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TECHNICAL COMMUNICATION

Using Multiple Methods to Predict Mine Water Inflow in the Pingdingshan No. 10 Coal Mine, China

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Abstract To ensure safe mining of the no. 2 coal seam in the Pingdingshan No. 10 coal mine, three methods (analogue, big well, and numerical simulation) were used to forecast mine water inflow and their performance. The big well method predicted the largest water inflow: 233.8 m^3/h in the −230 m level and 281.1 m^3/h in the −300 m level. The numerical simulation predicted the least inflow, 205.7 and 228.6 m^3/h respectively for the 230 and −300 m levels; this was closest to the measured values. Based on this work, it appears that combining numerical simulations with other methods are a good way to accurately forecast mine water inflow.

Keywords Prediction · Mine water inflow · AM · BWM · Numerical simulation

Introduction

Many coal mine water inrush accidents have taken place in China (Wu et al. 2013); therefore, accurate and reliable prediction of mine water inflow is essential for safe coal production and management (Chen et al. 2009). Many previous studies have forecast water inflow using analytical methods (Hua 2010; Peng and Yajun 2012) and numerical models (Adhikary 2012; Li 2013; Shao et al. 2014b), while Shao et al. (2014a) proposed a BP neural network method. However, these studies generally used a single method to forecast water inflow.

The Pingdingshan coalfield, which is located in central Henan Province (Fig. 1), has been mined for more than 50 years. The Pingdingshan No. 10 coal mine is located in the east of the coalfield, in the transition region between the hills and the plains; the topography is geologically high in the north and west, and low in the south and east. The mine is located in the footwall of the Guodishan fault, which is associated with a single anticlinal structure that is cut by a series of NW faults and plunges to the east. Mine water inrush accidents constitute a serious threat to safety there. A severe accident occurred at the −230 m level in the no. 2 coal seam in June 2010, with water inflow exceeding 50 m^3/h. The source of the inrush was limestone water from the underlying Taiyuan Formation, which also constitutes a potential threat to the mining of deeper coal seams. Thus, accurate prediction of mine water inflow is essential to ensure safe and efficient production at the Pingdingshan No. 10 coal mine. The main aim of the present study was to forecast mine water inflow there using a combination of three methods (analogue, big well, and numerical simulation), and to compare their performance with actual mine water inflow.

Hydrogeology of the Pingdingshan No. 10 Coal Mine

The main aquifers of the mine are the indirect aquifer of the Cambrian limestone and the direct fissure aquifer of the upper and lower members of Taiyuan Formation; the main aquiclude is the bauxitic mudstone of the Benxi Formation, which has good water-resistance. The upper and lower

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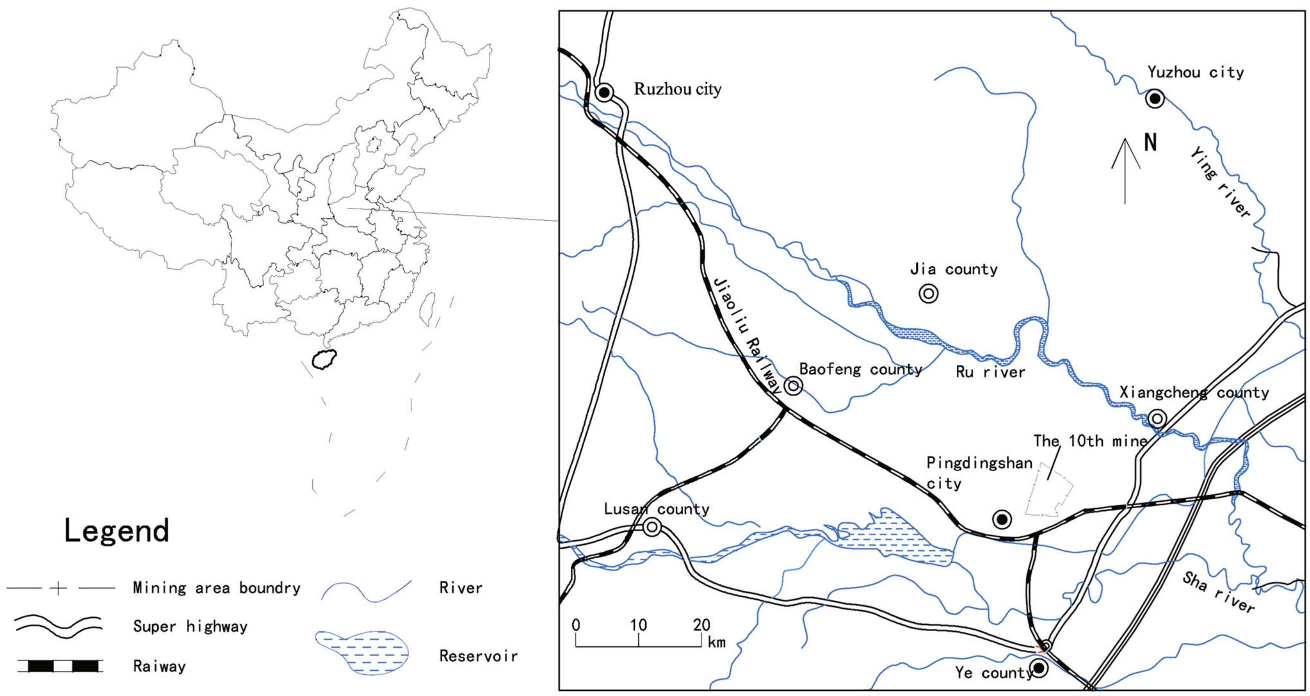

Fig. 1 Location of the Pingdingshan No. 10 coal mine

members of the Taiyuan Formation are 8.2 and 10.5 m thick, respectively, and the base of the coal-bearing strata, the Cambrian limestone aquifer, is hundreds of meters thick. These aquifers contain large quantities of water. Normal water inflow into the mine ranges from 177.8 to 209.8 m^3/h, but generally remains at about 196 m^3/h at the −220 m level. Equivalent inflow at the −300 m level ranges from about 190.8 to 230.8 m^3/h, generally remaining about 204 m^3/h. There are many fractures in the thick Cambrian limestone aquifer, so it is grouted to prevent water inrush. However, the fractured Taiyuan Formation aquifers remain problematic. Figure 2 shows the direct and indirect aquifers of the No. 2 coal seam in the Pingdingshan No. 10 coal mine.

Methodology

Analogue Method

The analogue method (AM) is based on the theory of steady flow, and forecasts water inflow of new mines using the mine's datasets, based on detailed observations in analogous mines with similar mining methods and geological and hydrogeological conditions. A precondition for

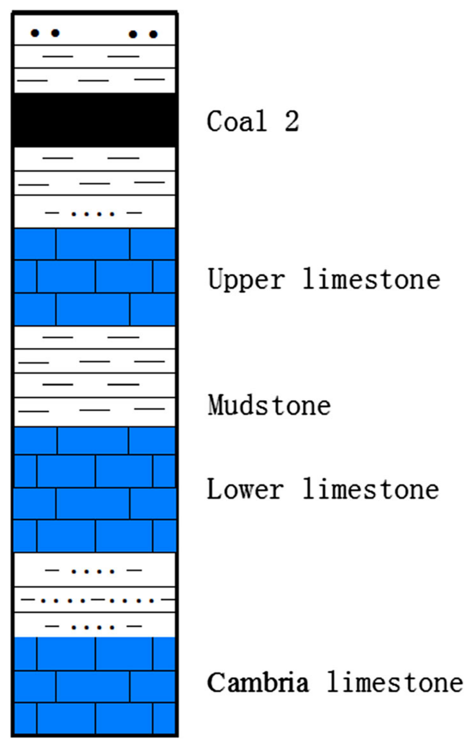

Fig. 2 The direct and indirect aquifer of the No. 2 coal seam in the Pingdingshan No. 10 coal mine

Table 1 The parameter values for the AM area

Mine level (m)	Q_1 (m^3/h)	F_1 (m^2)	F_2 (m^2)
−230	150	2.8×10^6	6.4×10^6
−300	150[a]	2.8×10^{6}[a]	7.1×10^6

[a] The −300 m level was unexploited, so the −230 m level parameter values were used, since the two levels have analogous conditions

using AM is reliable data from the earlier analogous mines (Lian et al. 2014). In this paper, we used the AM area (treating area as the variable) to forecast the mine water inflow, as in Eq. (1):

$$Q = Q_1 \sqrt{\frac{F_1}{F_2}} \tag{1}$$

where Q is the prediction of water inflow, Q_1 is the water inflow of the old mine, and where F_1 is the mining area, and F_2 is the expected mining area.

Due to long-term mining in the Pingdingshan No. 10 coal mine, there was a large goaf area. Both the No. 4 and No. 2 coal seams were to be mined at the −300 m level, for the two coal seams are located in the same geological unit and have analogous geological and hydrogeological conditions. Data from mining of the −230 m level was used (Table 1).

Big Well Method

In the big well method (BWM), the mine system is considered as a big well with an area equivalent to the mine, and equivalent water flow. Thus, the hydrogeological boundary of the mine can be generalized as the recharge boundary, and the water inflow of the big well can be calculated by the Dupuit stable well flow model (Cheng 2012), as in Eq. (2):

$$Q = \frac{2.73 KMS_2}{\lg \mathrm{R}_0 - \lg \mathrm{r}_0} \tag{2}$$

where K stands for the permeability coefficient of the aquifer, M stands for the thickness of the aquifer, R_0 stands for the influenced radius of the big well, S_2 is the drawdown of the water level, and r_0 stands for the substitute influence radius of the big well.

The upper and lower members of the Taiyuan Formation are confined aquifers with a high water yield, constituting the direct aquifer of the No. 2 coal seam. Thus, the study mainly focused on the influence of the Taiyuan Formation. Table 2 shows the parameter values using the BWM based on the data of the mine.

Numerical Simulation for Prediction of Water Inflow Using MODFLOW-2005

The mathematical model of the groundwater system used has been extensively described elsewhere (Dong et al. 2012; Wang and Anderson 1995). In this study, we built a MODFLOW-2005 (Harbaugh 2005) model for groundwater flow simulation. MODFLOW-2005, the most current release of MODFLOW, is a transient, three-dimensional, finite-difference ground-water flow model that solves the groundwater-flow equation using linear and nonlinear numerical solution methods (Niswonger et al. 2011).

In the model, the mid-northeast and southwest of the study area can be generalized as a flux boundary while other boundaries were designated as general head boundaries; five water years (May 2013–May 2018) were simulated, and the groundwater level observed in May 2013 was used to establish the initial water levels by interpolation and extrapolation (Fig. 3); based on that, we simulated the seepage field of the aquifers and forecast the water inflows.

The No. 2 coal seam is under serious threat from the underlying aquifers due to pressure; therefore, dewatering wells are required to decrease the water level to a reasonable elevation to reduce the likelihood of water inrush events.

The security level of the first mining area and deep mining area are −230 and −300 m, respectively, which were calculated by the thickness of the aquiclude floor. We separately arranged three dewatering wells (Fig. 4) in each mining area to pump water from the upper and lower members of the Taiyuan Formation; the total amount of water of all the pumped wells equals the predicted water inflow. Table 3 shows the pumping rate of each well in the different levels based on the mine's production data.

Results and Discussion

Figure 4 shows the seepage field of the (a) upper and (b) lower of the aquifers in the −230 m level after pumping, and Fig. 5 shows the seepage field of the

Table 2 The parameter values using the BWM

Parameter (Taiyuan Formation)	K (m d^{-1})	M (m)	S_2 (m)	R_0 (m)	R_0 (m)
The upper member	0.07	8.2	100.0 (−230 m)	1427.3	1691.6 (above −230 m)
					2244.1 (above −300 m)
The lower member	0.11	10.5	280.0 (−300 m)	1503.3	1759.0 (above −230 m)
					2432.0 (above −300 m)

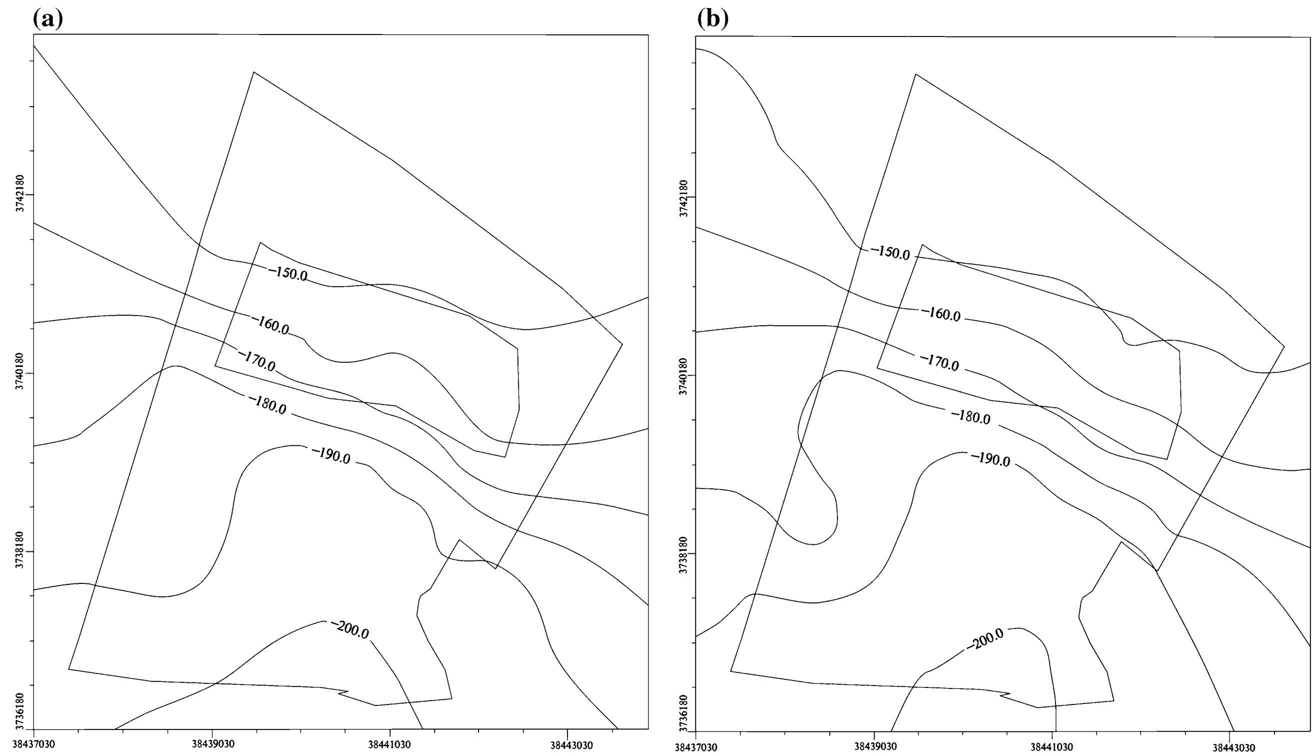

Fig. 3 The initial water levels of aquifers in the Taiyuan Formation: **a** the upper member, and **b** the lower member

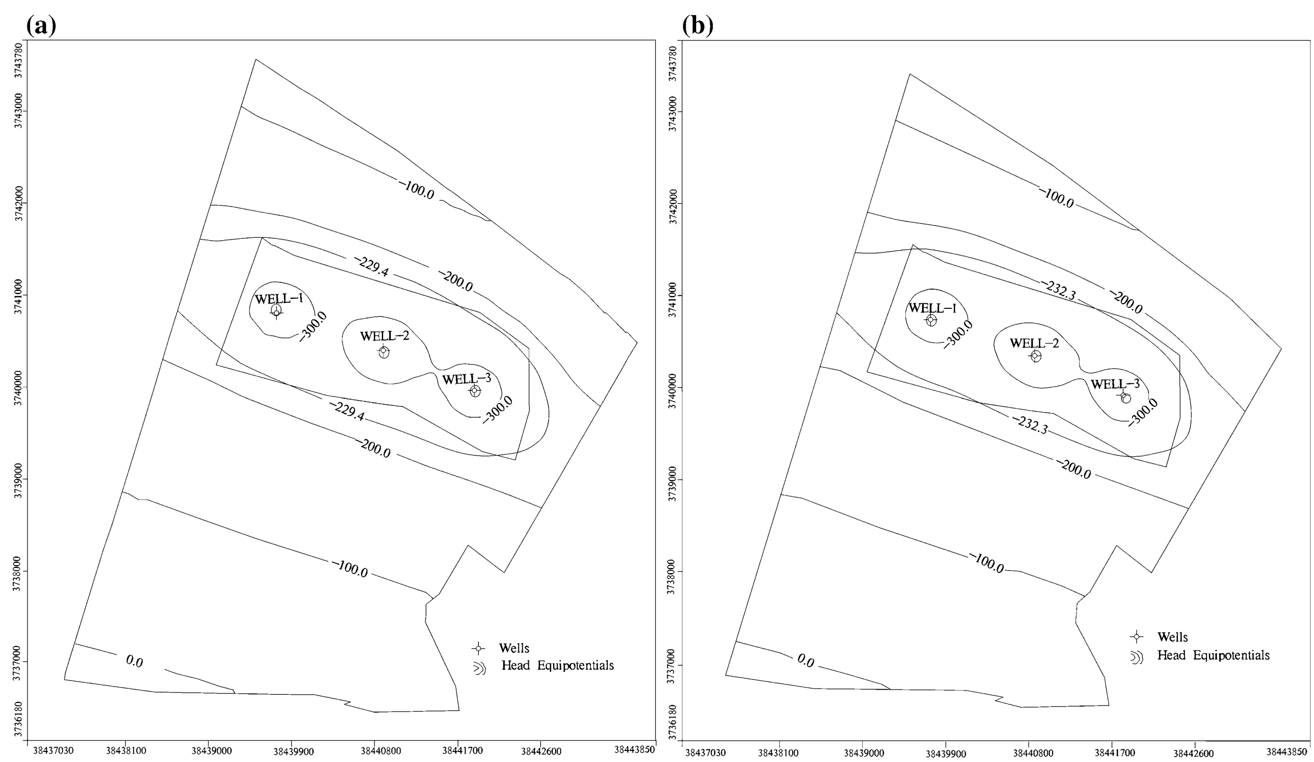

Fig. 4 The seepage field of (**a**) the upper, and **b** the lower of the aquifers in the −230 m level after pumping

Table 3 The pumping rate of each well in different levels (m^3/h)

Pumping well	The −230 m level			The −300 m level		
	Well-1	Well-2	Well-3	Well-4	Well-5	Well-6
The upper member of the Taiyuan Formation	28	30.5	32	32.3	43	38.3
The lower member of the Taiyuan Formation	35.2	40	40	33	41	41

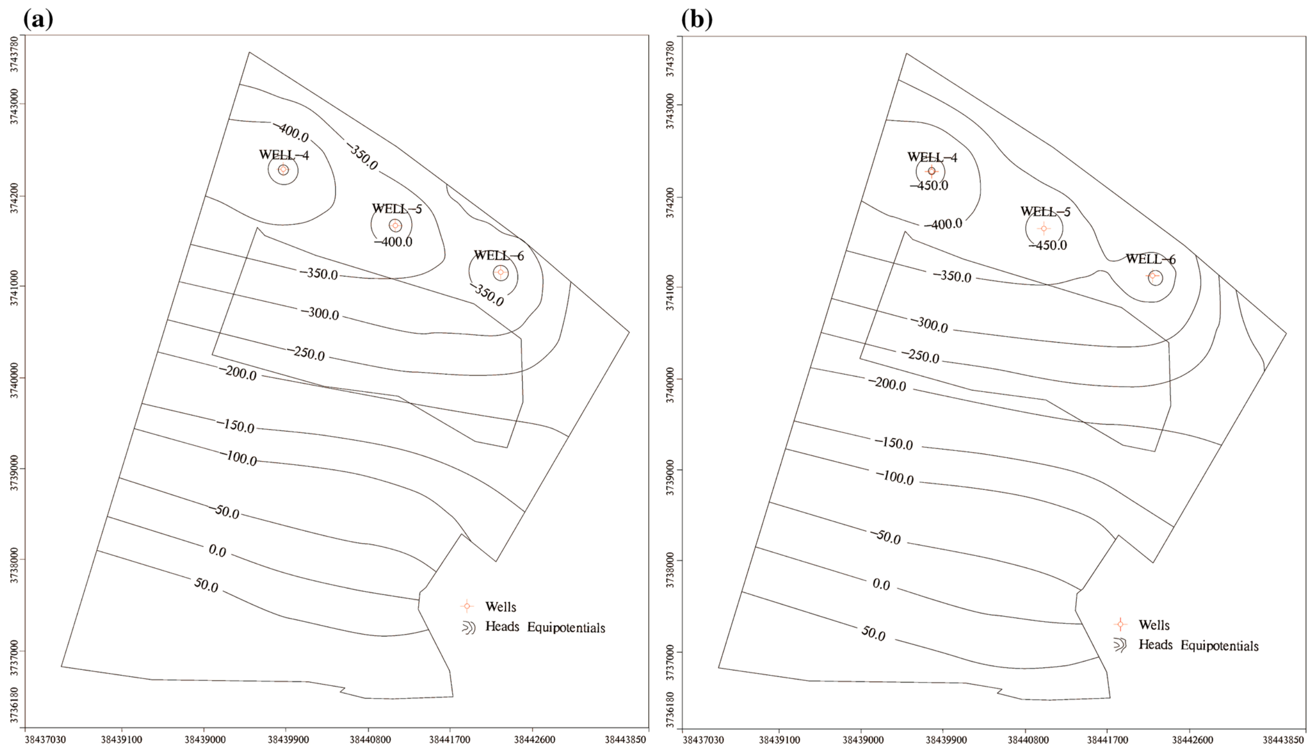

Fig. 5 The seepage field of (**a**) the upper, and **b** the lower of the aquifers in the −300 m level after pumping

(a) upper and (b) lower of the aquifers in the −300 m level after pumping. We observe that the water in the −230 and −300 m levels drop about 80 and 150 m, respectively, after pumping according to the above drainage plan, ensuring safe mining.

Table 4 shows the predicted water inflow into the No. 2 coal seam using AM, BWM, and numerical simulation.

Using AM, the water inflow of the −300 m level is greater than that of −230 m level: 238.8 and 226.8 m^3/h, respectively. In BWM, the water inflow from the upper member into the −230 m level is 89.4 m^3/h, which is less than that of the lower member; the water inflow from the upper member into the −300 m level is 105.1 m^3/h, which is also less than that of the lower member. The total inflow is 233.8 m^3/h into the −230 m level, and 281.1 m^3/h into the −300 m level. Similarly, the numerical simulation method predicted a water inflow of 90.5 m^3/h from the upper member into the −230 m and 113.6 m^3/h from the upper member into the −300 m level, which are both less than that contributed by the lower member. This is because the lower member of the Taiyuan Formation is recharged by water from the Cambrian limestone aquifer. The total amount of water calculated by the numerical model is 205.7 m^3/h in the −230 m level and 228.6 m^3/h in the −300 m level.

In addition, water inflow calculated by the three methods into the −300 m level, which has a larger mining area, were all greater than that of the −230 m level; the −300 m level also receives much more recharge from the underlying aquifers, which both lead to greater water inflow and more pumping at the deeper mining level.

We found that the BWM predicted the largest water inflow, and the numerical simulation the least, and that the calculated values were all larger than what was measured in the mine, making the numerical simulation method the most accurate in predicting water inflow. The numerical simulation method considers much more influences and has a strong description of boundaries; in addition, the numerical simulation method can also give dynamic water inflow predictions during different production stages and for different mining areas (Li 2014).

Table 4 Mine water inflow in m^3/h of the No. 2 coal seam, as calculated by AM, BWM, and numerical simulation

Mining level (m)	Area AM	BWM		Numerical simulation	
		Aquifer (Taiyuan Formation)	Total	Aquifer (Taiyuan Formation)	Total
−230	226.8	89.4/Upper member	233.8	90.5/Upper member	205.7
		144.4/Lower member		115.2/Lower member	
−300	238.8	105.1/Upper member	281.1	113.6/Upper member	228.6
		176.0/Lower member		115.0/Lower member	

The BWM prediction gave the largest error in this study because it only considered the water level changes and water yield of the aquifers and forecasted water inflow based on a comparatively ideal model, which increases the error margin, especially in areas with complex geological conditions (Hua 2009). The area AM was more reliable than the BWM in water inflow prediction, since it commendably analyzed the changes in water inflow in the old areas that had already been mined, and also considered the tectonic zonation and exploitation. However, the AM is limited by the richness of the measured data, and cannot be used without a mine that has analogous geological and mining conditions (Wenfu and Liwen 2011).

As mentioned above, the BWM can be used to predict water inflow into a mine with simple geological and boundary conditions. AM is a simple, economical, and useful method that can be used if there is a mine with abundant measured data as long as it comes from a similar area with respect to geological and mining conditions.

Conclusions

This study was undertaken to forecast mine water inflow into the No. 2 coal seam in Pingdingshan the No. 10 coal mine using multiple methods (AM, BWM, and numerical simulation), and to compare their performance. The following main conclusions were reached:

1. Water inflow calculated by AM, BWM, and numerical simulation were 226.8, 233.8, and 205.7 m^3/h, respectively, in the −230 m mining level, and 238.8, 281.1, and 228.6 m^3/h, respectively, in the −300 m mining level. BWM predicted the largest water inflow, while the numerical simulation predicted the least, which was the closest to the measured value.
2. The numerical simulation method was more accurate and fast, with inherent advantages compared to the AM and BWM. BWM has the advantage of simple calculation, and AM has the advantage of being simple and economical, but all three methods have their limits. The numerical simulation method was best at forecasting mine water inflow, especially in a mine with complex geological conditions. Using the numerical simulation method and combining it with others, as we did, is a good way to forecast and understand mine water inflow. Accurate prediction of mine water inflow is very important to safe mine exploitation. However, the problem is complex and requires more attention in the future.

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References

Adhikary D (2012) Numerical simulation of mine water inflow. In: Proceedings of international society for rock mechanics, Stockholm, Sweden. https://www.onepetro.org/conference-paper/ISRM-EUROCK-2012-078
Chen MZ, Liu SC, Yang GY (2009) The development of mining water inflow predict method. Chin J Eng Geophys 1:16 **(in Chinese)**
Cheng XB (2012) Parameter selection for prediction of water inflow using big well method. Coal 21:54–55 **(in Chinese)**
Dong D, Sun W, Xi S (2012) Optimization of mine drainage capacity using FEFLOW for the No. 14 coal seam of China's Linnancang coal mine. Mine Water Environ 31:353–360
Harbaugh AW (2005) MODFLOW-2005, the US Geological Survey modular ground-water model: the ground-water flow process. USGS, Reston
Hua JM (2009) A question against the open well method prediction of mine water inflow. N China I Sci Technol 6:74–76 **(in Chinese)**
Hua JM (2010) Unsteady flow analytic method in mine inflow computation. Coal Geol China 21:38–40 (**in Chinese**)
Li GC (2013) Application of numerical simulation in coal mine water inflow calculation. Meitan Jishu/Coal Technol 32:115–117
Li L (2014) Application of numerical simulation in water inflow prediction of mine. Coal Min Technol 19:126–128 **(in Chinese)**
Lian H, Xia X, Xu B, Xu H (2014) Evaluation and applicability study on prediction methods of water inflow in mines. N China I Sci Technol 11:22–27 **(in Chinese)**
Niswonger RG, Panday S, Ibaraki M (2011) MODFLOW-NWT, a Newton Formulation for MODFLOW-2005. USGS Tech Methods 6:A37
Peng Z, Yajun S (2012) Application of analytical method for water flow prediction of draining with mining under safe water pressure of aquifer. Zhongzhou Coal 4:10 **(in Chinese)**
Shao AJ, Meng QX, Wang SW, Liu Y (2014a) Prediction of mine inrush water based on BP neural network method. Adv Mat Res 989:1814–1820

Shao AJ, Wang S, Yang H, Liu Y (2014b) Numerical simulation and inflow prediction by the outflow test of coal mine. In: Proceedings annual international mine water association conference, Xuzhou, China, pp 31–37

Wang HF, Anderson MP (1995) Introduction to groundwater modeling: finite difference and finite element methods. Academic Press, San Diego

Wenfu W, Liwen C (2011) Comparative analysis for analogue method and analytical method in prediction of water inflow in some coal mine. China Coal 7:12 **(in Chinese)**

Wu Q, Cui FP, Zhao SQ, Liu SJ, Zeng YF, Gu YW (2013) Type classification and main characteristics of mine water disasters. J China Coal Soc 38:561–565 **(in Chinese)**