应用概率统计　第二十四卷
第一期　2008年2月

Chinese Journal of Applied Probability
and Statistics Vol.24 No.1 Feb. 2008

The Seismic Information in the Variety of Groundwater Level *

Li Yong　　Zhang Shumei

(*School of Mathematical Science, Beijing Normal University,*
Key Laboratory of Mathematics and Complex Systems, Ministry of Education, Beijing, 100875)

Abstract

To dig the seismic information in the groundwater level, a new statistic is proposed basing on the analysis of the relation between the groundwater lever and the seismic catalogue. Furthermore, a method is presented by means of this statistic to find out earthquake precursors. It is shown that this method is valuable.

Keywords: Statistic, seismicity, groundwater level.

AMS Subject Classification: 46N30.

§1. Groundwater Level and Earthquakes

In the process of crustal movements which may have a strong relationship with an earthquake, there are changes in the pore pressure of the underground rocks deforming the groundwater system. Hence the sudden or unusual changes in the groundwater level could be regarded as very important signals of an earthquake in the future.

Fang, S.[1] discussed the anomaly of groundwater level before an earthquake by means of calculating standard errors of groundwater level. Contadakis, M.E.[2] proposed that monitoring the shallow groundwater level for detecting seismic precursory phenomena can be considered as a useful method for seismic prediction. Li, Y.[3] discussed the method to clear up the rainfall effect from the groundwater data, and the nexus between the seismicity and local variation velocity of groundwater data without rainfall effect.

This paper discusses the seismic information behind the variety of groundwater level at Chicheng Station.

§2. The Groundwater Data and Earthquake Catalogue

There is a borehole of 69.45m in Chicheng Station, which is located at longitude 40°N and latitude 115°E. The groundwater data are collected and recorded at eight o'clock every

*Project (10371012) supported by the National Natural Science Foundation of China.
Receive September 9, 2004. Revised November 28, 2006.

day in the station. This paper uses the groundwater data[1] from 1 Jan. 1991 to 31 Dec. 2001, and the earthquake catalogue in the area of radius 300 kilometers around Chicheng station from 1 Jan. 1992 to 31 Dec. 2001.

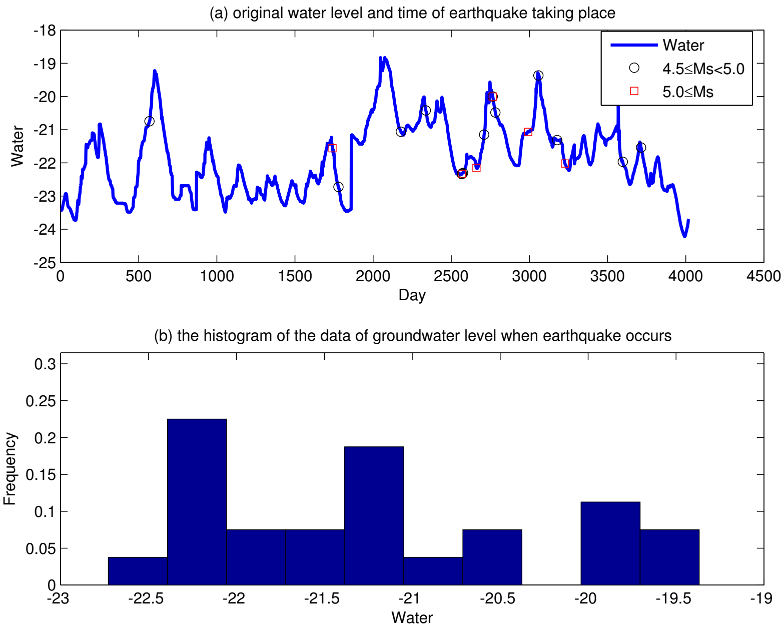

Figure 1 The plots of groundwater level and earthquakes

The focus will be on the relationship between the groundwater level and the earthquakes with magnitude $M_s \geq 4.5$ around Chicheng station. Figure 1(a) shows the original groundwater level (line) and the shock time of different grades of magnitudes of earthquakes (circles and squares). There are 19 earthquakes with magnitude $M_s \geq 4.5$ from 1992 to 2001. Figure 1(b) is the histogram of the data of groundwater level when earthquake occurs.

It is well known that the distribution of earthquakes in the time axis is extremely sparse. In addition to this, we also need to consider other factors for describing the seismic information. Here we consider how to describe the seismic information by means of groundwater level data. Figure 1(a) shows that the groundwater data distribute mainly in $[-23, -19]$, and Figure 1(b) suggests that the distribution of water level of earthquake occurrence is nearly the uniform distribution in $[-23, -19]$. Hence we can not directly dig the seismic information from original groundwater level data, and must find some method to collect the information behind the water data. We can also find out the yearly period

[1]The groundwater data were provided by Chicheng Station.

within the groundwater level curve form Figure 1(a). Moreover, the seismic series do not have the periodicity. In fact, the yearly period of the groundwater level is mainly caused by the factors such as rainfall, which are independent of the seismic constructing process. Thus the yearly period of groundwater level has nothing to do with seismicity.

In order to mine the seismic information from the water data more effectively, we should eliminate the information mixed in water data, which has no relation with seismicity. Therefore, we try first to extract the yearly period term from the original water data, then discuss the seismic information in the remain part of the data.

§3. The Seismic Information in the Groundwater's Yearly Trend Term

The decomposition technique was applied to the groundwater time series in order to examine the earthquake precursor connected to the local seismicity. Let

$$Y_t = \begin{cases} \dfrac{1}{t}\sum\limits_{k=1}^{t} X_k, & 1 \le t < 365, \\ \dfrac{1}{365}\sum\limits_{k=1}^{365} X_{t-k}, & 365 \le t \le 4018, \end{cases}$$

where X_t denotes the t-th day's groundwater data. Then

$$Y = (Y_1, \cdots, Y_{4018})$$

is defined as the yearly trend term of groundwater.

It is well known that different areas have different means of groundwater level which are decided by their own geologic structures and weather characteristics. To eliminate the influence of the area, we should center the yearly tend item, which is called the local centered tend item, as follows

$$Z_t = Y_t - \frac{1}{t}\sum_{k=1}^{t} Y_k, \qquad 1 \le t \le 4018.$$

Figure 2(a) displays the local centered trend item (line) and shock time with earthquakes magnitude $M_s \ge 4.5$. Figure 2(b) is the histogram of the data of local centered trend item when earthquake occurs. From Figure 2(a), we can find that most of the earthquakes occur after the local centered trend item curve arrives at its historical extremum. From Figure 2(b), it is easy to see that the Z's values are mainly in the interval $[0, 1.2]$

when earthquakes occur. Comparing Figure 2(b) with 1(b), we can conclude that the corresponding relationship of the seismic events with the local centered trend item is stronger than the one with the original water level.

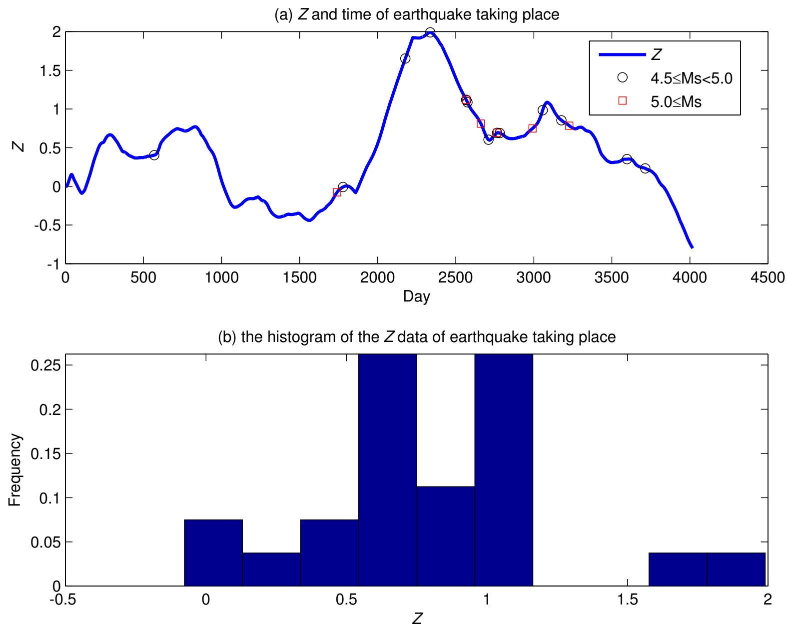

Figure 2 The plots of local centered trend item and earthquakes

After this, we further investigate the information of seismic constructing process in the local centered trend item.

§4. Seismicity Index

Figure 2(a) shows that

1. After the local centered trend item arriving its historical minimum, the trend item curve appears a rising process before an earthquake occurs.

2. After the local centered trend item arriving its historical maximum, the trend item curve appears a falling process before an earthquake occurs.

Hence we can study the information of seismic constructing process using the distance between the last historical extremum and the local centered trend item.

We first define the historical maximum and minimum value series of local centered trend item as follows

$$Z_t^{\max} = \max_{1 \le k \le t} Z_t, \qquad Z_t^{\min} = \min_{1 \le k \le t} Z_t, \qquad 1 \le t \le 4018.$$

Then we can define the seismicity index as

$$I_t = \begin{cases} \dfrac{Z_t - Z_t^{\min}}{Z_t^{\max} - Z_t^{\min}}, & \text{if the last extremum is the minimum,} \\ \dfrac{Z_t^{\max} - Z_t}{Z_t^{\max} - Z_t^{\min}}, & \text{if last extermum is the maximum.} \end{cases} \tag{4.1}$$

In formula (4.1), the factor $1/(Z_t^{\max} - Z_t^{\min})$ ensures $0 \leq I_t \leq 1$.

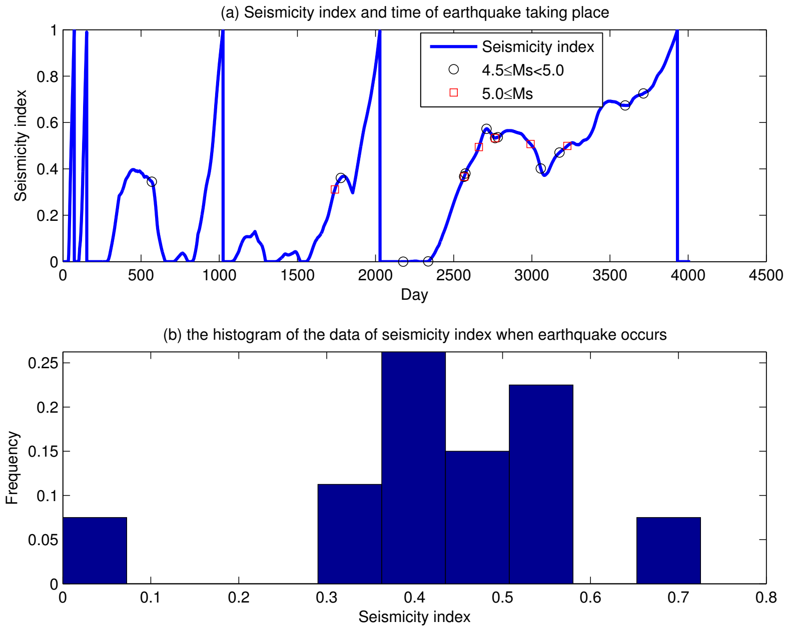

Figure 3　The plots of the seismicity index and earthquakes

Now we show the relation between seismic events and the seismicity index by graphs. In Figure 3, plot (a) displays the relation between the seismicity index (line) and seismic events with magnitude $M_s \geq 4.5$, and plot (b) shows the histogram of the data of seismicity index when seismic events occur.

From Figure 3(a), we can see that most of the earthquakes with magnitude $M_s \geq 4.5$ occur at the time when seismicity index is between 0.3 and 0.6. Especially, all earthquakes with magnitude $M_s \geq 5$ occur in the seismicity index interval $[0.3, 0.6]$. So it follows that the seismicity increases as the process of seismicity index goes up to the interval $[0.3, 0.6]$. Comparing Figure 3(b) with 2(b), we can conclude that the corresponding relationship of the seismic events with seismicity index is stronger than the one with local centered tend item.

Among the original groundwater level, the local centered trend item and the seismicity index, the latter is the best index to describe the seismic information. In the next section we compare the three relationships in the light of the quantile.

§5. Comparison of the Three Relationships

For convenience, we use the following notations. Let $\xi = \{\xi_k\}$, $\eta = \{\eta_k\}$ and $\zeta = \{\zeta_k\}$ represent the original water level, the local centered trend item and the seismicity index at the moment when the earthquake occurs. Let $\xi(p)$, $\eta(p)$ and $\zeta(p)$ represent their corresponding p-quantiles.

For given p_1 and p_2, if we regard the seismicity index in $[\zeta(p_1), \zeta(p_2)]$ as an earthquake precursor, we can successfully predict $(1 - p_1 - p_2) \times 100$ percent of seismic events. Then we are concerning on the days of forecasting earthquakes by this prediction method in the 4018 days. The shorter the prediction time in the 4018 days is, the better the prediction method will be.

For given $0 \le p_1 < p_2 \le 1$, let $X(p_1, p_2)$ be the ratio of the number of days during which the original water level falls into the range $[\xi(p_1), \xi(p_2)]$, $Y(p_1, p_2)$ be the ratio of the number of days during which the local centered trend item falls into the range $[\eta(p_1), \eta(p_2)]$, and $I(p_1, p_2)$ be the ratio of the number of days during which the seismicity index falls into the range $[\zeta(p_1), \zeta(p_2)]$.

$I(p_1, p_2)$ expresses the frequency of earthquake forecast by day basing on the seismicity index, which ensures $(1 - p_1 - p_2) \times 100$ percent of the earthquakes to be successfully forecasted. The smaller $I(p_1, p_2)$ is, the more effective to describe the earthquake precursor by the seismicity index will be. The meaning of $X(p_1, p_2)$ and $Y(p_1, p_2)$ is similar to $I(p_1, p_2)$.

Table 1 The relation between seismicity and the data

p_1	p_2	$X(p_1, p_2)$	$Y(p_1, p_2)$	$I(p_1, p_2)$
0.00	1.00	0.7555	0.7577	0.9132
0.05	0.95	0.6619	0.6934	0.7361
0.10	0.90	0.5574	0.5968	0.4539
0.15	0.85	0.5133	0.5059	0.3107
0.20	0.80	0.4911	0.4344	0.2319
0.25	0.75	0.4353	0.3564	0.2119
0.30	0.70	0.3206	0.2842	0.1752

Table 1 shows some values of $X(p_1, p_2)$, $Y(p_1, p_2)$ and $I(p_1, p_2)$. The data in the table imply that

1. It is nearly equally effective to use the original groundwater or the local centered trend item to describe the seismic information.

2. In the case that 80% of earthquakes with magnitude $M_s \geq 4.5$ can be predicted (including all of the earthquakes with $M_s \geq 5.0$), the seismicity index is the best in the three indexes.

§6. Conclusion

In application, we should be careful to forecast an earthquake, because such forecast will bring huge production loss for us. Hence it is insignificance that the frequency of the forecast by day is greater than 0.5. From Table 1, our conclusion is that the best index is the seismicity index.

References

[1] Fang, S., etc, Anomaly of ground water level before eastern sea area of Yangtze River mouth earthquake with M_s 6.1, *Seismological and Geomagnetic Observation and Research*, **21(3)**(2000), 51–55.

[2] Contadakis, M.E., etc, Recent results of the research for preseismic phenomena on the underground water and temperature in Pieria, northern Greece, *Natural Hazards and Earth System Sciences*, **1**(2001), 165–170.

[3] Li, Y., etc, The first research about the relationship between the variation of underground-water-level and the seismicity, *J. Beijing Normal University* (*Natural Science*), **37(6)**(2001), 739–745.

地下水位变化中的地震信息

李 勇 张淑梅

(北京师范大学数学科学学院, 数学与复杂系统教育部重点实验室, 北京, 100875)

为挖掘地下水位中蕴含的地震信息, 我们通过对地下水位与地震事件序列关系的分析提出了一个新统计量, 进而得到一种寻找地震前兆的方法. 数据分析表明这种探索地震前兆方法有应用价值.

关 键 词: 统计量, 地震活动性, 地下水位.

学 科 分 类 号: O213.9.