Mine Water Inflow Calculation Method Applied in Arid and Semiarid Mining Area

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**Abstract.** With the development of coal resources in Shendong mining area, collapse occurs continuously in the overburden layers of seams, forming caving zone and water-conducting fracture zone. Therefore, the structure of aquifers, runoff and discharge conditions of groundwater have changed. Groundwater level has changed significantly. In the collapsed zone and areas with induced fractures and water-enriched loose layers, groundwater level has lowered continuously. Prediction of mine water inflow is the main basis of mine waterproof, drainage system designing, mine water prevention and control measures. It is influenced by hydrology, geology, precipitation, mining conditions and other comprehensive factors, belonging to a grey system. Grey system method aims to solve the incomplete information system. In the grey system theory, the most commonly used is the GM (1, 1) prediction model. By using differential fitting method, the grey system theory dynamically processes the discrete, stochastic time series of original data information by the cumulative add and subtract, precision correction if necessary, in order to find the regularity from chaotic in the original data. The grey theory model is put forward to solve the traditional modeling method that cannot process the uncertain system of mine water inflow comprehensively and continuously.

**Introduction**

ShenDong mining area is located in the zone bordering Shaanxi northern loess plateau and the southeast margin of Maowusu desert. It is characterized with good quality of coal, big reserves, shallow burial depth, and relatively simple mining conditions. With the development of coal resources in Shendong mining area, collapse occurs continuously in the overburden layers of seams, forming caving zone and water-conducting fracture zone. Therefore, the structure of aquifers, runoff and discharge conditions of groundwater have changed. Groundwater level has changed significantly. In the collapsed zone and areas with induced fractures and water-enriched loose layers, groundwater level has lowered continuously, resulting in drying aquifer.

In the different stages of mine construction and production, mine water inflow dynamic prediction is an important task of mine hydrogeology work. Mine water inflow prediction is of great significance for mine safe production. Mine water inflow prediction is influenced by many complicated factors, belonging to a grey system. Grey system method, proposed by Professor Deng Julong in Hua Zhong University of Science and Technology, aims to solve the incomplete information system. In the grey system theory, the most commonly used is the GM (1, 1) prediction model.

By using differential fitting method, the grey system theory dynamically processes the discrete, stochastic time series of original data information by the cumulative add and subtract, precision correction if necessary, in order to find the regularity from chaotic in the original data. The grey theory model is put forward to solve the traditional modeling method that cannot process the uncertain system of mine water inflow comprehensively and continuously.

**Modeling Method**

The original discrete water inflow was set to dynamic sequences $x^{(0)}$, which have a total of $n$ observations: $x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)$. In order to reduce the error, the original sequences were made by smooth processing:
\( \bar{x}^{(0)}(1) = (3x^{(0)}(1) + x^{(0)}(2))/4 \)  
\( \bar{x}^{(0)}(k) = (x^{(0)}(k-1) + 2x^{(0)}(k) + x^{(0)}(k+1))/4 \)  
\( k = 2, 3, \ldots, n-1 \)  
\( \bar{x}^{(0)}(n) = (x^{(0)}(n-1) + 3x^{(0)}(n))/4 \)  

Based on this, an accumulated generating operation for the smooth processing sequences was done:

\[
\sum_{i=1}^{k} \bar{x}^{(0)}(k) \quad (k=1, 2, \ldots, n) 
\]

The generated sequences:

\( x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n) \)

For sequences \( x^{(1)} \), a prediction model in the simplified form of differential equation was established:

\[
\frac{dx^{(0)}}{dt} + a x(1) = u 
\]

In the equation: \( a \) and \( u \) were parameters to be estimated, where \( a \) is the mean development of grey number, where \( u \) is the mean endogenous grey numeral control.

\( \bar{a} \) was set as estimated parameters, and \( a \) and \( u \) were calculated by the least square method:

\[
\bar{a} = \begin{bmatrix} a \\ u \end{bmatrix} = (B^TB)^{-1}B^TY 
\]

In the equation:

\[
Y = \begin{bmatrix} x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n) \end{bmatrix}
\]

\[
B = \begin{bmatrix} -(x^{(0)}(1) + x^{(0)}(2))/2 & 1 \\ -(x^{(0)}(2) + x^{(0)}(3))/2 & 1 \\ -x^{(0)}(n-1) + x^{(0)}(n))/2 & 1 \end{bmatrix}
\]

By calculating the GM (1, 1) model, the following equation will be get:

\[
\hat{x}^{(1)}(k+1) = (x^{(0)}(1) - u/a)e^{-ak} + u/a 
\]

\( k = 1, 2, \ldots, n \)  

Reduction forecast data will get water inflow dynamic prediction:

\[
\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) 
\]

\( k = 1, 2, \ldots, n \)  

In the last-written equation, when \( k = 1, 2, \ldots, n \), \( \hat{x}^{(0)}(k) \) (\( k = 1, 2, \ldots, n \)) was the fitted value of the original data sequences \( x^{(0)}(k) \) (\( k = 1, 2, \ldots, n \)). When \( k > n \), \( \hat{x}^{(0)}(k) \) was the predictive value of the original data sequences \( x^{(0)}(k) \) (\( k = 1, 2, \ldots, n \)).

Dynamic processing for the original sequences by GM (1, 1) was made: after taking out \( x^{(0)}(1) \) and adding \( \hat{x}^{(0)}(n+1) \), the following sequences will be get:

\[
x^{(0)}(2), x^{(0)}(3), \ldots, \hat{x}^{(0)}(n+1) 
\]

As a new original sequence repeats the above steps, until the final prediction is obtained.

**Model Accuracy Check**

After modeling, the model should be tested in order to determine whether the precision of the model meeting the requirements, and then determine whether this model can make a prediction. Model
accuracy test methods include residual test and posterior difference test method, etc. In this paper, the residual test was used to test precision of grey model.

For residual test, main parameters are as follows:

Residual:
\[ \varepsilon(k) = x^{(0)}(k) - \hat{x}^{(0)}(k) \]  

The relative residual:
\[ \Delta k = |\varepsilon(k)| / x^{(0)}(k) \]  

Mean residual:
\[ \Delta k(\text{avg}) = \frac{1}{n} \sum_{i=1}^{n} |\Delta k| \]  

Precision:
\[ P = 1 - \Delta k(\text{avg}) \]  

Table 1. Model Accuracy Evaluation Form

<table>
<thead>
<tr>
<th>Precision grade</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1: outstanding</td>
<td>&gt;0.90</td>
</tr>
<tr>
<td>Level 2: good</td>
<td>0.80~0.90</td>
</tr>
<tr>
<td>Level 3: qualified</td>
<td>0.70~0.80</td>
</tr>
<tr>
<td>Level 4: unqualified</td>
<td>&lt;=0.70</td>
</tr>
</tbody>
</table>

Case Study

Conditions of the mine water and water inflow trend. The Jin Jie mine is located in the southeast of Maowusu desert edge in Shaanxi, belonging to the arid and semiarid regions. The area is a simple structure and smooth stratum, coal-bearing stratum is the Jurassic middle yanan group. Now the primary mineable coal bed is NO.3-1. The source of water-full is sandstone fissure water and quaternary system unconsolidated rock phreatic water. Channel of water-full is mainly caving zone and water flowing fractured zone. The mine is a typical northwest shallow buried type.

Early in the production of the mine, the mine water inflow showed a trend of increase year by year. The cause of the mine water inflow increase related to mine production increased year by year and worked-out area was gradually expanding, besides the number of drilling was growing. In October 2011, the mine water inflow grew to the peak, and then gradually declined. The reason for this is that as the mine production scale and face the effective work of ground water increasing, underground water levels declined and water filling aquifer recharge was less than the excretion. The mine water inflow data is shown in the Fig. 1.

Mine water inflow prediction based on grey theory. Mine water inflow is affected by geological and hydrogeological conditions, mining methods, time and other factors, especially a dynamic variation over time. In the case of knowing part of the water inflow data, the recent water inflow can be predicted by using the grey theory. By Fig. 1 showing, the mine water inflow gradually increase from September 2006 to October 2011. The mine water inflow fluctuations around 5000 m³/h from October 2011 to May 2012. Since May 2012, the mine water inflow began to decline. In this paper, according to the date of mine inflow in June 2012 to December 2012, the dynamic change of mine water inflow can be predicted by using the grey theory prediction method from January 2013 to December 2013.
According to the grey theory model, prediction equation can be obtained as follows:

$$46925.23 + 44856.18e^{-0.034(k-1)}$$

(16)

Forecast values of each point and the model test of residual results are shown in Table 3.

As table 3 shows, the model of mean residual is 0.34%, and the accuracy is 99.66%. Referring to table 1, the model precision for outstanding grade can make use of the established model of mine water inflow prediction of recent.

The mine water inflow prediction results are shown in table 4 from January 2013 to December 2013.
As table 4 shows, mine water inflow still declined in 2013, but decreased gradually slow. This phenomenon can be realized that with the continuous exploitation of coal mine and mine drainage, underground water level declined, groundwater recharge and mine water inflow became more stable.

**Conclusion**

The mine water inflow, belonging to the grey system, is affected by precipitation, geological and hydrogeological conditions, degree of exploration and mining technical conditions and many unknown factors. In this paper, a shallow buried type in the northwest Jurassic coal mine water inflow was forecasted through the establishment of the grey system theory GM (1, 1) model, achieved outstanding grade.

The grey theory prediction is a kind of trend prediction of mine water inflow, so there is a certain error. However, the results show that grey theory model has many advantages, such as less sample size required, without the sample distribution, smaller computational complexity, short operation time and higher prediction precision. Grey theory model can be used in the different stages of mine construction and production, the trend of change of mine water inflow dynamic prediction evaluation, for the design of waterproof and drainage system of the mine and to provide basis for the establishment of mine water prevention, which is an effective method.

**References**