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DEVELOPMENT OF TIME-AND-MAGNITUDE PREDICTABLE MODEL AND PREDICTION OF EARTHQUAKE HAZARD IN CENTRAL HIMALAYAS

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SUMMARY

Earthquake prediction is one of the necessary components of seismic risk reduction in India. This is associated with the fact that owing to the subjectively underestimated seismic hazard in the territory of India earthquake resistance level of buildings and structures had appeared to be significantly lower than the seismic hazard level. Earthquake Prediction should be considered as a stage-by-stage seismic hazard assessment that consequently passes from long-term to current one when strong seismic event is under preparation. This will allow for making decisions that are adequate to the hazard data and reduce the seismic risk. Strong main shocks in six seismogenic sources of the Central Himalayas have been used to show that the interevent time, T_t (in years), between two strong shallow earthquakes and the magnitude, M_f, of the following mainshock are given by the relation:

$$\log T_t = 0.46\, M_{min} + 0.09\, M_p + 0.14 \log m_o - 5.79$$

$$M_f = -\, 0.69\, M_{min} - 0.08\, M_p - 0.45 \log m_o + 22.52,$$

where T_t is the interevent time, measured in years; M_{min} the surface wave magnitude of the smallest mainshock considered; M_p the magnitude of preceding mainshock, M_f the magnitude of the following mainshock and m_o the moment rate in each source per year. These relations may be used for earthquake hazard assessment in the region. A multiple correlation coefficient equal to 0.78 and a standard deviation equal to 0.22 for the first of the above relations were computed. The corresponding quantities for the second of these relations are 0.73 and 0.39. Time dependent conditional probabilities for the occurrence of the next large ($M_s \geq 5.5$) shallow mainshocks during the next 30 years (2004-2034) in one of the six-seismogenic source are estimated, by use of the first of these relations. The magnitudes of the expected mainshocks are also determined, by the second of the above relations

Keywords: Seismogenic source, characteristic earthquake, interevent time, Time dependent conditional probability

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INTRODUCTION

The problem of earthquake prediction consists of consecutive, step-by-step, narrowing down the time interval, area, and magnitude range where a strong earthquake will occur. Such formulation is dictated both by the nature of the process leading to strong earthquakes and by the practical need earthquake preparedness. Of these, two main aspects can be distinguished in the science of earthquake prediction. The first concerns the study of the geophysical mechanisms that prepare and generate an earthquake as well as the possible symptoms (precursors) associated with the earthquake preparation. The second is focused on the prediction of particular earthquake events regardless the method is tried. Earthquakes occur because of the constant movements of Earth's crust. As it's tectonic plates slide past or over one another, stresses build up within or between them along cracks called faults. Because they are naturally sticky, the faults stay locked in place, deforming the plate nearby. They accumulate energy until they can take no more, and the strain is released in a sudden slip that can shake the ground for several km around. For better estimate of seismic potential and better forecasts of future large earthquake repeat times of large earthquakes can be used as extensive tool. Repeat times are taken to be the time intervals between the largest shocks that occur at a given place along a plate boundary or in a specific seismic zone, and they varies within and between seismic zones, depending not only on the rate of plate motion but also on other factors, i.e. length of rapture along strike, downdip width and dip of the plate boundary (Kelleher et al., 1973). Consequently, if a model can make use of the available repeat times, it offers a very useful tool for long-term earthquake prediction.

Most of the earthquake-generation models currently used for seismic hazard evaluation have attracted the attention of many scientists. Several workers (Cornell, 1968; Gardner and Knopoff, 1974; Papadopoulos and Voidomatis, 1987; Singh et al., 1994) reported that occurrence of earthquakes follow a Poisson distribution suggesting memoryless property of seismic-zones. Wallace (1970) and Nishenko and Singh (1987) among others reported time-dependent properties of earthquake generating sources for several regions. Two such kinds of time dependent models have been proposed: slip predictable model (Bufe et al., 1977; McNally and Minster, 1981; Singh et al, 1991 Wang et al., 1982, Kiremidjian and Anagnos, 1984) and time predictable mode (Shimazaki and Nakata, 1980; Anagnos and Kiremidjian, 1984; Papazachos, 1989; Singh et al., 1992). According to the first of these modes, the size (co-seismic slip, seismic moment, magnitude, etc) of future earth quake depends upon the time elapsed since the last earthquake, while according the second of these models, the time of occurrence of a future earthquake depends on the size and the time of occurrence of the last earthquake. The time-predictable model is based on the theory that earthquakes in fault zones are caused by the constant build-up and release of strain in the Earth's crust. When an earthquake occurs on the fault, a certain amount of accumulated strain is released. Following the quake, strain builds up again because of the continuous grinding of the tectonic plates. In the time-predictable model, a fault is assumed to slip once the stress builds up to a certain level. As plates move at more or less constant rates, the model suggests that it should take longer for an earthquake to recur after a large quake than after a small one - a large quake relieves more stress on a fault, so it takes longer to build up again to the critical level. It implies that after each quake, one should be able to predict the next one, based on how much the fault slipped. This is only possible, however, if the fault zone is relatively simple - if, for example, there is no other active fault nearby that might also relieve local stress. In principle, by the slip predictable model we can predict only the size of a future earthquake and by the time predictable model we can predict only the time of its occurrence. To estimate the long-term probabilities for the generation of strong earthquakes on single faults, the time predictable model seems to be more plausible than the slip-predictable model (Wesnousky et al., 1984, Astiz and Kanamori, 1984, Nishenko and Buland, 1987). Papazachos (1988a & b, 1992) proposed a time-predictable for prediction of earthquake hazard in seismogenic sources. Papazachos and Papaioannou (1993) by including a new parameter in the relations the interevent time and the magnitude of the expected main shock, improved the preceding methodology and applied the model to estimate the probability of occurrence, time and magnitude of next expected mainshock in each seismogenic source. In the present study efforts have been made to develop and apply the said methodology for identification of seismogenic sources in Central Himalayas, considered for earthquake hazard prediction.

REGIONAL CHARACTERISTICS OF REGION

The area constitutes the large Himalayan thrust fault and is the frontier of the Eurasian plate that is pushed northward by the Indian plate. Due to the northward intrusion of the Indian plate, the Himalayan front in southwestern China is characterized completely compression, resulting uplift and the mean *P* axis of direction NNE; almost normal to Himalayan arc (Molnar and Lyon-Caen, 1989). The present distribution of shallow seismicity is due to underthrusting of the continental lithosphere of the Indian plate (Isacks et al., 1968), whereas the occurrences of intermediate-depth earthquakes suggest the existence of the remnants of the old oceanic lithosphere (Mckenzie, 1969; Rastogi, 1974). The seismicity mainly attributed compressive stress between the two plates. The central Himalaya (27^0 N to 33 N^0 and 70^0 E to 90^0 E) includes the Nepal and part of Bihar and Eastern Himalaya including Darjeeling, Sikkim, Bhutan, Arunachal Pradesh and Lohit sectors. Garhwal Himalayas and Nepal region.

The motivation to select this region is guided by several considerations namely, seismically very active, availability of strong main shocks data and Vulnerability of our civilization to earthquake disasters. The Garhwal Himalayas is bounded by latitude 29.50° to 31.0° and longitude 77.5° to 79.5° E and constitutes the northwestern part of the Himalaya. The region is characterized by occurrence of moderate to local sized earthquakes. The high seismic activity is mainly due to the motion of the India plate. The instrumental seismicity is very high in a zone of 50 km width across strike in the Lesser Himalayas (India and Nepal), with a concentration of earthquakes just south of the Main Central Thrust (MCT)

The precise zonation, the calculation of the seismic moment rate, and the declustering of the data, are prerequisite for the model application. However, the zonation is not critical for the results of the model, accurate zonation will improve them (Papazachos and papadimitriou, 1997). For the purposes of the present analysis, the whole area has been separated into seismogenic sources on the basis of spatial clustering of the epicenters of strong earthquakes, seismicity level, maximum earthquake observed, type of faulting and geomorphological criteria (Papazachos, 1989). Each seismogenic source includes the main seismic fault, where the maximum (characteristic) earthquake occurs and possibly other smaller faults where smaller main shocks can also occur. The main characteristic of seismogenic region is the interaction among its faults during the important seismic excitations (redistribution of stress etc.). Therefore, zonation in the present case is the procedure of defining, as accurately as possible, the boundaries of the seismogenic regions.

On the basis of the gross seismotectonic and geological properties six of these seismogenic sources demarcated by elliptical boundaries, shown in Fig. 1 together with the epicenters of the data have been selected by the following criteria:

a) in each source at least three mainshocks (two repeat times) of magnitudes $M_s \geq 5.5$ occurred during the considered period;
b) in each source at least one mainshock with $M_s \geq 6.0$ occurred during this period of time; and
c) each source is characterized by distinct seismotectonic properties in relation to the adjacent region (same kind of faulting, high seismicity level, etc.).

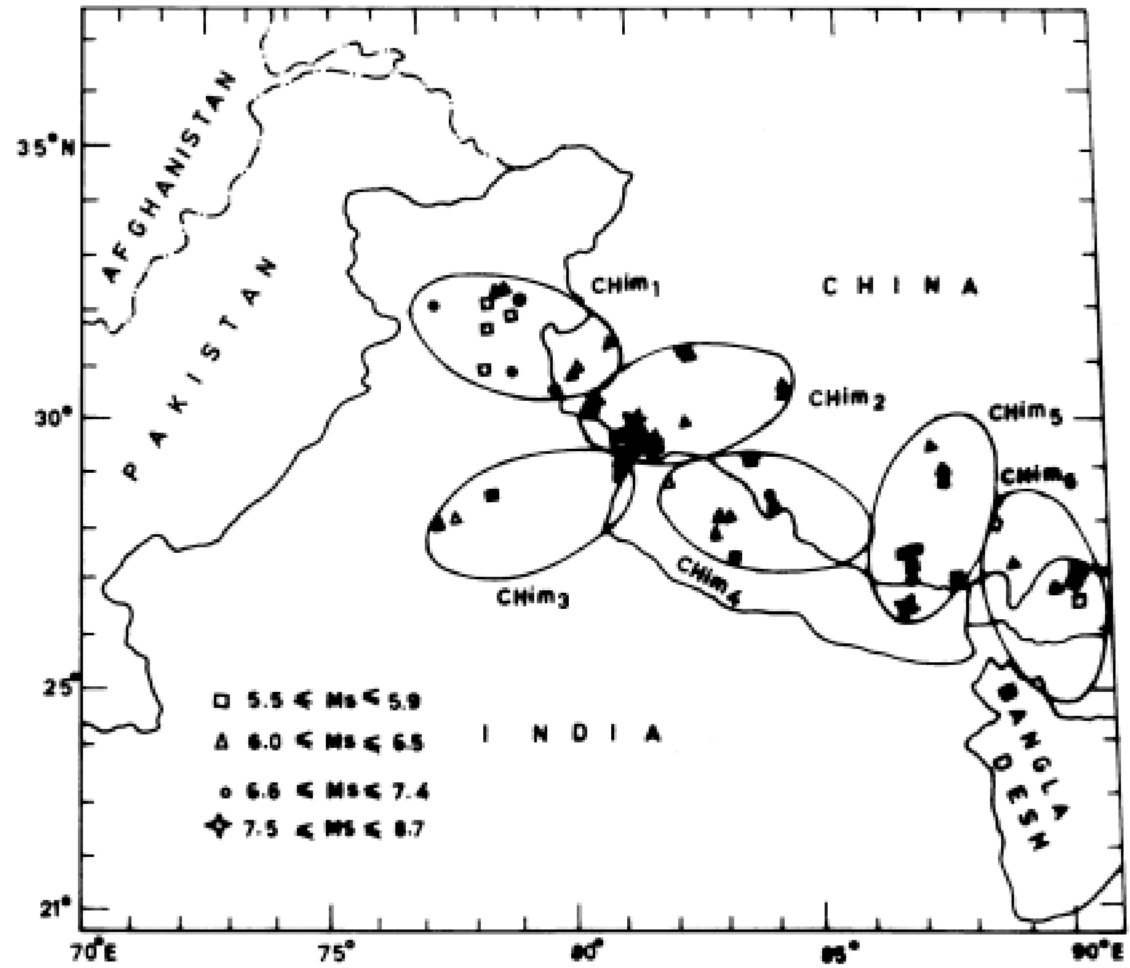

Fig. 1 shows only earthquake epicenters of magnitude 5.5 and greater for clarity. Earthquakes of 5.5 $<M_s < 8.4$ are considered within each zone for statistical derivation and the foreshocks and aftershocks are identified from the earthquake distribution in the time domain (open symbol). Filled symbols show mainshocks.

DATA TREATMENT

The earthquake catalogue prepared by National Earthquake Information Center (NEIC) U. S. Department of the Interior U. S. Geological Survey, USA was used for the period 1897-2002 with surface wave magnitude M_s >5.5 (Table 1). The data used in such studies must be homogeneous; that is, the magnitudes of the earthquakes must be in the same scale. The magnitudes used in the present study are surface wave magnitudes with the exception of some big earthquakes for which seismic moment magnitude is used due to the saturation of surface wave magnitude. Also, declustering and use of complete data, that is, determination of foreshocks, aftershocks and main shocks and use of a data samples which includes all earthquakes which occurred in a certain seismogenic region during a certain time period and have magnitudes larger than a certain minimum value, is necessary for such work. Thus, for the Central Himalayas the data have been considered complete for $M_s \geq 5.5$ since 1950, $M_s \geq 6.0$ since 1930 and $M_s \geq$ 7.0 sine 1897.

Table 1: Mainshocks, Foreshocks (f) and Aftershocks (a) data used in each seismogenic sources. M_s and M_w represents surface wave magnitude and moment magnitude, respectively.

Completeness	Seismogenic Sources	DA	MO	YEAR	LAT °N	LON °E	M_s	M_w
1930, 6.0	$CHim_1$	28	2	1906	32.00	77.00	7.0	7.0
1897, 7.0		27	6	1955	32.50	78.60	6.0	6.0
		12	5	1959	32.40	78.66	6.3	6.5
		13	7	1962	30.90	79.60	6.0	a
		14	7	1962	30.40	79.50	6.0	a
		6	3	1966	31.60	80.50	6.1	a
		19	1	1975	32.40	78.40	6.9	6.9
		19	10	1991	30.70	78.70	7.1	7.1
		28	3	1999	30.50	79.40	6.6	a
1950, 5.5	$CHim_2$	28	8	1916	30.00	81.00	7.5	7.5
1930, 6.0		5	3	1935	29.75	80.25	6.0	6.0
		4	6	1945	30.00	80.00	6.5	6.5
		23	2	1953	29.50	81.30	6.0	a
		18	12	1958	30.01	79.94	6.3	a
		28	10	1958	30.60	84.50	6.4	6.7
		13	1	1958	30.50	84.50	6.0	f
		24	12	1961	29.43	80.83	5.7	a
		30	1	1963	29.50	80.90	6.0	a
		26	9	1964	29.96	80.46	5.8	a
		27	6	1966	29.62	80.83	6.0	a
		27	6	1966	29.80	80.90	5.8	a
		27	6	1966	29.71	80.89	6.0	a
		16	12	1966	29.62	80.79	5.8	6.0
		31	5	1968	29.90	80.00	5.7	a
		29	7	1980	29.35	81.21	5.7	a
		29	7	1980	29.62	81.09	6.1	a
		29	7	1980	29.60	81.00	6.6	6.8
		23	1	1982	31.50	82.20	5.5	a
		23	1	1982	31.70	82.20	6.4	a
		18	5	1984	29.57	81.86	5.6	a
1950, 5.5	$CHim_3$	10	10	1956	28.15	77.00	6.0	6.3
1930, 6.0		27	8	1960	28.20	77.40	6.0	a
		24	11	1961	28.80	81.50	6.0	a
		15	8	1966	28.67	78.93	5.6	5.6
		29	7	1980	29.60	81.00	6.6	6.6
1950, 5.5	$CHim_4$	27	5	1936	28.50	83.50	7.0	7.0
1930, 6.0		18	1	1952	28.50	83.20	6.0	f
		29	8	1953	27.90	82.20	6.0	f
		4	9	1954	28.30	82.70	6.2	6.5
		24	11	1961	28.80	81.50	6.0	a
		6	1	1965	27.00	83.00	5.7	5.7
		11	2	1969	28.10	83.65	6.2	6.2
		9	8	1987	29.42	83.65	5.6	5.6
1950, 5.5	$CHim_5$	15	1	1934	26.50	86.50	8.4	8.4
1930, 6.0		28	5	1951	29.00	87.00	6.0	6.2
		19	11	1952	29.80	86.60	6.0	a
		12	1	1965	27.40	87.84	5.8	5.8
		20	4	1988	26.94	86.61	5.8	f
		20	8	1988	26.77	86.61	6.6	6.7
		20	3	1993	29.00	87.30	6.1	a
1950, 5.5	$CHim_6$	20	9	1955	27.50	90.00	5.7	5.9
1930, 6.0		29	7	1960	26.47	90.38	5.5	a
		21	8	1960	27.00	88.50	5.5	a
		25	12	1961	27.00	90.00	6.0	f
		27	3	1964	27.20	89.30	6.3	6.4
		19	11	1980	27.40	88.79	6.0	6.0

The minimum magnitude was considered in each case to define the corresponding M_p, M_f and repeat time in years (Table 2). The repeat time T, denotes the time from the beginning of one seismic sequence to the initiation of the next sequence. The T_p and T_f represent the year of occurrence of the preceding and following mainshock, respectively.

Table 2: Seismogenic source data used for parameter determination.

Seismogenic sources	M_{mim}	M_p	M_f	T	t_p	t_f
$CHim_1$	6.0	6.0	6.5	3.88	1955	1959
		6.5	6.9	15.69	1959	1975
		6.9	7.1	16.75	1975	1991
	6.5	6.5	6.9	15.69	1959	1975
		6.9	7.1	16.75	1975	1991
	6.9	6.9	7.1	16.75	1975	1991
	7.0	7.0	7.1	85.64	1906	1991
$CHim_2$	6.0	6.0	6.5	10.25	1935	1945
		6.5	6.7	13.40	1945	1958
		6.7	6.0	8.13	1958	1935
		6.0	6.8	13.62	1935	1980
	6.5	6.5	6.7	13.40	1945	1958
		6.7	6.8	21.75	1958	1980
	6.7	6.7	6.8	21.75	1958	1980
$CHim_3$	5.6	6.3	5.6	9.85	1956	1966
		5.6	6.6	13.95	1966	1980
	6.3	6.3	6.6	23.80	1956	1980
$CHim_4$	5.6	6.5	5.7	10.34	1954	1965
		5.7	6.2	4.10	1965	1969
		6.2	5.6	18.49	1969	1987
	5.7	6.5	5.7	10.34	1954	1965
		5.7	6.2	4.10	1965	1969
	6.2	7.0	6.5	18.27	1936	1954
		6.5	6.2	14.44	1954	1969
		7.0	6.5	18.27	1936	1954
$CHim_5$	5.8	6.2	5.8	13.62	1951	1965
		5.8	6.7	23.61	1965	1988
	6.2	8.4	6.2	17.37	1934	1951
		6.2	6.7	37.23	1951	1988
	6.7	8.4	6.7	54.60	1934	1988
$CHim_6$	5.9	5.9	6.4	8.52	1955	1964
		6.4	6.0	16.64	1964	1980
	6.0	6.4	6.0	16.64	1964	1980

COMPUTATIONAL ANALYSIS

Papazachos and Papadimitriou, 1997; based on the interevent times of strong mainshocks in seismogenic sources of the Aegean area, proposed relations of the following form:

$$\log T_t = b\, M_{min} + c\, M_p + d \log m_0 - t \quad (1)$$

and

$$M_f = B\, M_{min} - C\, M_p - D \log m_0 + m \quad (2)$$

where T_t is the interevent time measured in years, M_{min} is the surface-wave magnitude of the smallest mainshock considered, M_p is the magnitude of the preceding mainshock, M_f is the magnitude of the following mainshock, m_0 is the moment rate in each source per year which expresses the tectonic loading exerted in the volume of each seismogenic region, and t and m are constants. Table 2 lists the values of the parameters for each seismogenic source necessary to proceed. The model expressed by relations (1) and (2) has the advantage that all parameters (b, c, d, t, B, C, D and m) of these relations are calculated by all available data for all sources.

On the basis of interevent times of strong mainshocks in the six seismogenic sources of Central Himalayas; the time and magnitude predictable model relationships (Shanker and Singh, 1996; Shanker, 2002; Papazachos et al., 1997) has been determined as:

$$\log T_t = 0.46\, M_{min} + 0.09\, M_p + 0.14 \log m_o - 5.79 \quad (3)$$

with a correlation coefficient of 0.78 and standard deviation of 0.22. The positive correlation between the repeat time and the magnitude of the preceding mainshock i.e. The $\log T^* = \log T - 0.46\, M_{min} - 0.14 \log m_0 + 5.79$ as a function of M_p (Fig. 2), where T, M_{min} and $\log m_0$ and M_p are the observed values suggests that the time-predictable model hold in the area under study.

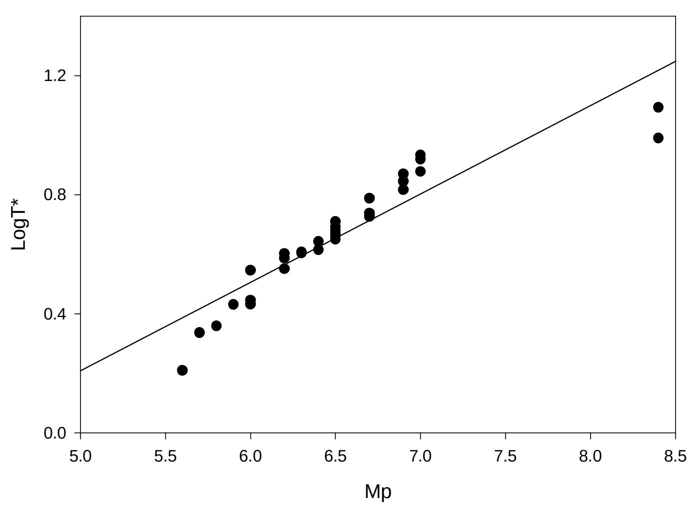

Fig. 2. Dependence of the repeat time on the preceding mainshock magnitude, M_p

The values of the parameters of (2) were determined by the use of all available information from Table 2, and the following formula was found:

$$M_f = -0.69\, M_{min} - 0.08\, M_p - 0.45 \log m_o + 22.52, \quad (4)$$

with a correlation coefficient equal to 0.73 and a standard deviation equal to 0.36. The $M_f^* = M_f + 0.69\, M_{min} + 0.45 \log m_0 - 22.52$, where M_f, M_{min} and $\log m_0$ are the observed values, is plotted versus the observed M_p in Fig. 3. The straight line is a least squares fit. The negative dependence of the magnitude of the following main shocks on the magnitude of the preceding mainshock indicates that a small one and a small mainshock follow a large mainshock by a large one.

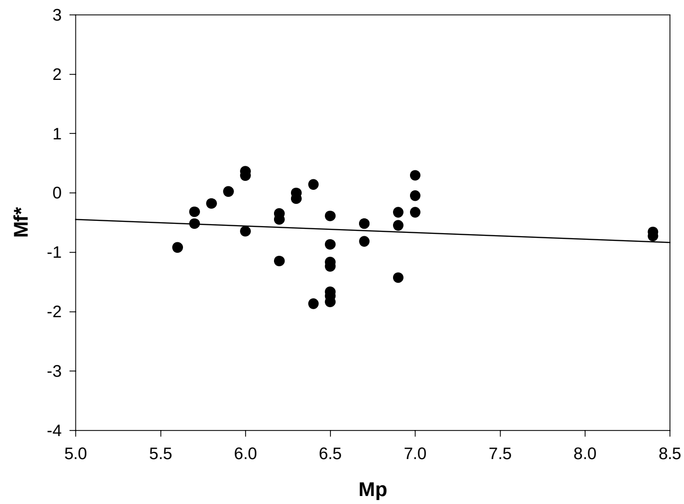

Fig. 3 Dependence of the magnitude of the following mainshock on the magnitude of the preceding mainshock.

Most of the parameters in the equations (1) and (2) and their values are self-explanatory. Similar results, that is, positive correlation between M_p and $\log T_t$ and negative correlation between M_p and M_f, were also found in other areas where this model has been tested (Papazochos, 1992; Singh et al., 1992; Papazachos and Papaioannou, 1993; Karakaisis, 1993).

PREDICTION OF THE NEXT SHALLOW MAINSHOCK

The model tested in the present study provides a means to calculate the time of occurrence of the next large mainshock in each one of the defined seismogenic sources using relation (3). However, since there is a considerable difference between repeat times, T_t, estimated from relation (3), and the corresponding actual repeat times, T, it is preferable to estimate the probability of occurrence of the next mainshock larger than a certain magnitude and in a given time interval.

It is found that lognormal distribution of T/T_t is more appropriate than the Gaussian or Weibull distributions (Papazachos, 1988b; Papazachos and Papaioannou, 1993). This distribution holds for each of the seismogenic sources. One can calculate the conditional probability, P for the occurrence of a main shock with $M \geq M_{min}$ during the next Δt years (from now), when the previous such earthquake occurred t years ago (from now) and had magnitude M_p, by the relation (Papazachos and Papaioannou, 1993):

$$P(\Delta t) = \frac{F\left(\frac{X_2}{\sigma}\right) - F\left(\frac{X_1}{\sigma}\right)}{1 - F\left(\frac{X_1}{\sigma}\right)} \tag{5}$$

where

$$X_2 = \log\frac{(t+\Delta t)}{T_t}, \qquad X_1 = \log\left(\frac{t}{T_t}\right)$$

and F is the complementary cumulative value of the normal distribution with mean equal to zero and standard deviation equal to σ. Given the date and the magnitude of the last event in a seismogenic source as well as the uncertainty of the model expressed by its standard deviation σ = 0.22, the probabilities of occurrence of the next shallow mainshocks with $M_s \geq 5.5$ during the next 30 years were computed. Table 3 gives information on the expected large shallow earthquakes based on the model expressed by relation (3) and (4). The first column gives the name of the seismogenic source.

Table 3. Expected magnitude, M_f and the corresponding probabilities, P_{30} for the occurrence of large ($M_{min} \geq 5.5$) shallow main shocks during 2004-2034 in the Central Himalayas

Seismogenic Source Name	$M_f \pm 0.39$	P_{30}	M_{min}	M_p	t_p
$CHim_1$	6.9	0.99	6.0	6.6	1999
$CHim_2$	7.0	0.99	5.6	5.6	1984
$CHim_3$	6.9	0.99	5.6	6.6	1980
$CHim_4$	7.0	1.00	5.6	5.6	1987
$CHim_5$	6.5	0.99	5.8	6.1	1993
$CHim_6$	6.2	0.98	5.9	6.0	1980

The next two columns give the magnitude of the expected mainshock; $M_{f;}$ relation (4) and the corresponding highest probabilities have calculated this magnitude, P_{30} for the occurrence of large mainshocks during the decades (2004-2034). Almost in all sources High probability has been found for the occurrence of earthquakes and warrants hazardous in near future. Namely region $CHim_4$ indicates more hazardous than the other five zones is expected to be struck by strong event of $M_f \geq 7.0$ with very high probability almost 1.00. One must note that the absolute values of the probabilities are of relative importance that is their change from source to source is significance. This is because these values may change if a larger sample of data is used.

DISCUSSION AND CONCLUSION

So for, from earlier century many earthquake recurrence models (seismic gap: Imamura, 1928; seismic cycle concept: fedotov, 1965; time and slip-predictable models: Shimazaki and Nakata, 1980) have been proposed only few of then have been accepted that gives satisfactory result of seismic activity of a particular area. The seismic gap concept can only give information on the spatial domain. It is insensitive to the time domain. The seismic cycle concept describes the probability for the occurrence of mainshock in a certain fault increases with the time elapsed since the occurrence of the previous mainshock in this fault. Originally proposed time and slip-predictable model states that if the final stress varies in time while the initial stress remains constant, the regularity makes it possible, to predict the occurrence time of the forthcoming event (time-predictable recurrence); and if the final stress remains constant and the initial stress varies, the coseismic slip produced by the coming event can be determined prior to the event (slip-predictable).

However, the time-dependent character of earthquake occurrence has quantitatively been studied and successfully used in long-term earthquake prediction studies (Papazachos, 1988). The model describes that the time interval elapsed from the last mainshock depends on the magnitude of previous mainshock (regional time and magnitude predictable model). This study attempts to the estimation of conditional probabilities and the magnitude of the expected event was based on the time and magnitude predictable model expressed by the relations (3) and (4). This methodology enables the use of more interevent times than are usually available in studies using only the recurrence times of characteristic events, since in each seismogenic source not only the main fault but also other secondary faults, where smaller earthquakes occur, are cnsidered. This is expressed by the term "bM_{min} " in relation (3) and (4). Although there are some uncertainities involved in the methodology followed in the present study, our results indicate that the time and magnitude predictable model can probably play an increasingly important role in earthquake prediction. The reliability of the method depends upon the availability of a good amount of reliable seismicity data. The ambiguity in assessment of forthcoming earthquakes increases for seismogenic sources showing very long repeat times.

The opinion that only a precise short-term prediction and estimate of seismic hazard are practically useful that sometimes emerges in the seismological literature can lead to costly mistakes. The earthquake forecasts described above have a limited accuracy. Nevertheless they are useful in earthquake hazard assessment and loss prevention in seismically active regions.

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REFERENCES

1. Anagnos T, Kiremidjian A.S "Stochastic time predictable model for earthquake occurrences". Bull. Seismol. Soc. Am. 1984; 74: 2593-2611.
2. Bufe CG, Harsh PW Buford RO. "Steady-state seismic slip-a precise recurrence model". Geophys. Res. Lett. (1977); 4: 91-94.
3. Cornell CA. "Engineering seismic risk analysis". Bull. Seismol. Soc. Am. 1968; 58: 1583 - 1606.
4. Fedotov SA. 'Regularities of the distribution of strong earthquakes in Kamchatka, the Kurile Islands and northeastern Japan". Tr. Inst. Fiz. Zemli, Akad, Nauk SSSR, 1965; 36: 66-93.
5. Gardner JK Knopoff L. "Is the sequence of earthquakes in the southern California with aftershocks removed Poissonian?" Bull. Seismol. Soc. Am. 1974; 64: 1363-1368.
6. Imamura A. "On the seismic activity of central Japan". Jpn. J. Astron. Geophys. 1928; 6: 119-137.
7. Karakaisis GF. "Long term earthquake prediction in New Guinea-Bismark sea region based on the time and magnitude predictable model". J. Phys. Earth. 1993; 41: 365-389.
8. Kelleher JA Sykes LR. Oliver J. "Possible criteria for predicting earthquake locations and their applications to major plate boundaries of the Pacific and Caribbean". J. Geophys. Res. 1973; 78: 2547-2585.
9. Kiremidjian AS Anagnos T. "Stochastic slip predictable model for earthquake occurrences". Bull. Seismol. Soc. Am. 1984; 74: 739-755.
10. Mckenzie DP. its margin". Geophys. J. Int. 1989; 99: 123-153.
11. McNally KC Minster JB. "Non uniform seismic slip rates along the Middle America trench". J.Geophys. Res. 1981; 86: 4949-4959.
12. Molnar P, Lyon-Caen H. "Fault plane solutions of earthquakes and active tectonics of the Tibetan plateau and its margin". Geophys. J. Int. 1989; 99: 123-153.

13. National Earthquake Information Center (NEIC) U.S. Department of the Interior U.S. Geological Survey, USA. Catalogue of earthquakes for the period (1905-1999).
14. Nishenko SP Buland R. "A generic recurrence interval distribution for earthquake forecasting". Bull. Seismol. Soc. Am. 1987; 77: 1382 - 1399.
15. Nishenko SP Singh S K. "Conditional Probabilities for the recurrence of large and great interplate earthquakes along the Mexican subduction zone". Bull. Seismol. Soc. Am. 1987; 77: 2094-2114.
16. Papadopoulos GA Voidomatis P. "Evidence for periodic seismicity in the inner Aegean seismic zone". Pure Appl. Geophys. 1987; 125: 613-628.
17. Papazachos BC. "Seismic hazard and long term earthquake prediction in Greece European School of Earthquake Science, Course on Earthquake Hazard Assessment, Athens, Greece," 9-16, May 1988, 1-10.
18. Papazachos BC "Long term prediction of earthquakes in seismogenic sources of Greece". UN Sem. On prediction of Earthquakes, Lisbon, Portugal, 14-18 Nov. 1988, 1-10.
19. Papazachos BC. "A time predictable model for earthquake generation in Greece". Bull. Seismol. Soc. Am. 1989; 79: 77-84.
20. Papazachos BC. "A time and magnitude predictable model for generation of shallow earthquakes in the Aegean area". Pure Appl. Geophys. 1992; 138: 287-308.
21. Papazachos BC, Papaioannou Ch A. "Long term earthquake prediction in Aegean area based on a time and magnitude predictable model". Pure Appl. Geophys. 1993; 140: 593-612..
22. Papazachos BC, Papadimitriou EE. "Evaluation of the global applicability of the regional time and magnitude-predictable seismicity model". Bull. Seismol. Soc. Am. 1997; 87: 799-808.
23. Rastogi BK. "Earthquake mechanism and plate techtonics in the Himalayan region". Tectonophysics, 1974; 21: 47-56
24. Shimazaki K Nakata T. "Time-predictable recurrence model or large earthquakes". Geophys. Res. Lett. 1980; 7: 279-282.
25. Singh VP, Shanker D, Ram A. " Seismological approach to earthquake prediction in Himalayas". J. Scientific Research 1991; 41(B): 101-110,
26. Singh VP Shanker D, Singh J. "On the validity of time-predictable model for earthquake generation in northeast India". Proc. Indian Acad. Sci. (Earth Planet Sci.), 1992; 101(4): 361-368.
27. Singh VP Shanker D, Hamada K. "A study of seismicity of north-east India and adjoining areas based on statistical analysis". Current sciences 1994; 66(12): 922-926.
28. Shanker D. "Seismogenic source identification and prediction of earthquake hazard in Hindukush-Pamir-Himalayas region". Proceedings of 12th Symposium on Earthquake Engineering held at Indian Institute of Technology Roorkee, India, 2002;1:296-305
29. Shanker D. and Singh, V. P. (1996), "Regional Time- and Magnitude-Predictable Seismicity model for north-east India and vicinity". Acta Geod. Geoph. Hung. Vol. 31(1-2), pp. 181-190.
30. Wallace RE. "Earthquake recurrence intervals on the San Andreas Fault". Geol. Soc. Am. Bull. 1970; 81: 2875-2890.
31. Wang SC McNally KC Geller RJ. "Seismic strain release along the Middle America Trench, Mexico". Geophys. Res. Lett. 1982; 9: 182-185.
32. Wesnousky SG, Jones LM, Scholz C, Deng Q. "Historical seismicity and rates of crustal deformation along the margin of the Ordos Block, North China". Bull. Seismol. Soc. Am. 1984; 74: 1767-1783 "Speculations on the consequences and causes of plate motions". Geophys.J. 1969; 18: 1-32.