates the G-R relationship.

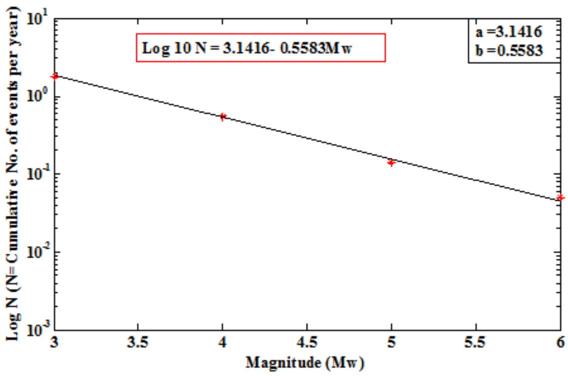
$$\log_{10}(N) = a - b*M \quad (1)$$

In Equation (1), the cumulative number of earthquakes in the study region is represented by N. The seismicity parameters are represented by the letters "a" and "b," where "b" is sometimes referred to as the b-value. The slope of the G-R plot in Figure. 5 is used to derive the b-value, while the intercept of the G-R plot represents "a".

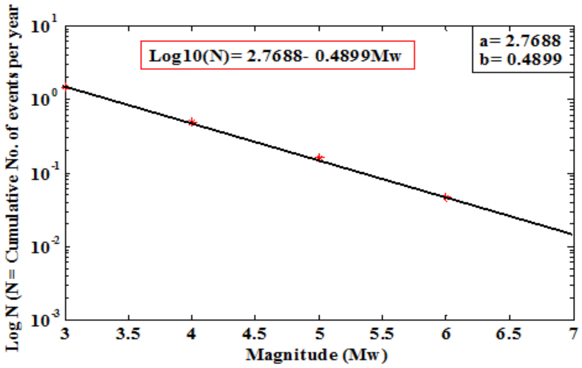
Table 1.Seismicity Parameters for District Headquarters of Central Chhattisgarh

Name of District Headquarters	a	b	α	β
Raipur	3.1416	0.5583	7.24	1.29
Mahasamund	2.7668	0.4899	6.38	1.13
Kawardha	4.6311	0.8387	10.67	1.94
Bilaspur	3.1948	0.5681	7.36	1.31
Janjgir	2.8682	0.5087	6.61	1.18
Raigarh	2.7252	0.4847	6.28	1.12

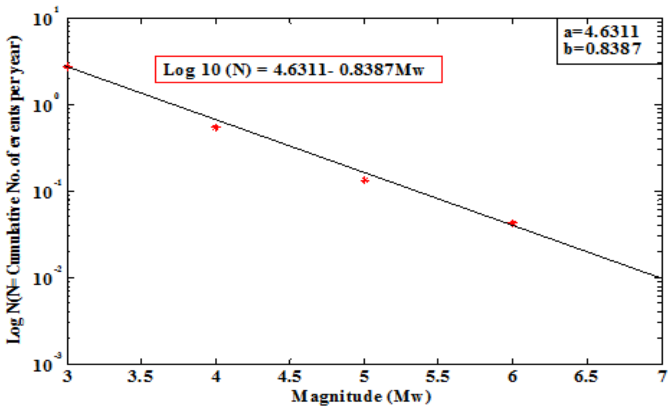
Note: α =2.303*a, β = 2.203*b



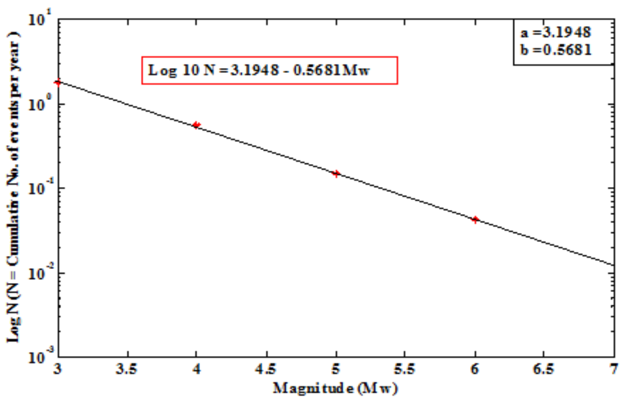
(a) Raipur



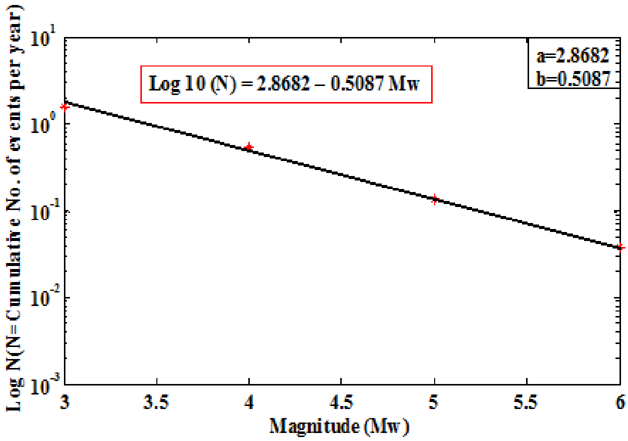
(b) Mahasamund



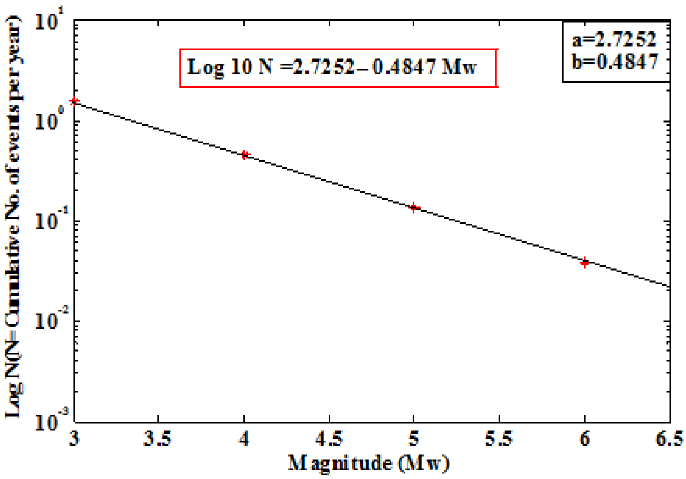
(c) Kawardha



(d) Bilaspur



(e) Janjgir



(f) Raigarh

Figure 5. Recurrence Relationship for District Headquarters of Central Chhattisgarh

In Eq. (1), the M represents the magnitude of the earthquake. The completeness of a seismic catalog can be determined by considering the range of magnitudes and the observation interval. The number of earthquakes recorded in a specific time period 'T' is indicative of the number of samples in the catalog. The extreme part refers to a significant span of time during which we have access to information solely pertaining to major historical occurrences. The entire section further reflects the data from the most recent decades, when information on earthquakes of both major and minor magnitudes was accessible. The aforementioned method, which is suitable for engineering applications, may just estimate such a doubly truncated Gutenberg-Richter relationship with statistical errors in values of the magnitude that have occurred in the past. The time period between successive events is known as the recurrence interval, indicating the frequency at which an event is expected to happen again. The seismogenic fault's dynamic process is closely related to the recurrence interval of large earthquakes, which is a crucial parameter for evaluating seismic hazards. The data of Appendix-Table 3.has been used to generate graphs as shown in Figure 5., for finding out the recurrence relationship for particular district headquarters. The recurrence relationship gives the important seismic parameter, b value. The b values were estimated and tabulated in Table 1. The maximum and minimum b values are estimated by the study as, 0.8387 and 0.4847 for district headquarters Kawardha and Raigarh respectively.

7. MAXIMUM MAGNITUDE FOR SEISMIC SOURCES

The maximum magnitude of the seismic source plays a vital role in the estimation of PGA, using site-specific ground motion attenuation interaction. For estimation of maximum magnitude, methods of Wells & Coppersmith and Gupta have been used. The maximum magnitude of each seismic source of district headquarters is tabulated as in Appendix – Table4.&Table 5.

8. ATTENUATION RELATIONSHIPS

Ground motion attenuation interactions were used to envisage the distributions of peak ground motion, at the location. To ensure practical application in engineering design and seismic risk evaluation, the ground motion equation needs to be presented clearly and concisely, specifically in terms of distance and magnitude.Ground Motion Attenuation Equations (GMPEs) are typically developed through a process of regression analysis. This involves analyzing ground motion records from past occurrences or random simulations. GMPE models illustrate the dispersion of ground motion with median and logarithmic standard deviations. Iyengar and RaghunathKanth have proposed a comprehensive predictive attenuation relationship for Peninsular India.

$$\ln Y = C1 + C2\,(M-6) + C3\,(M-6)^2 - \ln(R) - C4\,(R) + \ln(\varepsilon) \quad (2)$$

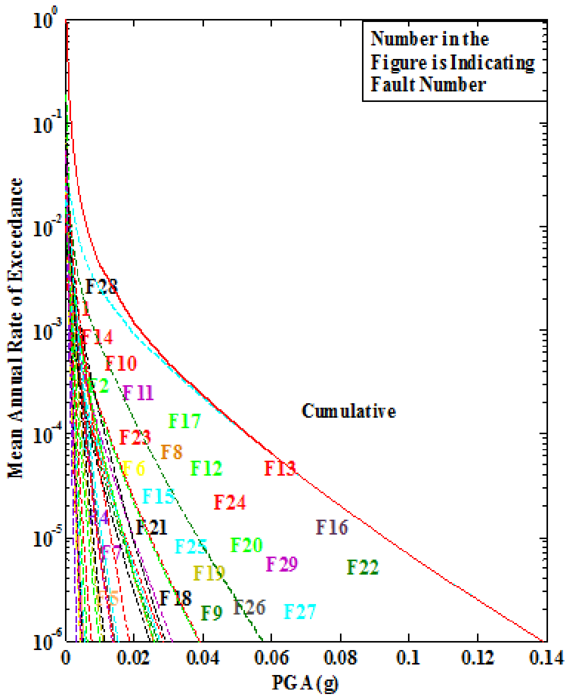
In the Peninsular India Region, the parameters C1, C2, C3, and C4 refer to PGA(g), moment magnitude, hypocentral distance, and ln ε standard deviation, respectively. Their respective values are 1.6858, 0.9241, -0.0760, and 0.0057, with σ (ln ε) equal to 0.4648. To calculate the hypocentral distance, R, you can use the formula $R = \sqrt{(d^2+f^2)}$. In this formula, ‘d’ represents the shortest distance on the map from the site to the fault being analyzed, and ‘f’ is the assumed focal depth of 10 km. For the prediction of Peak Ground Acceleration (PGA), Iyengar and Raghu Kanth model has been used for the study area.

9. SEISMIC HAZARD CURVE

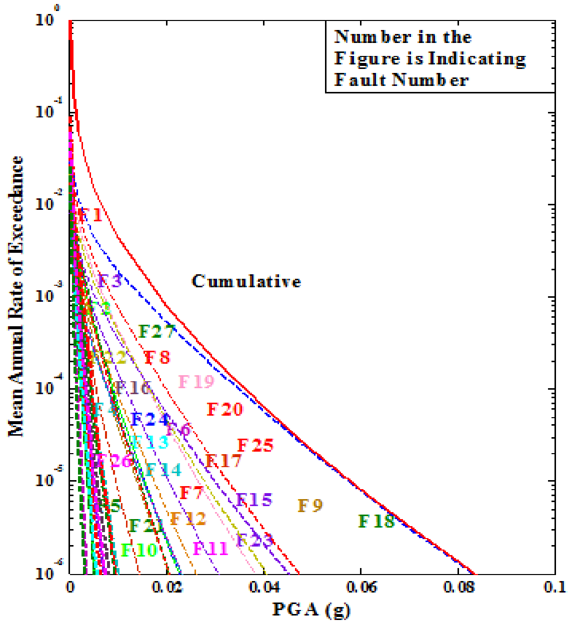
In PSHA, there are three categories of uncertainty, including source-to-site distance, past earthquake magnitude, and ground motion. The recurrence relationships are utilized to characterize the seismicity's source. Equations for predicting ground motion are used to ascertain the site's ground motion, as well as its inherent uncertainty, resulting from the possibility of earthquakes of varying magnitudes originating from each source. The probability of the ground motion parameter's value being exceeded within a specific time period can be determined by combining the uncertainties in ground motion, magnitude, and earthquake location. If the site is shaken by more than one source (let's say Ns sources), then the given equation is used to calculate the combined uncertainties for all conceivable source-to-site distances and magnitudes:

$$\lambda_{y^*} = \sum_{i=1}^{N_S} \sum_{j=1}^{N_M} \sum_{k=1}^{N_R} \nu_i \int\int P[Y > y^* \mid m_j, r_k] P[M = m_j] P[R = r_k] \quad (3)$$

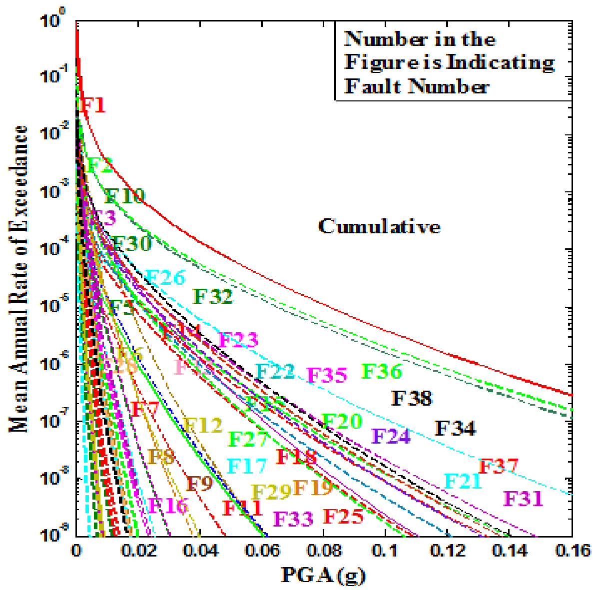
In equation (3) $\nu = \exp(\alpha - \beta^* m0)$, $\alpha = 2.303^* a$, $\beta = 2.303^* b$ and $m_0 = 3.0$ (Minimum Earhquake Magnitude)



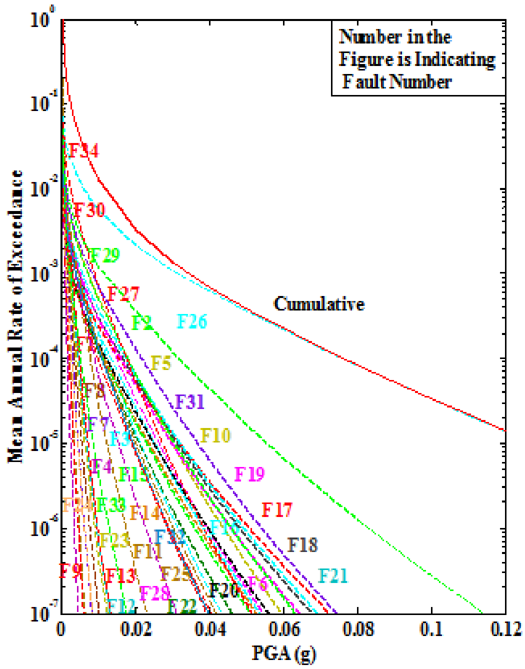
(a) Raipur



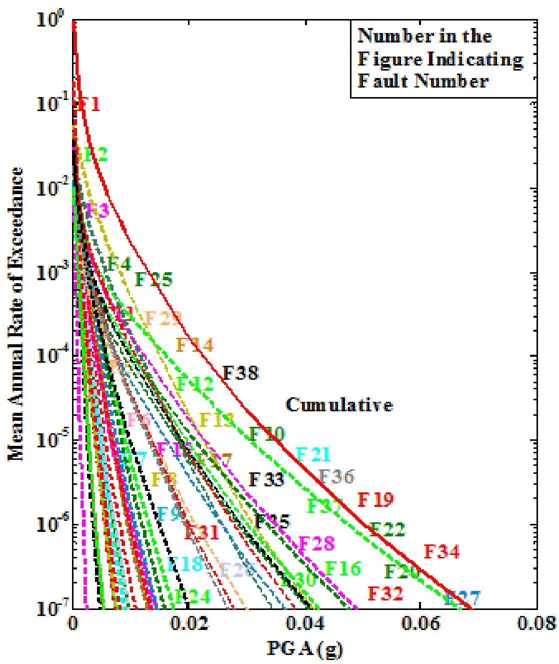
(b) Mahasamund



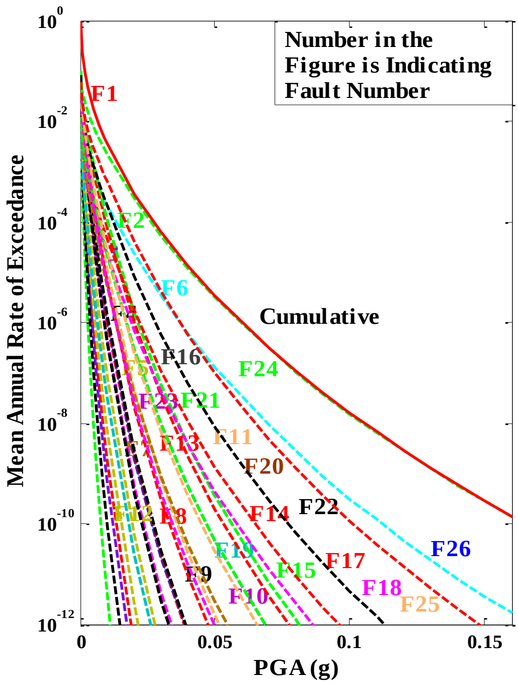
(c) Kawardha



(d) Bilaspur



(e) Janjgir



(f) Raigarh

Figure 6.Hazard Curve for District Headquarters of Central Chhattisgarh

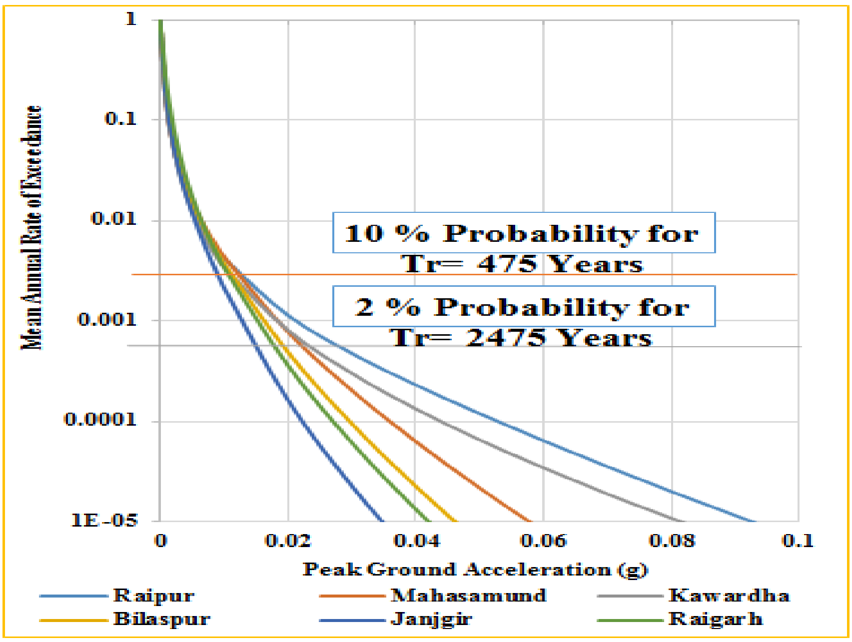


Figure 7. Hazard Curve for District Headquarters of Central Chhattisgarh

Table 2.PGA (g) Values for % Probability for Various Return Periods

Probability	Raipur	Mahasamund	Kawardha	Bilaspur	Janjgir	Raigarh
	Value of Peak Ground Acceleration(g) [For Time Period 50 Years]					
10% Probability with Return of Period 475 Years	0.0155	0.0145	0.0139	0.0130	0.0102	0.0120
2 % Probability with Return of Period 2475 Years	0.0325	0.0249	0.0270	0.0211	0.0165	0.0198

Using the MATLAB program, seismic hazard curves have been drawn for six district headquarters with all active seismic sources and are shown in Figure 6. The importance of the hazard curve is to find out the PGA(g) values for various % of probabilities for the particular time periods. Table 2. displays the Peak Ground Accelerations (PGA) for district headquarters, calculated using mean hazard curves from Figure 7. The calculations were done for a time period of 50 years and 10% and 2% probability of exceedance. The return periods used were 475 years and 2475 years. The PGA(g) values for district headquarter in Raipur for a return period of 500, 2500 and 5000 years are calculated as 0.0090g, 0.02250g and 0.0270g respectively.

Table 3.PGA (g) Values for District Headquarters Raipur for various Return Periods

Name of District Headquarters	Return Period (Years)		
	500	2500	5000
	PGA(g) Values		
Raipur	0.0090	0.0225	0.0270
Raipur [Development of Probabilistic Seismic Hazard Map of India in 2011]	0.0100	0.0200	0.0200

National Disaster Management Authority has constituted a working Committee of Experts for the Microzonation of India. Prof. R.N. Iyengar has submitted a Technical Report on "Development of ProbabılıstıcSeısmıc Hazard Map of Indıa". In this report, the PGA(g) values were calculated for various return periods for different districts of India. In Table 3., the PGA(g) values for Raipur with the same return period are closely comparable to the value mentioned in the Technical Report.

10. RESULTS AND DISCUSSION

The central Chhattisgarh district headquarters has undergone a PSHA to determine the PGA values at the substratum level in the current study. The regional recurrence relationship is depicted in Figure 5., while Table 1. displays the "b" values obtained for district headquarters, which are 0.5583, 0.4899, 0.8387, 0.5681, 0.5087 and 0.4847, respectively. District headquarters of Raipur, Mahasamund, Kawardha, Bilaspur, Janjgir, and Raigarh were evaluated for PGA values over 50 years. The calculated values for a 10% probability with a return period of 475 years are as follows: Raipur – 0.0155g, Mahasamund - 0.0145g, Kawardha - 0.0139g, Bilaspur - 0.0130g, Janjgir - 0.0102g, and Raigarh - 0.0120g.The PGA values for a 2% probability with a return period of 2475 years were calculated as follows: 0.0325g, 0.0249g, 0.0270g, 0.0211g, 0.0165g, and 0.0198, all of which were calculated for the same time period. The above-stated results clearly reveal that the Captial of Chhattisgarh, Raipur is a more seismically affected region than other district headquarters, due to rapid growth of infrastructure and construction activity with thickly populated areas. In accordance with the 2016 IS-1893-Part-I recommendation for Zone II, the design of earthquake-resistant structures in and around the main district headquarters of central Chhattisgarh can be directly applied based on the results of this analysis.

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