Seismic activity characteristics in the East Sea area

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ABSTRACT

In this paper, seismic activity characteristics in the East Sea area was analyzed by authors on the base of the unified earthquake catalog (1900-2017), including 131505 events with magnitude $3 \leq Mw \leq 8.4$. The seismic intensity in the East Sea during the period 1900 - 2017 is characterized by the earthquake representative level $Mw = 4.7$. The strong earthquake activity in the East Sea area clearly shows the regularity in each stage. In the period from 1900 to 2017, the East Sea area has four periods of strong earthquake activity, each stage is nearly 30 years with particular characteristics. The distribution of the maximum earthquake quantities by years has a cyclicity in all four periods. In each stage there are 1-2 strong earthquakes with $M_{max} \geq 8.0$. The strong earthquakes with $M_{max} \geq 7.5$ have occurred by a repeatable rule of 3-5 years in all four stages. This allows the prediction of the maximum earthquake repeat cycle of $M_{max} \geq 7.5$ in the study area is 3-5 years. In other hand, the maximum magnitude values for the East Sea region has assessed by GEV method with several different predict periods (20, 40, 60, 80, 100 years), with predicted probability 80%. We concluded that it is possible that earthquake have $M_{max} = 8.7$ will occur in next 100 years.

Keywords: Seismic activity; macximum earthquake magnitude; earthquake catalog, the East Sea; Generalized Extreme Value distribution - GEV.

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1. Introduction

Earthquake is one of the most serious disasters in Asia. Study of earthquake and seismotectonics in the mainland is interested recently by many workers (Duan et al, 2013). However, the study of the earthquake in the sea is limited due to lack of data and methodology. Based on the relation between the seismotectonics and geodynamic, the East Sea is a part of Southeast Asia. Southeast Asia is located at the boundary between the two major seismic activity belts associated with the two-main tectonic-destroying belts: the Pacific Earthquakes belt and the Mediterranean-Hymalaya belt. Consequently, South East Asia generally and the East Sea region particularly are influenced by the tectonic activities of these belts. The East Sea area is the transition zone between the Philippine Sea Plate in the east, the Eurasian Plate in the west, and the Australian Plate in the southeast. These plates move with different velocities. The Philippine sea plate moves from east to west

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at the rate of 50 mm/yr (Yingchun Liu et al., 2007) or 55.6 mm/yr (Le Huy Minh et al., 2014). The Eurasian plate move north-west nearly 10 mm/yr (Bautista et al., 2001, Yingchun Liu et al., 2007, Le Huy Minh et al., 2014). And the Australian migration in the north-east direction moves at the speed of 6-7 cm/yr (Phan Trong Trinh et al., 2011). These movements make the East Sea in danger of earthquakes and tsunamis. Therefore, the study about the characteristics of earthquake activities and assessing the maximum earthquake magnitude for this area are significantly important; it plays a critical role in forecasting earthquakes and tsunamis in the East Sea. There are various studies about these topics. We can mention to the earthquake zonation studies, recent basalts and features of the East Sea tsunami (Pham Van Thuc, 2001) or Pham Van Thuc and Nguyen Thi Kim Thanh (Pham Van Thuc and Nguyen Thi Kim Thanh, 2004). In the research in 2004, Pham Van Thuc and Nguyen Thi Kim Thanh built a zoning evaluation map with scale 1: 1 000 000 for the East Sea and coastal. It is said to be the first project which divides the East Sea into different tectonic-dynamic regions. The authors divided the study area which contains the earthquakes catalog collected from 1524 to 2002 into nine sub-regions with corresponding M_{max} values. In this paper, the strongest earthquake zone is the North East Coast of the East Sea with $M_{max} = 7.5$ and the weakest one is the western part of the East Sea with $M_{max} = 3$ (Pham Van Thuc and Nguyen Thi Kim Thanh, 2004).

Moreover, the tectonic stress field in the East Sea was studied by Nguyen Van Luong, 2002, Nguyen Van Luong et al., 2003, 2008 (a, b). It shows the suitability of geodynamic mechanisms on seismic fault systems. Specifically, there are the oblique reverses on the Manila subduction zone. Meanwhile, on the fault systems North East North and East Sea East, the most popular type of focal mechanism is strike-slip. In other works, the authors have concentrated on the assessment of earthquake risk like Pham Van Thuc et al., 2004; Nguyen Van Luong et al., 2003; Nguyen

Hong Phuong, 2001; Nguyen Hong Phuong et al., 2012, 2015.

There are more studies about the causes of earthquake-tsunami after the Sumatra tsunami in December 2004, (Bui Cong Que et al., 2010; Cao Dinh Trieu et al., 2008; Phan Trong Trinh, 2006; Phan Trong Trinh et al., 2010; Nguyen Dinh Xuyen et al., 2007; Cao Dinh Trieu et al., 2009; Vu Thanh Ca et al., 2008).

Vietnam and East Sea earthquake risk map was established in 2004 by Nguyen Hong Phuong (Nguyen Hong Phuong, 2004). In this study, the author used the software to filter the foreshocks and aftershocks, and adjusted the boundaries of the source regions according to the seismic data in the period of 114-2002. In the following years, Nguyen Hong Phuong and his co-authors have continued to study about the seismic source of this area. In these studies, the data included historical seismic data and machine seismic data. Tsunami source zones in the East Sea have been identified, within the Northern Manila Trench is the highest seismic risk with $M_{max} = 8.7 \pm 0.93$ for 2658 years (Nguyen Hong Phuong et al., 2012, 2015). This result is the same with result of another Chinese author using earthquake data from NEIC in the period 1900-2013 and Global CMT's catalog in the period 1963-2013 with M> 5.0 (Zhiguo Xu, 2015). Meanwhile, a group of authors from the Nanyang Technological University in Singapore shown that the tsunami earthquake in this area could reach 9.0 (Megawati al., 2009). It is noticeable that these studies didn't show a specified duration for predicting M_{max}. The methodology of the Generalized Extreme Value Distribution (GEV) can solve this problem. This probabilistic method has been developed by Pisarenko and his colleagues to evaluate the maximum earthquake magnitude for many catalogs such as the Harvard earthquake list (Pisarenko et al., 2008, 2014), the Japanese earthquake catalog (Pisarenko et al., 2010),…

Thus, in general, it has been shown that the East Sea area has the potentially high seismic

risk. However, historical earthquake data and machine data were used and the magnitudes have not been unified. In addition, predicting M_{max} does not have a specified duration. In this paper, the characteristics of earthquake activity in the East Sea area will be studied on the basis of the unified earthquake catalog for the period 1900-2017, and M_{max} will be estimated by GEV method.

2. Data and Methodology

2.1. Data

The study area is limited by the coordinates $\varphi = 5°S \div 30°N$; $\lambda = 100° \div 127°E$. However, some foreshocks and aftershocks in the East Sea region can belong to main shocks which are not in this region. Therefore, to ensure the independence of events in the study area, it needs to extend the area for collecting seismic data. The area extended is limited by the coordinates $\varphi = 11.2°S-35.5°N$; $\lambda = 92.5°E-132°E$.

Earthquake data were collected and adjusted from various sources: International Seismological Center (ISC), U.S. Geological Survey (USGS), Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES). The earthquake catalog of the East Sea and neighboring for the period 1900-2017 has 316516 earthquakes with magnitude $M \geq 3.0$. It should be noted that there is some kind of magnitude scales: local magnitude (M_L), surface-wave magnitude (M_S), body-wave magnitude (m_b), moment magnitude (M_w). Therefore, it is necessary to unify magnitude scale. On the other hand, M_L, M_S, m_b have saturated value which is almost the same value of strong earthquakes. In addition, the moment magnitude is used the most common to estimate the seismic hazard and warn tsunami. Therefore, in this paper, the M_w is only scale used. The others will be converted to M_w by practical functions.

In the extensive region, period 1900 - 2017, we collected 377784 events with Mw in the range from 3 to 9.1. The spacetime window method which proposed in (Ngo and Tran, 2013) was used to separate the groups of foreshocks and aftershock from the above-mentioned earthquake. The independence catalog of the East Sea region and neighboring area includes 202544 events with magnitude Mw ($3 \leq Mw \leq 9.1$) in which has 131505 events with magnitude $3 \leq Mw \leq 8.4$ belong to the East Sea region. This is a list of earthquakes that will be used in the calculations below.

2.2. Methodology

The distribution function generalized extreme value is defined as follows (Pisarenko, 2007, 2008, 2010):

$$GEV(x \mid \sigma, \mu, \zeta) = \begin{cases} \exp(-[1 + \frac{\zeta}{\sigma} \cdot (x - \mu)]^{-\frac{1}{\zeta}}, \zeta < 0; \sigma > 0; x \leq \mu - \sigma/\zeta, \zeta \neq 0 \\ \exp\left(-\exp\left[-\frac{x - \mu}{\sigma}\right]\right), \qquad \zeta = 0 \end{cases} \quad (1)$$

Where x is variable representing the magnitude earthquake value, σ is the scale parameter, μ is the location parameter, ζ is the form parameter.

To determine the GEV function, we need to identify 3 parameters ζ, σ, μ in formula (1). These parameters ζ, σ, μ are determined in each period T, solving by the equations below:

$$\frac{1}{n}\sum_{k=1}^{n} x_k = \mu - \frac{\sigma}{\zeta} + \frac{\sigma}{\zeta}\Gamma(1 - \zeta) = M1 \quad (2)$$

$$\frac{1}{n}\sum_{k=1}^{n}(x_k - M1)^2 = (\frac{\sigma}{\zeta})^2[\Gamma(1 - 2\zeta) - (\Gamma(1 - \zeta))^2] = M2 \quad (3)$$

$$\frac{1}{n}\sum_{k=1}^{n}(x_k - M1)^3 = (\sigma)^3\left[-2(\Gamma(-\zeta))^3 - \frac{6}{\zeta}\Gamma(-\zeta)\Gamma(-2\zeta) - \frac{3}{\zeta^2}\Gamma(-3\zeta)\right] = M3 \quad (4)$$

With Γ (x) is the Gamma function: Γ (t) = $\int_0^\infty x^{t-1} e^{-x} dx$, n is the number of earthquakes in each T-intervals, x_k is magnitude of kth earthquake.

It is important to determine T-intervals fit with each catalog because T-intervals influence the values of the three parameters ζ, σ, μ of the GEV function. To find T-intervals, we determine the density Poisson distribution (λ) of the magnitude values:

$\lambda = \dfrac{N}{t'}$, where N is the number of independent earthquakes, t is the time between the first event and the last event.

The T- intervals value (days) must satisfy three conditions:

(a) All T-intervals is non-empty.

(b) Value $1 / \lambda T \to 0$ (with λ is the frequency earthquakes with magnitude $M \geq m$).

(c) Value of parameter ζ is enough stable to determine the GEV function.

Choose an interval of values (T_L; T_H) for time interval durations T, for which the catalog still contains a sufficient number of T-intervals;

Choose in this interval (T_L;T_H) a finite set of u time-interval durations $T(T_L \leq T_1 < T_2 <\ldots< T_u \leq T_H)$;

The GEV parameters are estimated by the equations (2-4) for each of the u time - interval durations T, which yields the following set of parameters:

$\zeta(T_1)$, $\zeta(T_2)$,..., $\zeta(T_u)$;
$\sigma(T_1)$, $\sigma(T_2)$, ...,$\sigma(T_u)$;
$\mu(T_1)$, $\mu(T_2)$,..., $\mu(T_u)$;

To estimate the average values $\overline{\zeta}$, $\overline{\sigma}$,$\overline{\mu}$ of the GEV parameters ζ, σ, μ

The τ is the predict period (from the time of the earthquake event was chosen as supporting event). The parameters ζ, σ, μ are represented as the functions of τ by the formulas (5-7) below:

$$\zeta(\tau) = \zeta(T); \tag{5}$$
$$\sigma(\tau) = \sigma(T) \cdot (\tau/T)^{\xi}; \tag{6}$$
$$\mu(\tau) = \mu(T) + (\sigma(T) /\xi) \cdot ((\tau/T)^{\xi} - 1); \tag{7}$$

The quantile in this period is:
$$Q_q(\tau) = h + (s/\xi) \cdot (a \cdot (\lambda\tau)^{\xi} - 1) \tag{8}$$
Inside:
$a = (\log(1/q))^{-\xi}$,
$h = \mu + (\sigma/\xi) \cdot ((\lambda T)^{-\xi} -1$;
$s = \sigma \cdot (\lambda T)^{-\xi}$.

When $\tau \to \infty$ then $Q_q(\tau) = M_{max}(\tau) \to M_{max}$:
$$M_{max}^{predict} = \lim_{\tau \to \infty} Q_q(\tau) \tag{9}$$

Thus, after finding the appropriate T-intervals, in each time period T-intervals the parameters ζ, σ, μ would be determined. From that we will determine the GEV function, decile point value of $Q_q(\tau)$, and assess the value M_{max}.

In order to estimate the Mean Square Error (MSE) of these estimates, we use formulas (Gumbel, 1958):

$$MES_{\zeta} = \left[(1/n) \sum_{j=1}^{n} (\zeta_j - \overline{\zeta})^2 \right]^{1/2}$$

$$MES_{\sigma} = \left[(1/n) \sum_{j=1}^{n} (\sigma_j - \overline{\sigma})^2 \right]^{1/2}$$

$$MES_{\mu} = \left[(1/n) \sum_{j=1}^{n} (\mu_j - \overline{\mu})^2 \right]^{1/2}$$

3. Characteristic of earthquake activity in the East Sea

Based on the earthquake catalog with 131505 independent events, this study focused on the seismic activity in the East Sea.

The Gutenberg - Richter magnitude-frequency relationship.

Base on Table 1, the Gutenberg-Richter relation between the number of earthquakes with magnitudes written for the natural logarithm is:

$$LgN = 8.89 - 0.91M_w \tag{10}$$

With correlation coefficient R = 0.99

Where N is number of earthquakes of magnitude M_w in certain range (Table 1).

Table 1. The number of earthquakes depened on magnitude value

M_w	N	Log(N)	M_w	N	Log(N)
3-3.4	11297	4.05296313	6-6.4	909	2.95856
3.5-3.9	24373	4.38690899	6.5-6,9	327	2.51455
4-4.4	60435	4.78128853	7-7.4	139	2.14301
4.5-4.9	23336	4.36802642	7.5-7.9	61	1.78533
5-5.4	8357	3.9220504	8-8.4	10	1
5.5-5.9	2261	3.35430056			

Table 1 and Figure 1 show that the East Sea has threshold earthquake magnitude M = 4.7.
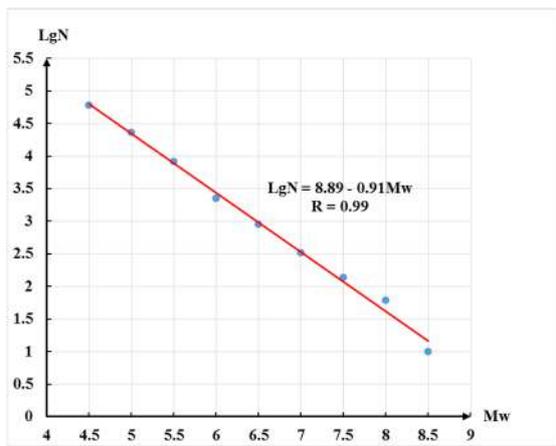

Figure 1. The Gutenberg-Richter frequency-magnitude diagrams (1900 - 2017)

Distribution of earthquake number with the depth

Base on the collected database, we analyze the distribution of earthquake number with the depth. The results are performed in Figure 2 and Table 2.

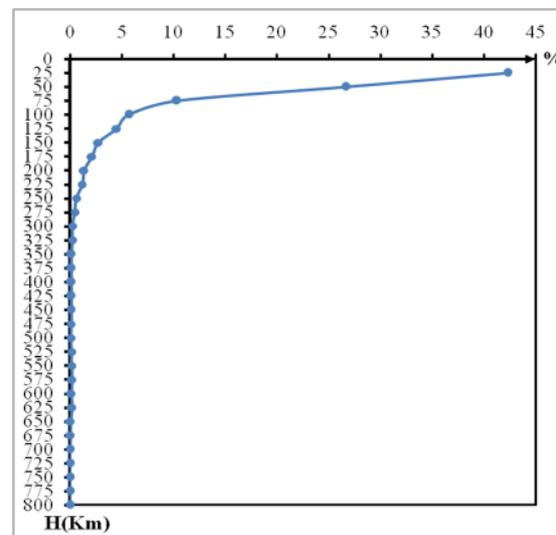**Figure 2.** Distribution of earthquake number depended on depth

Table 2. Distribution of earthquake number with the depth

H(Km)	50	100	150	200	250	300	350	400
N	90650	21055	9512	4574	2358	858	451	296
%	59.1	59.1	13.7	6.2	3	1.5	0.6	0.3
H(Km)	450	500	550	600	650	700	750	800
N	292	242	410	435	322	46	1	3
%	0.2	0.2	0.3	0.3	0.2	0	0	0

Table 2 and Figure 2 show that the majority of earthquakes in the East Sea area occur in the depth of 0-75 km (79.27%) equivalent to the crust of the Earth. This result is nearly similar to the previous study on the Northern Luzon subduction model where the authors used shorter period data 1619-1997 (Bautista et al., 2001). This proves the objectivity and reliability of this work.

Distribution of earthquake epicenters in the period 1900-2017

Based on the earthquake catalog and a regional geodynamic scheme in accordance with the structure, we have established an earthquake epicenter distribution map of the East Sea with Mw ≥ 5.0 (Figure 3). Figure 3 shows that the majority of earthquake epicenters in East Sea region are distributed around Philip-

pine. Noticeably, throughout the study period (1900-2017), there were eight the strongest earthquakes with the magnitude $M_w \geq 8.0$, of which the strongest with M = 8.4 occurred on the 12th September 2007 at coordinates $\varphi = -4.4°N$, $\lambda = 101.4°E$ (Table 3). Most of them located in the eastern and southeastern part of

the study area (Figure 3). These results are quite similar to the results obtained by Zhiguo Xu using earthquake catalog's NEIC from 1900 to 2013, and the earthquake catalog's Global CMT from 1963 to 2013 (Zhiguo Xu, 2015) or by Hsu using the data period 1973-2010 with M_w 4.6-7.7 (Hsu et al., 2012).

Table 3. The strongest earthquakes catalog ($M_w \geq 8.0$) in the East Sea from 1900 to 2017

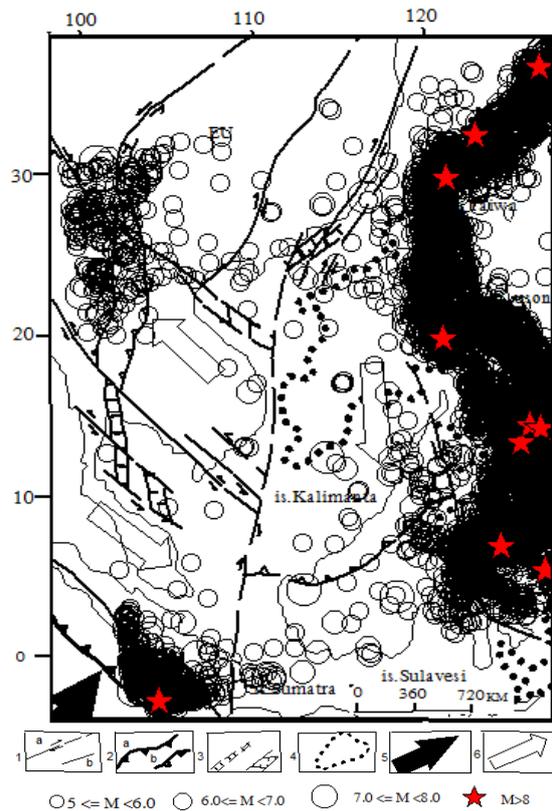| No.	Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Mw
1	1910	4	12	0	22	24	25.9	124	235	8.1
2	1918	8	15	12	18	21	6	124.4	20	8.3
3	1920	6	5	4	21	35	23.7	122	20	8.1
4	1924	4	14	16	20	36	6.7	126	15	8
5	1939	12	21	21	0	31	-0.1	122.5	35	8.1
6	1965	1	24	0	11	17	-2.6	126	20	8.2
7	1972	12	2	0	19	52	6.4	126.6	60	8
8	2007	9	12	11	10	26	-4.4	101.4	34	8.4

Figure 3. Earthquake distribution in East Sea and its adjacent regions 1900-2017 (M≥5.0)

←Note: 1, 2 - major faults, active in Late Cenozoic: 1- transverse (a - determine and assume, b - fault the planet); 2 - Large subsidence zone (a - Benhiop zone, b- Other subsidence zone); 3- Expansion structures: a - Deep coastal trenches, b - Sediment tanks within the continental limits and continental shelf; 4 - Deep-water seabed belt; 5, 6 - Moving vectors: 5 - of the main lithosphere, 6 - of the eastern part of the European - Asian plate. Main arrays are marked by the letters: EU - Europe - Asia, P - Pacific, PH - Philippine Plates. The Roman numerals denote the blocks: I - Tibet - Hymalaya, II - Southeast China, III - Indochina, VI - East Sea, V - Middle East, VI - Kalimantan - Iava

The time - magnitude distribution of the catalog is presented in Table 4 and in Figure 4. It illustrated that before 1964, the number of earthquakes was not recorded much (few dozen times/year). Later in the year of 1964 - 1983, the number of earthquakes raised to hundreds and since 1984 reached thousands; it reached the peak of 8748 earthquakes in 2012. A part of the phenomenon comes from the seismic network that was sparse and the sensitivity of the seismograph which was not high enough to record weak and distant earthquakes. Hence, considering the rule of strong earthquake activity, we need to pay special attention to the earthquake threshold.

Earthquake procedure time line in the East Sea period 1900-2017

With N is the number of earthquakes annually.

The distribution of maximum earthquake magnitude by year

The annual maximum earthquake magnitude is shown in Table 5 and Figure 5.

Table 4. The time - magnitude distribution of the East Sea's catalog ($3 \leq Mw \leq 8.4$) from 1900 to 2017

| Year	N	Year	N	Year	N	Year	N	Year	N
1900	2	1924	9	1948	7	1972	377	1996	4133
1901	3	1925	14	1949	3	1973	405	1997	3715
1902	2	1926	16	1950	18	1974	358	1998	4567
1903	1	1927	9	1951	45	1975	565	1999	5941
1904	1	1928	8	1952	14	1976	618	2000	5421
1905	1	1929	15	1953	9	1977	604	2001	5421
1906	5	1930	8	1954	17	1978	648	2002	6058
1907	5	1931	18	1955	27	1979	668	2003	5399
1908	4	1932	30	1956	19	1980	956	2004	5461
1909	5	1933	17	1957	25	1981	691	2005	5834
1910	7	1934	21	1958	28	1982	912	2006	6533
1911	2	1935	22	1959	22	1983	911	2007	8188
1912	3	1936	20	1960	17	1984	1125	2008	7402
1913	3	1937	10	1961	20	1985	2059	2009	8307
1914	2	1938	16	1962	26	1986	2800	2010	6990
1915	5	1939	7	1963	29	1987	960	2011	6749
1916	1	1940	10	1964	228	1988	914	2012	8748
1917	1	1941	22	1965	247	1989	1044	2013	7713
1918	8	1942	7	1966	289	1990	1597	2014	8360
1919	8	1943	7	1967	244	1991	1639	2015	8093
1920	3	1944	3	1968	349	1992	1750	2016	3684
1921	4	1945	4	1969	303	1993	2303	2017	3388
1922	5	1946	4	1970	442	1994	2114		
1923	8	1947	3	1971	199	1995	3173		
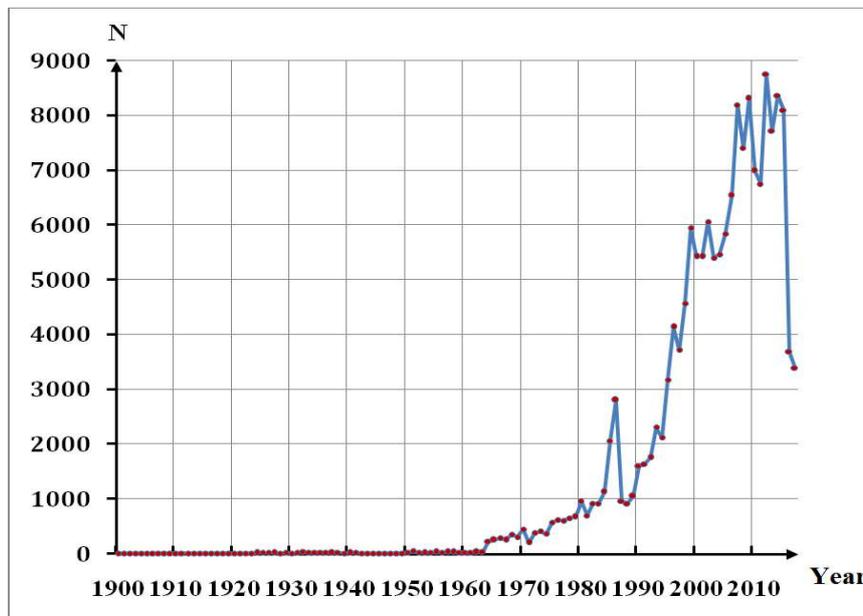
Figure 4. Earthquake procedure time line in the East Sea period 1900-2017

Table 5. The annual maximum earthquake magnitude

Year	M_{max}	Year	M_{max}	Year	M_{max}
1900	7	1940	6.9	1980	6.8
1901	7.5	1941	7.5	1981	6.6
1902	7	1942	7.5	1982	7.1
1903	7	1943	7.8	1983	6.9
1904	7.8	1944	6.8	1984	7.5
1905	7.8	1945	6.8	1985	7
1906	7.3	1946	6.8	1986	7.5
1907	7.6	1947	7.4	1987	6.9
1908	7.2	1948	7.8	1988	7.3
1909	7.6	1949	7.4	1989	7.6
1910	8.1	1950	7.3	1990	7.8
1911	8.2	1951	7.8	1991	7.5
1912	7.5	1952	7.4	1992	7.3
1913	7.8	1953	6.9	1993	7
1914	7.6	1954	6.7	1994	7.9
1915	7.4	1955	7.5	1995	7.2
1916	7.2	1956	6.7	1996	7.9
1917	7	1957	7.3	1997	7
1918	8.3	1958	7.2	1998	7.7
1919	7.1	1959	7.5	1999	7.7
1920	8.2	1960	6.6	2000	7.9
1921	7.5	1961	6.9	2001	7.5
1922	7.5	1962	6.5	2002	7.5
1923	7.4	1963	7.2	2003	7
1924	8	1964	7.4	2004	7.3
1925	7.3	1965	8.2	2005	7.1
1926	6.8	1966	7.7	2006	7.1
1927	7	1967	6.8	2007	8.4
1928	7.5	1968	7.6	2008	7.4
1929	7.3	1969	7.6	2009	7.2
1930	6.9	1970	7.4	2010	7.8
1931	6.8	1971	7	2011	7.4
1932	7.8	1972	8	2012	7.6
1933	6.8	1973	7	2013	7.3
1934	7.6	1974	6.8	2014	7.7
1935	7	1975	7.2	2015	8
1936	7.8	1976	7.9	2016	7.9
1937	7.6	1977	7	2017	7.3
1938	7.7	1978	7.4		
1939	8.1	1979	7.1		

With M_{max} as the maximum earthquake magnitude in the year, Figure 5 shows the cyclical nature of the strong earthquake activity at each stage. It is possible to divide the study period into 4 stages, each stage lasting nearly 30 years (from 1900 to 2017). Each stage has particular characteristics shown below:

Stage 1: From 1900 to 1927, it was characterized by the majority of $M_{max} \geq 8.0$ and the minimum were above 7.0.

Stage 2: From 1927 to 1960 with the majority of $M_{max} \geq 7.5$, while the minimum are 6.7 to 7.0.

Stage 3: From 1960 to 1987 was characterized by the majority of $M_{max} \geq 7.5$, with some points below 7.5, the minimum points are 6.5 -7.0.

Stage 4: From 1987 to 2013 with most of the M_{max} in the range of 7.0-7.8. At the end of this period, there was 8.4 in the year 2007.

Figure 5 shows that the maximum number of earthquakes is seasonal in all four stages (Figure 5). In each phase, there are 1 to 2 max with $M_{max} \geq 8.0$. Each 3-5 years, there is one earthquake with magnitude 7.5. This allows forecasting the maximum earthquake repeat cycle of $M_{max} \geq 7.5$ in the study area of 3-5 years.

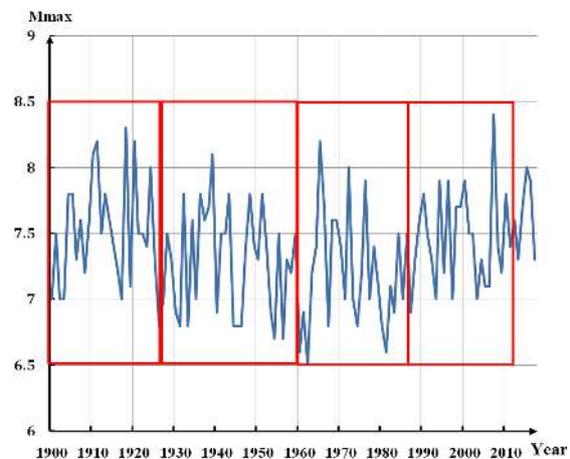From the increasing trend of the graph, we can see a new cycle with a maximum earthquake magnitude.

Figure 5. The distribution of maximum earthquake magnitude by year

4. Results of estimating M_{max} by the gev method for the East Sea region

To assess the maximum earthquake magnitude in the East Sea region, the used of magnitude values must be greater than or equal to the selected threshold value. This threshold value must greater than the earthquake magnitude which represent for catalog of the study

area and it is sufficiently reliable in calculating parameters of GEV function. Accordingly, the threshold magnitude value was chosen M^* = 5.0.

In order to ensure the reliability of results, the used data should be continuous. Analysis shows that it is continuous since 1917, so we chose the period from 1917 to 2017 for estimating M_{max}. There are 12006 earthquakes with $M \geq 5.0$ in this period.

In next section, we present the calculation results for the given data.

Step 1: Calculate the density Poisson distribution (λ)

The period from 30/7/1917 (t_1) to 8/12/2017 (t_n) is used with the daily unit. The total is 36655 days.

Density Poisson distribution is calculated as follows:

$\lambda = N/t = 12006 / 36655 = 0,33$

Step 2: Select the jump (T)

The longest time of two events in the catalog is 291 days (from 11/11/1921 to 29/8/1922). Therefore, to satisfy the condition (a) above, the greater value of T-intervals is 291 days. The T-intervals in the corresponding product λT are the following:

In principle above, the closer values to the value "0" ($1/\lambda T$) are, the better T-intervals are. From Table 6, the greater T-intervals are, the smaller values of $1/\lambda T$ are. However, to satisfy the condition (c), Figure 6 shows an approximate "stabilization" of the ζ- estimates with T in range 300-350 days. Therefore, the value of T-interval is 350 days.

Table 6. Table of T, λT, $1/\lambda T$

T(days)	290	295	300	305	310	315	320	325
λT	95	97	98	100	102	103	105	106
$1/\lambda T$	0.0105	0.0103	0.0102	0.0100	0.0098	0.0097	0.0095	0.0094
T(days)	330	335	340	345	**350**	355	360	365
λT	108	110	111	113	**115**	116	118	120
$1/\lambda T$	0.0093	0.0091	0.0090	0.0088	**0.0087**	0.0086	0.0085	0.0083
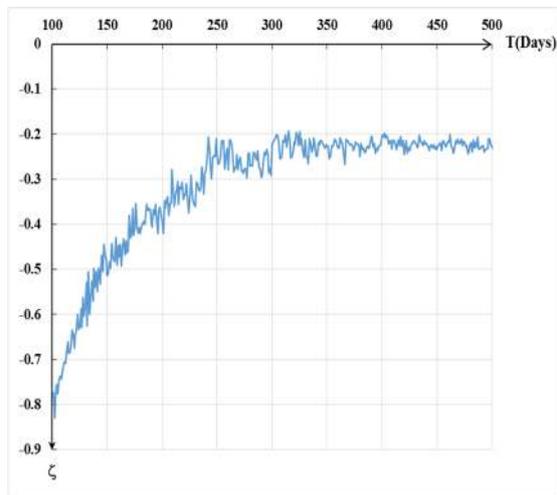
Figure 6. Graph the function ζ(T)

Step 3: Determine the parameters ζ, σ, μ

With T = 350 days, then the number of T-intervals is:

$$n = \text{interger}\frac{t_n-t_1}{T} = \text{interger}\frac{36655}{350} = 104$$

We need to solve 104 systems of equations (2-4) to receive 104 sets of the three parameters ζ, s, m. Taking the average of these three parameters in turn gives us the value of the parameters:

ζ = -0.23; σ = 0.46; μ = 6.23.

There are results:

MSE(ζ) = 0.05; MSE(s) = 0.06; MSE(m) = 0.21.

Therefore, the parameters are:

ζ = -0.23±0.05; s = 0.46±0.06; m = 6.23± 0.21.

Step 4: Determine predicted M_{max}

In use of earthquake catalog, the last strongest earthquake, which has occurred on January 10th 2017 with magnitude M = 7.3 at latitude φ = 4.5°N and longitude λ = 122.6°E.

So we have chosen this event as supporting event.

$$M_{max}^{predict} = \lim_{\tau \to \infty} Q_q(\tau)$$

Using the results of the previous sections, we get the graph of the function $Q_q(\tau)$ in Figure 7 and its value in Table 7, with probability of 80%.

Table 7. The values of $Q_{0,8}(\tau)$ at the different τ

τ (year)	20	40	60	80	100
Period	2017-2037	2017-2057	2017-2077	2017-2097	2017-2117
$Q_{0,8}(\tau)$	8.25	8.50	8.6	8.65	8.7

According to the Figure 7 and Table 7 above, we have $Q_{0,8}(20) = 8.25$. It means the prediction of M_{max} is $M_{max} = 8,25$ in the next 20 years from the supporting event.

When τ proceeds to infinity (since the value of 100 years), graph of the function $Q_{0,8}(\tau)$ is almost unchanged (Figure 7). It means that the M_{max} predicted the value for the East Sea region is $M_{max} = 8.7$ with probability 80%.
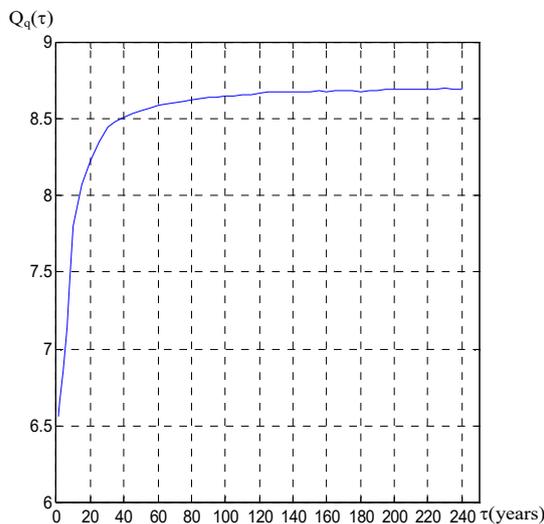

Figure 7. Graph of the function $Q_q(\tau)$ with q = 0.8 for the East Sea region (M ≥ 5,0) period 1917-2017

5. Discussions

Comparing the results obtained in this work with a series of previous research results of different authors in the East Sea region (Pham Van Thuc, 2001, Pham Van Thuc et al., 2004; Nguyen Van Luong et al., 2012; Zhiguo Xu, 2015), the East Sea is considered to be a high risk area for earthquakes, especially the possibility of strong earthquakes from the east of the study area along the Manila Trench. The maximum earthquake magnitude in the area is estimated at $M_{max} \geq 7.5$.

From the results of calculating the maximum earthquake magnitude M_{max} above, we see that when using the universal value distribution function GEV, the result will depend on the factors such as the completeness and uniformity of the set: How to select the T jump, and how to select the magnitude earthquake threshold value. Because of the method of using the GEV predictive function, M_{max} is one of the probability methods, so its results are consistent with the predicted results by other probabilistic methods such as the maximum rational method by Nguyen. Hong Phuong used $M_{max} = 8.7 \pm 0.93$ for a repeat cycle of 2658 years for the northern part of Manila submergence zone (Nguyen Hong Phuong, 2015). Meanwhile, the results in this work are slightly higher than the results of the tectonic geological methods have been applied by other authors such as author Phan Trong Trinh results $M_{max} = 8.6$ (according to the author) fault or $M_{max} = 8.3$ (by fault length) (Phan Trong Trinh et al., 2011); Bui Cong Que evaluated $M_{max} = 8.5$ (in terms of fault length) (Bui Cong Que, 2010); Or, according to a regular meeting held by the USGS in 2005, this confirmed that the potential for strong earthquakes exceeded 8.5 (Kirby et al., 2005). This difference may be due to the fact that the tectonic geological methods have evaluated M_{max} through intermediate variables such as faults. Fault lengths based on fixed assumptions for all source areas fracture is a rectangle that is twice the width of the width; it is also possible that the field results do not fully reflect these parameters. In addi-

tion, the probability result depends on the probability of expectation (the larger the probability, the smaller the M_{max} result). Therefore, when evaluating M_{max} for any given region, reference should be made to the results of both probabilistic and geological methods.

In spite of the similarity of these assessments, the results obtained in this work are more reliable because the calculations made using seismic data are purely logarithmic. Received by machine, the earthquake list was established on the basis of calibration and unification of data from different sources for a single magnitude torque. In addition, other probabilistic methods for evaluating M_{max} over a very long period, several hundred years or several thousand years, but the results of the M_{max} evaluation in this work are limited to periods. It should be noted, however, that during the data period of the study, although the highest density of earthquakes was observed in the eastern part of the East Sea, some of the strongest earthquakes with $M_w \geq 8.0$ occurred out in the southeast of the study area. Therefore, in order to confirm that the maximum earthquake magnitude $M_{max} = 8.7$ is predicted for a specific part of the East Sea, it is still necessary to evaluate the maximum magnitude of the earthquake for the particular region of the zone. That is the direction that research should continue in the East Sea.

6. Conclusions

Based on seismic data collected from different sources, we have the following conclusion:

The seismic region of the East Sea between 1900 and 2017 is characterized by the magnitude 4.7. The earthquakes are mainly distributed in the earth's crust at the eastern and southeastern part of the study area.

Strong earthquake activity in the East Sea area shows that the cyclicality through each period. From 1900 to 2017, it has four stages of strong earthquake activity, each stage lasts

nearly 30 years with particular characteristics. In each phase, there are 1-2 strong earthquakes with $M_{max} \geq 8.0$. The strong earthquakes with $M_{max} \geq 7.5$ occur according to the rule of repeatability of 3-5 years.

On the basis of the unified earthquake catalog in period 1917-2017 with $M_w \geq 5.0$, maximum magnitude values for the East Sea region has assessed by GEV method with several different predict periods (20, 40, 60, 80, 100 years). With predict period 100 years, we have

$$M_{max}^{predict} = \lim_{\tau \to \infty} Q_q(\tau) = 8.7.$$

This result is quite similar to previous research results. It proves that the results of previous studies are objective and the application of the GEV method to evaluating M_{max} is feasible.

Acknowledgments

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