Homogenization of Earthquake Catalog in terms of Magnitude using General Orthogonal Regression

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SUMMARY:

In this study, a procedure is given for the preparation of homogenized earthquake catalog in moment magnitude $M_{w,}$ using General Orthogonal Regression (GOR). A GOR relation has been developed between m_b and M_w values for 184 events from ISC and GCMT databases for Indian Himalaya region for the period 1976-2007. In order to obtain M_w estimate using the derived GOR relation for any given m_b value of the catalog, corresponding $m_{b,proxy}$ value can be determined from a linear relation developed for this purpose based on the same dataset of 184 events. The accuracy of the above procedure has been checked with another dataset of 50 events not used earlier. The estimated M_w using prposed procedure are observed to be in good agreement with the given M_w values. The derived GOR relation is useful for homogenization of earthquake catalog for the region.

Keywords: General Orthogonal Regression, Homogenization of Catalog, Magnitude Conversion, Indian Himalaya region

1. INTRUDUCTION

For description of seismicity of a region and for comparison of earthquake activity occurring in different seismic regions, earthquake magnitude is most commonly used as the descriptor. The most widely used magnitude scale is the local magnitude or Richter magnitude defined by Richter (1935). In addition, several other magnitude types including body wave magnitude (m_b), surface wave magnitude (M_s), moment magnitude (M_w) are commonly used in seismic catalogs.

Earthquake catalogs showing the seismicity for the Indian Himalaya region for different time periods are reported in different studies (Bapat et al., 1983; Gupta et al., 1986; Chandra et al., 1992) are heterogeneous in earthquake magnitude estimates. Because of the complexity of the earthquake phenomena and variations in propagation characteristics of seismic waves at different epicentral distances, most magnitude determinations contain measurement errors.

Uncertainties associated with different magnitude types play a vital role during magnitude conversions. Very few studies have been devoted towards quantifying these uncertainties inherent in different magnitude scales and their scaling law (Ameer *et al.,* 2005).

For seismological applications including homogenization of earthquake catalogs, it is essential to know how different magnitude determinations compare with each other and the associated measurement errors. It is widely in use to obtain regression conversions following standard linear least squares approach (Gasperini and Ferrari, 2000; Gasperini 2002; Bindi *et al.*, 2005).This approach is based on the assumption that one of the magnitudes (independent variable) is either error free or the order of its error is very small compared to the dependent variable measurement errors. Further, the errors in the dependent variable are taken to be independent and normally distributed. Many empirical relationships have been developed in the past between various magnitude scales for mapping one type magnitude on to the other (Gutenberg and Richter, 1956; Marshal, 1970; Gibowicz, 1972; Ameer *et al.,* 2005) for different regions in the world.

Applying least-squares linear regression procedure may, however, lead to wrong results due to both the magnitudes having measurement errors. Therefore, it is appropriate to use General Orthogonal Regression (GOR) procedure which takes into account the errors on both the magnitudes (Stromeyer *et al.,* 2004; Thingbaijam *et al.,* 2008; Ristau 2009; Das et al., 2011). But the use of this regression procedure requires the knowledge of the error variance ratio for the two magnitudes, which is generally not known.

The use of such orthogonally regressesed magnitude conversion to a unified moment magnitude leads to a more realistic seismic hazard assessment. In this paper, we discuss the methodology to be adopted for derivation and use of GOR relation. To demonstrate the new procedure, a GOR relation between body wave magnitudes and moment magnitudes has been developed based on a dataset of 184 events from ISC and GCMT databases for Indian Himalaya region bounded by latitude 22^0-37^0 N and longitude 72^0-87^0 E. A linear relation has also been derived for determination of $m_{b,proxy}$ value corresponding to a given m_b value to be used in the GOR relation for getting M_w estimates. Validity of the proposed procedure has been tested on a separate data set of 50 events.

2. PROCEDURE FOR DERIVING GOR RELATION

As explained earlier, GOR relation should preferably be used when both the dependent and independent variables contain errors. The details of GOR are described in the literature (Madansky, 1959; Fuller, 1987; Kendall and Stuart, 1979; Carroll and Ruppert, 1996; Das et al., 2011; Das et al., 2012).In this study, we demonstrate the applicability of GOR for conversion of m_b magnitudes to M_w for preparing a homogenized earthquake catalog. The procedure followed is described below.

a) For deriving the GOR relation, a data set of 184 events (Table 1) with m_b and M_w values has been considered from ISC and GCMT databases for the Himalayan region for the period 1964-2007. A GOR relation has been developed between m_b and M_w and expressed in the form given in Eqn. 1.

b) For each of the observed data pair (m_b ,M_w), the corresponding orthogonally projected point on the GOR line gives predicted M_w as well as the $m_{b,proxy}$ values (as shown in Fig. 1a). In this step M_w values can be estimated only for those events where observed M_w is also available along with m_b. For orthogonally regressed relation, m_b value should not be directly substituted in the right hand side of the GOR relation to obtain the predicted M_w, as is done in the case of least-squares linear regression.

c) The step b) above is not applicable for those events where only m_b is known but M_w value is unknown. In such cases, determination of $m_{b,proxy}$ and consequently predicted M_w requires the development of a linear relation between the observed m_b and $m_{b,proxy}$ values (Eqn. 2) using the data pairs explained in step a) above. This linear relation can be used to determine the $m_{b,proxy}$ value corresponding to any given $m_{b,obs}$ value. The predicted M_w value is then obtained by directly substituting the $m_{b,proxy}$ value into the GOR relation. The above procedure can also be used in the case of conversion of other magnitude types into moment magnitude

3. REGRESSION RELATIONSHIPS

A GOR relation for conversion of body wave magnitudes to moment magnitudes has been developed for Indian Himalaya region. In order to validate the results of the developed relationship, the data set has been subdivided into two sets with 184 events in the first set and remaining 50 events (Table 2) in the second set. While the first set has been used to develop GOR relation, the second set has been used to test and validate the proposed procedure developed for using GOR for homogenization of earthquake catalogue.

The GOR relation has been developed by taking the error ratio (η) equal to 0.2 (Das et al., 2011) as follows (see Fig. 1a):

$$M_w = 1.63(\pm 0.0101)m_{b,\,proxy} - 3.194(\pm 0.281) \qquad (1)$$

$$R^2 = 0.836, \sigma = 0.03$$

The use of $m_{b,proxy}$ instead of m_b in this relation is dictated by the criterion of minimization of perpendicular residuals. For example, the event No. 123 in Table 1 (i.e., November 18th , 2001 , event) has m_b as 5.9 and M_w as 5.6. This point on projection on the GOR line shows M_w as 5.8 but for the $m_{b,proxy}$ equal to 5.6 and not 5.9.

In order to obtain the M_w value estimated by the GOR relation for any observed value of m_b of the catalog, the corresponding $m_{b,proxy}$ value is required to be determined which can be directly substituted in the r.h.s of the derived GOR relation (Eqn.1). In this regard, a linear relation is obtained using the same 184 pairs of m_b and $m_{b,proxy}$ values (see Fig. 1b) which is as follows.

$$m_{b,\,proxy} = 0.724(\pm 0.03)m_{b,\,obs} + 1.455\ (\pm 0.16) \qquad (2)$$

$$R^2 = 0.8, \sigma = 0.14.$$

On substituting the $m_{b,proxy}$ value given by Eqn. 2 in to the GOR relation (Eqn. 1), the M_w estimate corresponding to the observed m_b value is obtained. Using this procedure, predicted M_w values for all the observed m_b values contained in a catalog are obtained.

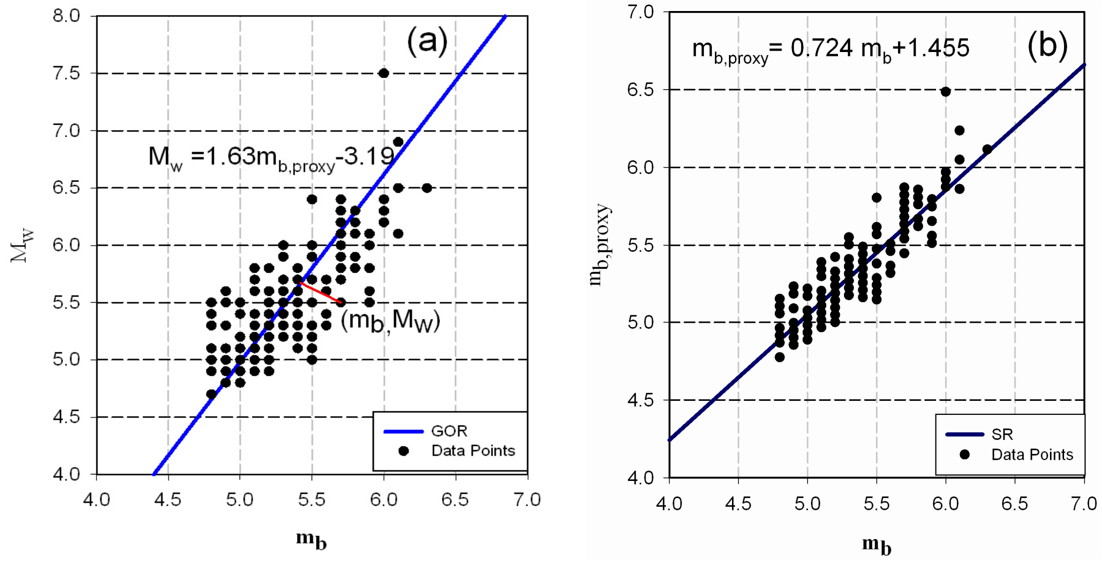

Figure 1. a) GOR relation for m_b and M_w showing the observed point (m_b ,M_w) and the corresponding point ($m_{b,proxy}$, M_w) on the GOR line, b) Linear regression relation between m_b and $m_{b,proxy}$.

An attempt has been made to validate the results of the proposed procedure of estimating M_w values from GOR and a linear relation between $m_{b,proxy}$ and m_b using a test sample (not used in deriving the GOR relation) of 50 observed data events. The M_w estimated using the above methodology and the M_w reported for the 50 events are observed to be in good agreement (Table 2). The procedure developed in this study can be used for conversion of different magnitude types with measurement errors to a unified moment magnitude to obtain a homogenized catalog. The new methodology has also been applied for Northeast India region in a separate study by Das et.al. (2012).

Table 1. Data for 184 events with observed m_b and M_w along with the estimated $m_{b,proxy}$ and M_w values from the GOR line for Indian Himalaya region.

Event No	Date	Time	Lat (^0N)	Long (^0E)	m_b	M_w	Point on GOR line corresponding to (m_b, M_w)	
							$m_{b,proxy}$	M_w
1.	19770219	061525.1	31.7968	78.4317	5.4	5.1	5.160809	5.246257
2.	19771013	113209.1	23.4697	93.3329	5.2	5.4	5.2399	5.375602
3.	19771118	052010.3	32.6483	88.3892	5.7	6.4	5.821034	6.32599
4.	19780404	004029.2	32.9825	82.2552	5.5	5.9	5.544075	5.87305
5.	19780731	115540	35.4742	82.001	5	5.5	5.229977	5.359375
6.	19790520	225911.6	29.9322	80.2699	5.7	5.8	5.553997	5.889277
7.	19790619	162908.4	26.7422	87.4817	5.2	5	5.061874	5.08446
8.	19800222	030244.8	30.5515	88.6459	5.7	6.3	5.776529	6.253205
9.	19800306	210018.2	36.1227	91.9518	5	5.4	5.185472	5.28659
10.	19800622	143853.2	30.1326	81.765	5.1	5.1	5.079166	5.112739
11.	19800624	073544.7	32.9957	88.548	5.1	5.7	5.346204	5.549453
12.	19800712	203934.6	36.8832	93.7694	5.4	5.2	5.205316	5.319044
13.	19800729	122307.7	29.3389	81.2137	5.7	5.5	5.420478	5.67092
14.	19800729	145841.6	29.6285	81.0913	6.1	6.5	5.974399	6.576802
15.	19800823	213649	32.9637	75.7509	5.2	5.5	5.284406	5.448388
16.	19800823	215001.2	32.9023	75.7974	5.2	5.5	5.284406	5.448388
17.	19801007	09328.7	35.6154	82.1365	5.4	5.8	5.472354	5.755758
18.	19801119	190044.6	27.4015	88.7972	6	6.2	5.813665	6.313939
19.	19801120	181411.4	22.7363	93.9228	5.2	5.2	5.150887	5.230031
20.	19810209	231307.5	36.3052	87.0669	5.1	5.3	5.168179	5.25831
21.	19810609	220818.6	34.5138	91.4238	5.3	6	5.534152	5.856822
22.	19810630	215549.8	22.5004	95.189	5.1	4.9	4.990154	4.967168
23.	19810912	071553.8	35.6789	73.5983	6.1	6.1	5.796373	6.285659
24.	19820122	042955.9	30.8911	89.8667	5.3	5.5	5.311621	5.492895
25.	19820123	173729.2	31.6752	82.2837	6	6.3	5.858171	6.386724
26.	19820222	175957.2	35.5531	73.7956	5.4	5.2	5.205316	5.319044
27.	19821031	184052.8	35.9011	82.4341	5.2	5.4	5.2399	5.375602
28.	19830227	203307	32.6021	78.5677	5.3	5.2	5.178101	5.274537
29.	19830531	210540.5	34.5928	79.6649	5	5	5.007446	4.995447
30.	19830830	103927.2	25.0393	94.6695	5.7	5.7	5.50949	5.816491
31.	19831105	194824.6	33.9196	89.9452	5.1	5.6	5.301698	5.476666
32.	19840305	212642.6	24.516	94.6204	5.2	5.4	5.2399	5.375602
33.	19840506	151911.3	24.2152	93.5256	5.7	6	5.64301	6.034848
34.	19841230	233335	24.6573	92.8468	5.5	6	5.588581	5.945836
35.	19850421	132127.5	35.5595	87.2793	4.9	5.6	5.24727	5.387655
36.	19850520	151138.9	35.5622	87.2036	5.2	5.8	5.417925	5.666745

37.	19850615	151740.3	34.6342	82.9942	5.4	5.3	5.249823	5.39183
38.	19850801	121345.4	29.1522	95.1634	5.4	5.7	5.427847	5.682972
39.	19850811	160601.6	36.1453	95.6432	5.3	5.3	5.222608	5.347323
40.	19860110	034630.9	28.6525	86.5632	5.5	5.1	5.188024	5.290765
41.	19860208	002853.5	23.8665	93.0026	5.2	5.4	5.2399	5.375602
42.	19860219	173423.2	25.1044	91.1302	5.2	5.3	5.195394	5.302817
43.	19860426	073516.2	32.1529	76.4048	5.5	5.5	5.366049	5.581906
44.	19860620	171247.2	31.2157	86.8241	5.9	6	5.697438	6.123861
45.	19860706	192423.1	34.4458	80.197	5.7	5.9	5.598503	5.962062
46.	19860716	220306.5	31.0514	78.0019	5.6	5.4	5.348757	5.553628
47.	19860719	201253	31.182	86.8597	5.1	5.1	5.079166	5.112739
48.	19860726	202449.6	23.7149	94.1938	5.2	5.4	5.2399	5.375602
49.	19860820	212353.9	34.5649	91.6422	5.5	6.4	5.766607	6.236979
50.	19870518	015351.3	25.2287	94.2076	5.7	6.2	5.732022	6.180419
51.	19870925	231629.2	29.8407	90.3668	5.1	5	5.03466	5.039954
52.	19880125	011222.2	30.1572	94.8741	5.4	5.2	5.205316	5.319044
53.	19880206	145045.4	24.6677	91.5619	5.8	5.8	5.581211	5.933783
54.	19881029	091052.7	27.8657	85.6375	5.5	5.2	5.23253	5.36355
55.	19881105	021430.1	34.3515	91.8463	5.8	6.2	5.759236	6.224926
56.	19881125	222940.1	34.3237	91.9207	5.2	5.5	5.284406	5.448388
57.	19890203	17500.2	30.187	89.9442	5.4	5.4	5.294329	5.464615
58.	19890403	193931.5	25.1516	94.6641	5.3	5.6	5.356127	5.56568
59.	19890409	023136.3	29.1128	90.0223	5.1	5.1	5.079166	5.112739
60.	19890413	072533.4	24.4041	92.4312	5	5.4	5.185472	5.28659
61.	19890513	231939.7	35.2677	91.5753	4.9	5.3	5.11375	5.169298
62.	19900305	204706.6	36.8989	73.0236	5.7	6.1	5.687516	6.107634
63.	19900306	180708.4	36.9206	73.0749	5	5.4	5.185472	5.28659
64.	19900306	213953.7	36.8825	73.0984	5.2	5.1	5.106381	5.157246
65.	19900602	003235.8	32.4452	92.8108	5.5	5.2	5.23253	5.36355
66.	19910105	145711.2	23.5455	95.9627	6.1	6.9	6.152424	6.867944
67.	19910511	021522.2	24.258	93.6762	5	5.4	5.185472	5.28659
68.	19911204	032723.5	23.9714	93.9102	4.9	5.5	5.202763	5.314869
69.	19911220	020605.2	24.6903	93.1177	5.3	5.3	5.222608	5.347323
70.	19920405	074748	35.7664	80.6758	5.5	5.7	5.455061	5.727478
71.	19920615	024856.1	24.0044	95.9676	5.8	6.3	5.803742	6.29771
72.	19920627	132120.8	35.1608	81.1486	4.9	5	4.980231	4.950941
73.	19920730	082449.2	29.5658	90.1799	5.8	6.1	5.71473	6.15214
74.	19921222	164237	34.5481	88.0555	5	5.2	5.096458	5.141018
75.	19930118	124204.5	30.8436	90.378	5.7	5.9	5.598503	5.962062
76.	19930320	145159.7	29.027	87.3284	5.7	6.2	5.732022	6.180419
77.	19930320	212639.7	29.0103	87.3403	4.9	5.1	5.024737	5.023726
78.	19930408	034933.2	35.6903	77.6365	5	5.2	5.096458	5.141018
79.	19930615	231226.2	35.6499	77.7638	4.8	5	4.953017	4.906435
80.	19940629	182233.1	32.555	93.6877	5.8	5.9	5.625718	6.006569

81.	19940630	004829.2	32.5757	93.6493	5	5	5.007446	4.995447
82.	19940723	205758.5	31.0967	86.6009	5	5.4	5.185472	5.28659
83.	19941228	035617.4	35.8381	90.6933	4.9	5.1	5.024737	5.023726
84.	19950217	024424.7	27.6369	92.3959	5.1	5.4	5.212686	5.331096
85.	19960401	080803.1	31.46	73.4642	5.4	5.2	5.205316	5.319044
86.	19960609	232515.7	28.3772	92.2606	5.1	5.2	5.123673	5.185525
87.	19960703	064441.5	30.1058	88.191	5.6	5.6	5.437769	5.699198
88.	19960703	101037.7	30.1876	88.2438	4.9	5	4.980231	4.950941
89.	19960731	80030.7	30.2358	88.2089	5	5.4	5.185472	5.28659
90.	19961119	001216	24.567	92.6825	5.4	5.3	5.249823	5.39183
91.	19970105	084724.5	29.8741	80.5646	5.4	5.5	5.338835	5.537401
92.	19970209	112815.2	35.7154	95.9067	4.8	5.5	5.175549	5.270363
93.	19970508	025314.5	24.8899	92.2768	5.5	5.9	5.544075	5.87305
94.	19970521	225128.1	23.0911	80.0818	5.8	5.8	5.581211	5.933783
95.	19970731	155937	23.9099	93.2207	5.3	5.2	5.178101	5.274537
96.	19971103	022948.1	29.0362	85.3917	5.4	5.5	5.338835	5.537401
97.	19971108	100253.4	35.1163	87.3741	6	7.5	6.392248	7.260152
98.	19971109	002451.2	33.7129	88.3437	5.1	5.3	5.168179	5.25831
99.	19971121	112303.5	22.2195	92.6839	5.9	6.1	5.741944	6.196646
100.	19980720	010601.2	30.175	88.2454	5.3	5.7	5.400633	5.638466
101.	19980721	144047.9	30.3022	88.2085	4.8	5	4.953017	4.906435
102.	19980825	074143.1	30.2724	88.1617	5.1	5.8	5.39071	5.622238
103.	19980828	220155.1	30.2876	88.2246	4.8	5	4.953017	4.906435
104.	19980926	182701.3	27.7646	92.8068	5.5	5	5.143517	5.217978
105.	19980930	022955.5	30.014	88.1178	4.9	5.1	5.024737	5.023726
106.	19990222	113744.9	23.264	93.642	5.1	5	5.03466	5.039954
107.	19990328	190512.3	30.511	79.421	6.3	6.5	6.028827	6.665813
108.	19990405	223252.6	24.935	93.716	5.3	5.5	5.311621	5.492895
109.	19990509	213805.3	36.833	73.234	4.8	5.3	5.086536	5.124792
110.	19990529	201040.6	32.876	93.745	5.2	5.3	5.195394	5.302817
111.	19991005	170445	26.293	91.982	5.2	5.2	5.150887	5.230031
112.	20000105	094513.8	32.202	92.681	5.2	5.4	5.2399	5.375602
113.	20000126	213757.5	30.893	95.487	4.9	5.1	5.024737	5.023726
114.	20000415	093229.2	32.885	95.442	5.1	5.2	5.123673	5.185525
115.	20000619	224147.7	35.186	77.464	5.1	5.4	5.212686	5.331096
116.	20000710	042513.7	32.795	92.228	5.5	5.3	5.277037	5.436336
117.	20001126	020149.2	35.875	90.561	5.1	5.3	5.168179	5.25831
118.	20010303	225556.8	23.901	93.678	5.3	5.2	5.178101	5.274537
119.	20010305	155007.6	34.258	86.86	5.3	5.9	5.489646	5.784037
120.	20010716	160718.1	32.845	73.13	5	5.1	5.051952	5.068233
121.	20010725	160250.8	33.086	95.562	5.2	5.5	5.284406	5.448388
122.	20010928	043755.6	33.296	75.832	5.1	4.9	4.990154	4.967168
123.	20011118	215952.7	35.693	93.702	5.9	5.6	5.519413	5.832718
124.	20011119	174523.6	35.761	93.706	5.6	5.3	5.304251	5.480842

125.	20011127	073151.6	29.691	81.716	5.5	5.5	5.366049	5.581906
126.	20011127	085353.8	29.641	81.704	5.3	5.4	5.267114	5.420109
127.	20011201	122519.6	35.641	93.932	4.9	5.1	5.024737	5.023726
128.	20011208	041247.9	35.746	92.906	5.1	5.2	5.123673	5.185525
129.	20020604	143602.6	30.566	81.42	5.4	5.6	5.383341	5.610187
130.	20020629	065443.4	34.009	94.399	5.3	5.6	5.356127	5.56568
131.	20020927	171438.1	33.318	93.528	4.8	5.1	4.997524	4.97922
132.	20021019	072436.8	35.6161	93.0463	5	5.1	5.051952	5.068233
133.	20021026	202847.8	35.0189	95.9845	4.8	5.3	5.086536	5.124792
134.	20021101	220928.2	35.3611	74.718	5.3	5.3	5.222608	5.347323
135.	20021103	073335.4	35.3591	74.636	5.3	5.3	5.222608	5.347323
136.	20021120	213227.4	35.3458	74.5921	5.7	6.3	5.776529	6.253205
137.	20030211	103617	32.5282	93.7393	5	5.1	5.051952	5.068233
138.	20030325	185126.8	27.2558	89.3791	4.8	5.4	5.131042	5.197577
139.	20030520	183433.5	32.6714	93.0532	4.9	5.1	5.024737	5.023726
140.	20030524	112756.9	32.4806	92.3204	4.9	5	4.980231	4.950941
141.	20030529	141851.2	35.7922	80.6579	5	5	5.007446	4.995447
142.	20030707	065543.7	34.5889	89.5034	5.2	5.8	5.417925	5.666745
143.	20030726	231817	22.8929	92.3317	5.4	5.6	5.383341	5.610187
144.	20030727	120729	22.8371	92.3359	5	5.4	5.185472	5.28659
145.	20030818	090302.9	29.5475	95.5627	5.5	5.5	5.366049	5.581906
146.	20040210	053938	32.614	83.2624	4.8	4.9	4.908511	4.833649
147.	20040214	103022.8	34.7465	73.1608	5.4	5.4	5.294329	5.464615
148.	20040214	115659.4	34.7709	73.1659	5.4	5.3	5.249823	5.39183
149.	20040215	232315	36.7218	78.4445	5	4.8	4.918433	4.849876
150.	20040306	115440.9	33.2426	91.9252	5	5	5.007446	4.995447
151.	20040307	132944.6	31.6501	91.2206	5.2	5.6	5.328912	5.521173
152.	20040327	184527.7	33.9433	89.2131	5.3	6	5.534152	5.856822
153.	20040327	200554.2	33.9501	89.2938	5	5	5.007446	4.995447
154.	20040328	222729.2	33.9596	89.2262	5	5.1	5.051952	5.068233
155.	20040328	220544.1	34.0702	89.2451	5.1	5.2	5.123673	5.185525
156.	20050215	111505.8	24.5336	92.376	5.1	5	5.03466	5.039954
157.	20050215	130548.2	24.4056	94.4474	5.1	5.2	5.123673	5.185525
158.	20050323	055906.4	26.0632	95.1798	4.9	4.9	4.935725	4.878154
159.	20050325	133437.9	25.4596	94.7682	5.2	5.2	5.150887	5.230031
160.	20050326	203209.7	28.1938	87.8612	4.8	4.7	4.819498	4.688077
161.	20050407	200440.2	30.5171	83.6553	5.8	6.3	5.803742	6.29771
162.	20050407	214134.6	30.5063	83.7167	4.8	5.4	5.131042	5.197577
163.	20050408	195133.9	30.366	83.6542	4.8	5	4.953017	4.906435
164.	20050601	200639.6	28.8245	94.5849	5.9	5.8	5.608426	5.97829
165.	20050820	125048.7	31.2773	88.0857	5	4.9	4.962939	4.922661
166.	20050825	210811.1	36.869	79.1376	5.4	5.4	5.294329	5.464615
167.	20051007	212550.3	34.7161	92.8545	4.9	4.8	4.891219	4.805369
168.	20051008	104627.9	34.7198	73.1436	6	6.4	5.902678	6.459511

169.	20051008	211330.8	34.7337	73.2265	5.9	5.5	5.474906	5.759932
170.	20051008	220425.6	34.63	73.2454	5	4.9	4.962939	4.922661
171.	20051009	045854.5	34.7252	73.0815	5	5	5.007446	4.995447
172.	20051009	070918	34.6052	73.1592	5.3	5.3	5.222608	5.347323
173.	20051009	08300.5	34.7352	73.215	5.6	5.7	5.482276	5.771984
174.	20051009	092234.7	34.5763	73.4403	4.9	4.9	4.935725	4.878154
175.	20051009	112143.9	34.7041	73.163	4.9	5	4.935725	4.878154
176.	20051009	123813	34.8103	73.1474	4.9	4.9	4.980231	4.950941
177.	20051009	194659.4	34.6847	73.0249	4.9	4.9	4.935725	4.878154
178.	20051009	192035.8	34.3513	73.6948	5.5	5.3	5.277037	5.436336
179.	20051010	123813.9	34.7935	73.0961	4.9	4.9	4.935725	4.878154
180.	20051012	202336.7	34.8636	73.1541	5.5	5.3	5.277037	5.436336
181.	20051013	204923.7	34.7414	73.1734	5.2	4.9	5.017368	5.011674
182.	20051014	193740.7	34.8765	73.1958	5	4.8	4.918433	4.849876
183.	20051017	104308.3	34.8048	73.1641	5	4.9	4.962939	4.922661
184.	20051019	124728.1	34.7755	73.1089	4.9	5.1	5.024737	5.023726

Table 2. Comparison of estimated M_w values obtained using GOR relation corresponding with the values obtained through orthogonal projection of (m_b , $M_{w,}$) on the GOR line.

Event No							Projection of observed point on GOR line	M_w (using col. 5 & Eqns. (1) and (2)) (8)	Diff (8)-(7) (9)
	Date (1)	Time (2)	Lat (^{0}N) (3)	Long (^{0}E) (4)	m_b (5)	M_w (6)	M_w (7)		
1	20051019	023328.3	34.8	73.1	5.6	5.6	5.683005	5.8	0.12
2	20051019	031621.5	34.8	73.0	5.4	5.4	5.475295	5.6	0.12
3	20051023	150420.4	34.9	73.0	5.7	5.4	5.62481	5.9	0.28
4	20051023	192826.3	34.9	73.1	4.9	4.8	4.902005	5	0.10
5	20051024	131417.4	34.8	73.2	4.9	4.8	4.902005	5	0.10
6	20051026	014240.3	34.2	73.9	4.8	4.8	4.852167	4.9	0.05
7	20051028	213415.2	34.7	73.2	5.3	5.2	5.317424	5.5	0.18
8	20051029	165252.5	33.8	88.9	4.6	4.8	4.75249	4.7	-0.05
9	20051031	055114	29.7	81.8	4.8	4.7	4.79815	4.9	0.10
10	20051031	214754.5	28.5	84.9	5	4.7	4.897827	5.1	0.20
11	20051106	020953.7	34.9	73.1	4	5.1	4.615508	4	-0.62
12	20051120	053501.9	34.7	73.2	4.9	4.8	4.902005	5	0.10
13	20051121	082613.7	34.8	73.1	5.2	5.2	5.267585	5.4	0.13
14	20051201	153826.3	34.8	73.1	5	4.7	4.897827	5.1	0.20
15	20051214	070951.8	30.5	79.3	5.2	5.1	5.21357	5.4	0.19
16	20051225	080205	34.6	73.3	5.2	5.2	5.267585	5.4	0.13
17	20051228	220429.9	34.7	73.4	5	5.1	5.113892	5.1	-0.01

18	20060118	002348.8	34.5	87.8	4.7	4.9	4.856344	4.8	-0.06
19	20060201	222411	30.3	80.4	4.7	4.7	4.748312	4.8	0.05
20	20060202	21491.8	34.7	73.2	4.9	4.9	4.956021	5	0.04
21	20060203	015748.2	27.3	86.4	4.8	4.7	4.79815	4.9	0.10
22	20060208	125728.3	34.9	73.3	4.8	4.8	4.852167	4.9	0.05
23	20060214	005524.8	27.4	88.4	5.3	5.3	5.37144	5.5	0.13
24	20060215	01554.1	33.7	81.3	4.8	4.8	4.852167	4.9	0.05
25	20060221	151021.9	31.7	95.0	4.7	4.9	4.856344	4.8	-0.06
26	20060223	200454.5	27.0	91.7	5.4	5.4	5.475295	5.6	0.12
27	20060226	021350.9	35.2	89.6	5	5.4	5.275942	5.1	-0.18
28	20060301	093641.6	35.4	89.6	4.9	5.1	5.064054	5	-0.06
29	20060310	075015.2	33.1	73.8	4.9	4.9	4.956021	5	0.04
30	20060319	024855	34.7	73.2	4.5	4.9	4.756668	4.6	-0.16
31	20060320	174046	34.8	73.8	5.4	5.2	5.367262	5.6	0.23
32	20060325	201331.5	23.2	93.8	5	5.1	5.113892	5.1	-0.01
33	20060329	233856.1	35.3	95.7	4.9	5.3	5.172087	5	-0.17
34	20060404	091224.8	34.7	73.1	4.7	4.6	4.694295	4.8	0.11
35	20060414	092740.6	35.3	89.7	5.4	5.6	5.583328	5.6	0.02
36	20060419	210540.8	31.6	90.4	5.1	5.7	5.487829	5.2	-0.29
37	20060511	172254.8	23.4	94.3	5.7	5.6	5.732843	5.9	0.17
38	20060812	204611.7	24.7	92.7	4.8	5	4.960199	4.9	-0.06
39	20060901	200807.9	35.4	89.9	4.5	4.8	4.702651	4.6	-0.10
40	20060911	181223.1	35.6	78.2	5.5	5.5	5.57915	5.7	0.12
41	20061103	144310.3	22.1	93.3	4.8	5	4.960199	4.9	-0.06
42	20061110	132124.7	24.5	92.3	4.8	4.9	4.906183	4.9	-0.01
43	20070211	043918.2	36.7	73.0	4.8	5.1	5.014215	4.9	-0.11
44	20070225	014941.5	33.2	90.6	5	5.4	5.275942	5.1	-0.18
45	20070315	183010.8	35.7	89.4	4.3	5	4.711007	4.3	-0.41
46	20070316	215117.1	35.5	89.4	4.6	5	4.860522	4.7	-0.16
47	20070409	162340.2	35.7	89.4	4.5	4.9	4.756668	4.6	-0.16
48	20070505	085140.2	34.3	82.0	5.7	6.1	6.002925	5.9	-0.10
49	20070505	173823.3	34.7	90.0	4.2	5	4.661168	4.2	-0.46
50	20070520	141815.9	27.3	88.3	4.9	4.9	4.956021	5	0.04

4. DISCUSSION AND CONCLUSIONS

The applicability of General Orthogonal Regression for conversion of body wave magnitudes to M_w for the purpose of a homogenized earthquake catalog has been discussed in this study. In order to derive the GOR relation, a data set of 184 events with m_b and M_w values has been considered from ISC and GCMT databases for Indian Himalaya region for the period 1964-2007. A GOR has been developed as given in Eqn. 1. For each of the observed data point, the corresponding point on the GOR line is to be determined as predicted M_w and the $m_{b,proxy}$ values for the observed pair (m_b ,M_w).Therefore, a linear standard regression relation (Eqn. 2) has been obtained between the observed m_b and $m_{b,proxy}$ values. This linear relation can be used to determine the $m_{b,proxy}$ value corresponding to any given m_b observe value. The corresponding M_w value is then obtained by directly substituting the $m_{b,proxy}$ values into the GOR relation given in Eqn. 1. The GOR procedure developed in this study can be used to homogenize any catalog containing magnitudes (e.g., M_L, m_b, M_S) with measurement errors, by their conversion to moment magnitude.

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