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НОВОЙ ПАРАДИГМЫ НАУКИ
В ЭПОХУ
ПОСТИНДУСТРИАЛЬНОГО ОБЩЕСТВА**

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ФОРМИРОВАНИЕ И РАЗВИТИЕ НОВОЙ ПАРАДИГМЫ НАУКИ В ЭПОХУ ПОСТИНДУСТРИАЛЬНОГО ОБЩЕСТВА: сборник статей Международной научно-практической конференции (25 июля 2026 г., г. Воронеж). - Уфа: Аэтерна, 2026. – 318 с.

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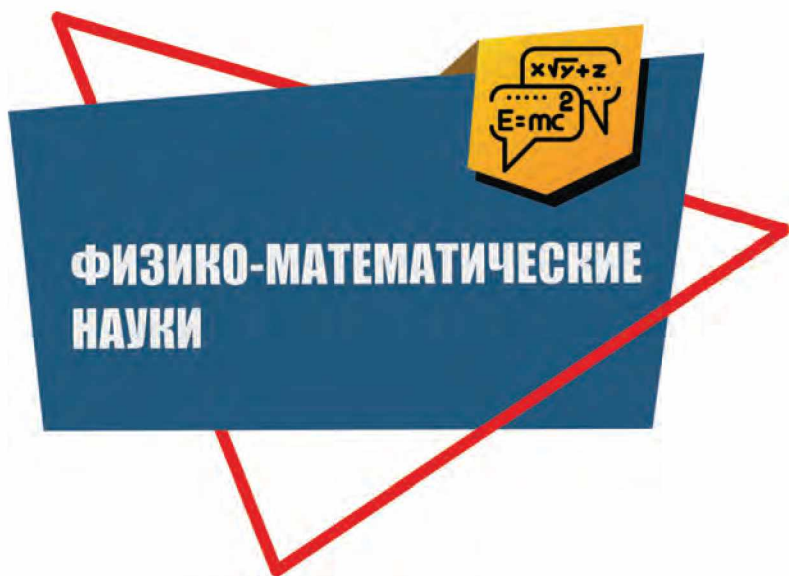
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The research results allow the use of PVA film dyed by methyl red for dosimetry in radiation processing at any time.

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DEVELOPMENT OF A MULTI - LAYER PERCEPTRON (MLP) MODEL FOR AIR TEMPERATURE PREDICTION IN COAL LONGWALL MINING FACES: A CASE STUDY AT KHE TAM COAL MINE

ABSTRACT

This study evaluates the effectiveness of different optimization algorithms for predicting air temperature in longwall mining faces at an underground coal mine operated by Duong Huy Coal Company – Vinacomin, Quang Ninh Province, Vietnam. Three optimization algorithms, namely Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Bayesian Optimization (BO), were employed to optimize the hyperparameters of a Multilayer Perceptron (MLP) neural network model. The resulting hybrid models were denoted as PSO - MLP, GA - MLP, and BO - MLP, respectively. A total of 153 datasets were collected from longwall faces operating at different mining depths and under various operating conditions. The datasets included key factors influencing air temperature in the mining faces. Model performance was evaluated using the coefficient of determination (R^2), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE). The results demonstrated that the PSO algorithm provided the most effective optimization when integrated with the MLP model, significantly improving prediction accuracy compared with the other optimization techniques. Among the developed models, the PSO - MLP model achieved the best predictive performance, with $RMSE = 0.12$, $R^2 = 0.97$, and $MAE = 0.10$. The findings confirm the potential of artificial intelligence - based hybrid models for predicting air temperature in longwall mining faces and highlight their applicability in improving environmental management and ventilation safety in underground coal mining operations.

Keywords

Longwall face air temperature; Multilayer Perceptron (MLP); Bayesian Optimization (BO); Genetic Algorithm (GA); Particle Swarm Optimization (PSO); Khe Tam Coal Mine.

1. Introduction

Khe Tam Coal Mine, operated by Duong Huy Coal Company, is currently implementing a shaft mining project extending to the - 250 m level, with a designed production capacity of 2.5 million tons per year. The mine operates 10 longwall faces simultaneously and maintains 35 development headings. The primary mining method involves drilling and blasting, while roadway support is provided by mobile hydraulic supports. Mine ventilation is predominantly based on an exhaust ventilation system consisting of five main ventilation fan stations, ensuring an adequate supply of fresh air to all underground workplaces. However, as mining activities advance to deeper levels, air temperatures in several longwall faces have shown an increasing trend, in some cases exceeding the allowable limits specified by national regulations [Ministry of Industry and Trade of Vietnam, 2011]. Elevated air temperatures not only reduce workers' concentration and productivity [Mazlomi et al., 2017] but also pose significant occupational safety risks, increasing the likelihood of accidents and operational incidents during mining activities [Varghese et al., 2018]. To develop effective mitigation measures, comprehensive studies on air temperature conditions in underground coal mines in the Quang Ninh coal basin, Vietnam, are urgently needed. Such studies are essential not only for controlling air temperature in deep mining operations but also for providing an early - warning basis and supporting the development of optimal strategies to minimize adverse impacts on mine workers. In recent years, numerous researchers have adopted artificial intelligence (AI) techniques as alternatives to conventional modeling approaches due to their superior predictive capabilities. For example, Bascompta et al. (2020) applied a multivariate regression model to predict air temperature in mine ventilation networks using variables such as air temperature, airflow quantity, and roadway length. Similarly, Truong Tien Quan et al. (2023) employed an Artificial Neural Network (ANN) model to predict air temperature in longwall faces. However, their study did not incorporate optimization algorithms for tuning the ANN hyperparameters. Although these approaches achieved promising results, their predictive accuracy remained limited, and their applicability across different mining conditions has not been fully investigated. Among AI techniques, the Multilayer Perceptron (MLP) neural network has been widely recognized as an effective tool for solving nonlinear regression problems due to its ability to learn and model complex relationships between input and output variables. Nevertheless, the predictive performance of MLP strongly depends on the selection of hyperparameters, including the number of hidden layers, the number of neurons in each layer, learning rate, batch size, and activation function. Determining an optimal set of hyperparameters remains a critical challenge for improving both prediction accuracy and model generalization. To address this issue, various optimization techniques have been proposed. Among them, the Genetic Algorithm (GA) [Carr et al., 2014], Particle Swarm Optimization (PSO) [Eberhart and Kennedy, 1995; Nguyen et al., 2019], and Bayesian Optimization (BO) [Snoek et al., 2012] are widely used due to their effectiveness in exploring complex search spaces. These optimization methods offer several advantages, including global search capability, reduced risk of becoming trapped in local optima, and improved efficiency in identifying optimal hyperparameter configurations for machine - learning models. Although previous studies have reported encouraging results, the application of advanced optimization algorithms to enhance the performance of MLP models for longwall face air - temperature prediction remains relatively limited, particularly under the geological and operational conditions of underground coal mines in Vietnam. Therefore, the development of more accurate hybrid models is necessary to support ventilation design, underground microclimate management, and

occupational safety in coal mining operations. Accordingly, this study aims to evaluate the effectiveness of three optimization algorithms—PSO, GA, and BO—in combination with the MLP model for predicting air temperature in longwall faces at Khe Tam Coal Mine. Three hybrid models, namely PSO - MLP, GA - MLP, and BO - MLP, were developed and compared. Model performance was evaluated using the coefficient of determination (R^2), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE), with the objective of identifying the most suitable predictive model for the investigated problem.

2. Theoretical Background of MLP - Based Optimization Algorithms

As outlined in the previous section, the primary objective of this study is to develop and evaluate hybrid prediction models based on a Multilayer Perceptron (MLP) neural network integrated with three optimization techniques: Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Bayesian Optimization (BO). Given that the theoretical foundations of MLP, PSO, GA, and BO have been comprehensively documented in the literature, only a brief overview is provided herein. The focus of this study is placed on the construction and performance evaluation of the proposed hybrid models for predicting air temperature in underground coal mine longwall faces. An MLP is a feedforward neural network architecture composed of an input layer, one or more hidden layers, and an output layer. Each neuron processes information received from the previous layer through a weighted linear combination followed by a nonlinear activation function. The output of a neuron can be mathematically represented by Equation (1) [Haykin, 2009].

$$y = f \left(\sum_{i=1}^n w_i x_i + b \right) \#(1)$$

where x_i - represents the input variables, w_i - denotes the connection weights, b - is the bias term, $f(\cdot)$ - is the activation function, and y - is the output of the neuron.

The predictive performance of the MLP model is significantly influenced by the choice of hyperparameters, including the number of hidden layers, the number of neurons per layer, learning rate, batch size, training epochs, and activation function. Identifying the optimal hyperparameter configuration remains a challenging optimization problem because of the large search space and the complex nonlinear characteristics of the model. In this study, Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Bayesian Optimization (BO) were employed to automatically determine the optimal hyperparameter configuration of the MLP model. Three corresponding hybrid models, namely PSO - MLP, GA - MLP, and BO - MLP, were developed and evaluated. For each hybrid model, the optimization algorithm explores the hyperparameter search space to identify the configuration that maximizes predictive accuracy while minimizing model prediction error. The Root Mean Square Error (RMSE) was selected as the objective function for the optimization process. The RMSE is widely used to quantify the discrepancy between predicted and observed values and is defined by Equation (2) [Hastie et al., 2009].

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \#(2)$$

Where (y_i) denotes the observed value, $(\hat{y}_i)$ denotes the corresponding predicted value generated by the model, and n represents the number of data samples.

For each optimization technique, the hyperparameter configuration corresponding to the lowest RMSE value is selected as the optimal MLP model configuration. The optimization process is conducted through multiple iterations to improve the exploration of the search space and increase the probability of obtaining a globally optimal solution. Following the training and optimization stages, the three hybrid models, namely PSO - MLP, GA - MLP, and BO - MLP, are evaluated using the coefficient of determination (R^2), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). Figure 1 presents the overall framework of the proposed hybrid models for longwall face air - temperature prediction, illustrating the complete workflow from data acquisition and preprocessing to model training, hyperparameter optimization, and performance assessment.

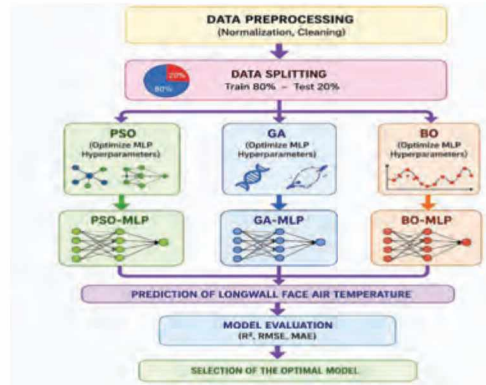


Figure 1. Overall Framework of the Proposed Hybrid Models

3. Model Performance Evaluation Metrics

The predictive performance and reliability of the developed models were assessed using three widely adopted statistical metrics: Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and the coefficient of determination (R^2). These metrics provide quantitative measures of the agreement between the predicted and observed values and are expressed by Equations (3), (4), and (5), respectively [Hastie et al.,2009].

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad \#(3)$$

$$R^2 = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \bar{y}_i)^2} \quad \#(4)$$

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \quad \#(5)$$

where:

n : number of samples;

y_i : observed (actual) value of the i th sample;

$\hat{y}_i$: predicted value of the i th sample;

$\bar{y}_i$: mean value of the observed data.

MSE quantifies the overall magnitude of prediction errors, giving greater weight to larger deviations due to the squared - error term. Therefore, a smaller RMSE value indicates better predictive performance. R^2 measures the explanatory power of the model by quantifying the proportion of variance in the dependent variable explained by the model. Its values range from 0 to 1, with values approaching 1 indicating a stronger agreement between predicted and observed values. MAE represents the average absolute deviation between predicted and observed values. Unlike RMSE, MAE treats all prediction errors equally and is less sensitive to large outliers, providing a straightforward measure of prediction accuracy.

4. Study Area and Dataset Description

4.1. Study Area

The study area includes all longwall faces operated using the drilling - and - blasting mining method and supported by ZRY; XDY; ZH and GK hydraulic support systems. A schematic representation of the drilling - and - blasting longwall face employed in this study is shown in Figure 2.

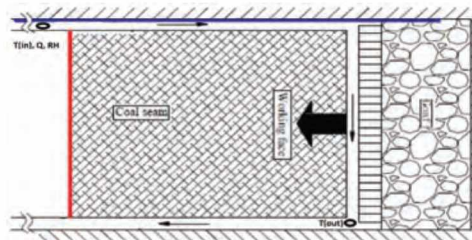


Figure 2. Layout of the Study Area

4.2. Dataset Description

Data used in this study were collected from sensor monitoring systems, records obtained from the Mine Rescue Center of VINACOMIN [Mine Rescue Center, 2023–2025], and field measurements conducted at the mine. The datasets were gathered from multiple longwall mining faces and included the following parameters: inlet air temperature at the longwall face, T_{in} ($^{\circ}\text{C}$), ranging from 24 to 29 $^{\circ}\text{C}$; average relative humidity, RH (%), ranging from 86 % to 96 %; mining depth, D (m); mining district length, L (m); installed power of mining equipment, P (kW); coal production rate, A (t / day), ranging from 200 to 500 t / day; airflow quantity through the mining district, Q (m^3 / s), ranging from 4 to 8 m^3 / s; and outlet air temperature at the longwall face, T_{out} ($^{\circ}\text{C}$), ranging from 25 to 30 $^{\circ}\text{C}$. The collected data cover the period from 2023 to 2025.

The dataset collected during 2023–2025 reveals considerable variations in both microclimatic and mining operating conditions across different longwall faces. The inlet air temperature varied between 24 and 29 $^{\circ}\text{C}$, while the outlet air temperature ranged from 25 to 30 $^{\circ}\text{C}$. This increase in temperature indicates that the airflow absorbed heat from the surrounding rock mass, mining equipment, and production activities as it passed through the mining district, resulting in higher temperatures at the longwall face outlet.

The relative humidity remained consistently high, ranging from 86 % to 96 %, which reflects the typical humid conditions of underground coal mines. Such conditions are largely influenced by groundwater, process water used during mining operations, and heat - moisture exchange between

the airflow and surrounding rock strata. The combination of elevated humidity and temperature can significantly affect the underground working environment and thermal comfort of mine workers.

Variations in mining depth and mining district length indicate that the collected data encompass a wide range of geological and operational conditions. From a theoretical perspective, increasing mining depth is generally associated with higher virgin rock temperatures and stronger geothermal effects, which contribute to elevated underground air temperatures.

The installed power of mining equipment and coal production rates represent different production intensities among longwall faces. These factors are important heat sources generated by electric motors, mechanical friction, and coal extraction activities. In addition, the airflow quantity varied between 4 and 8 m³ / s, indicating that the ventilation system was adjusted according to production requirements in order to dissipate heat and maintain safe working conditions.

Overall, the selected input variables, including inlet air temperature, relative humidity, mining depth, mining district length, equipment power, production rate, and airflow quantity, have clear physical significance and are expected to influence the outlet air temperature of the longwall face either directly or indirectly. Therefore, the use of these variables as inputs for the MLP, PSO - MLP, GA - MLP, and BO - MLP models is both scientifically justified and practically meaningful for underground mine air - temperature prediction. The distribution of the collected variables is illustrated in Figure 3.

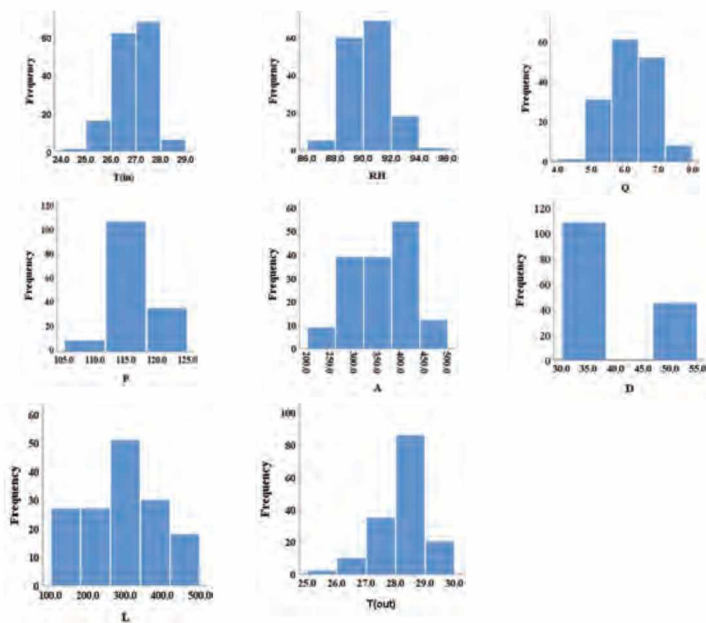


Figure 3. Frequency Distributions of the Research Dataset

5. Results and Discussion

The dataset consisting of 153 observations was randomly partitioned into training and testing subsets. Specifically, 80 % of the data were used for model training and development, whereas the

remaining 20 % were utilized for independent model validation. To improve model convergence and mitigate the risks of overfitting and underfitting, the dataset was normalized before the training process. Furthermore, five - fold cross - validation was adopted during model development to ensure robustness and enhance the generalization performance of the proposed models.

5.1. MLP Model

For the Multilayer Perceptron (MLP) model, the training dataset was employed to develop an air - temperature prediction model for underground coal mines. The network architecture comprised an input layer, two hidden layers, and an output layer. The hidden layers contained 10 and 5 neurons, respectively, and the Rectified Linear Unit (ReLU) activation function was adopted to improve the model's capability to learn complex nonlinear relationships between the input and output variables. Model training was performed using the backpropagation learning algorithm coupled with a suitable optimization technique to minimize the prediction error. After the training process was completed, the developed model was applied to predict air temperature in the underground mining environment. Figure 4 illustrates the prediction performance of the MLP model, including the relationship between the predicted and observed values obtained from the testing dataset.

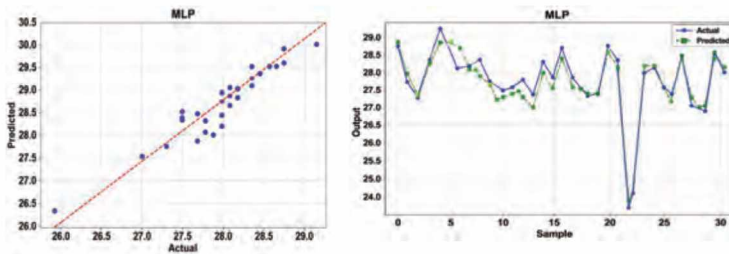


Figure 4. Relationship Between Predicted and Observed Air Temperatures on the Testing Dataset for the Baseline MLP Model

5.2. PSO - MLP Model

Initially, a Multilayer Perceptron (MLP) model was established to develop an air - temperature prediction model for underground coal mines. Subsequently, the Particle Swarm Optimization (PSO) algorithm was employed to optimize the hyperparameters of the MLP network, including the number of neurons in the hidden layers, the regularization coefficient (α), and the learning rate. The PSO algorithm was configured using several control parameters, including the swarm size (p), inertia weight (w), cognitive learning coefficient (c_1), and social learning coefficient (c_2). During the optimization process, each particle represented a candidate set of MLP hyperparameters and continuously updated its position based on both its personal best experience and the global best solution found by the swarm, thereby searching for the global optimum within the hyperparameter space. The Root Mean Square Error (RMSE), defined in Equation (4), was adopted as the objective function, and the optimal hyperparameter configuration was determined as the one corresponding to the minimum RMSE value. Each PSO - MLP model was executed for a maximum of 5,000 iterations to ensure convergence of the optimization process and identification of the optimal network configuration. After the optimization stage, the MLP model with the optimal

hyperparameter set was trained using the backpropagation algorithm to predict air temperature in the underground mining environment. The prediction performance of the PSO - MLP model on the testing dataset is presented in Figure 5.

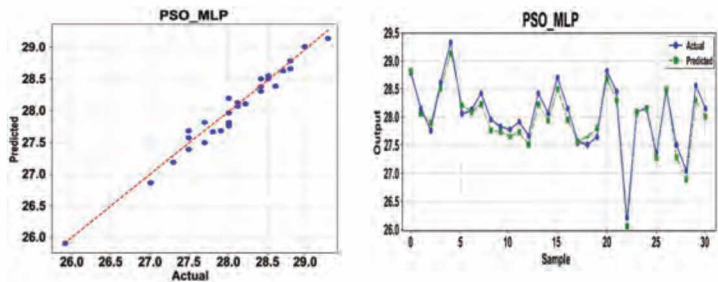


Figure 5. Relationship Between Predicted and Observed Air Temperatures on the Testing Dataset for the PSO - MLP Model

5.3. GA - MLP Model

In this study, the GA - MLP (Genetic Algorithm–Multilayer Perceptron) model was developed using the training dataset to predict air temperature in underground coal mines. The MLP network was constructed with the ReLU activation function and a two - hidden - layer architecture. To enhance the predictive performance of the model, the Genetic Algorithm (GA) was employed to optimize the hyperparameters of the MLP network, including the number of neurons in the hidden layers, the regularization coefficient (alpha), and the learning rate. The optimization process was performed based on the principles of biological evolution, in which each individual in the population represented a candidate set of MLP hyperparameters. The fitness of each individual was evaluated using the Root Mean Square Error (RMSE), defined in Equation (4), as the objective function. Through the genetic operations of selection, crossover, and mutation, the population evolved over successive generations to identify the optimal hyperparameter configuration that minimized the RMSE value. Upon completion of the optimization process, the best - performing hyperparameter set was used to construct the final MLP model. The optimized model was subsequently trained using the backpropagation algorithm and applied to predict air temperature in the underground mining environment. The prediction results of the GA - MLP model on the testing dataset are presented in Figure 6.

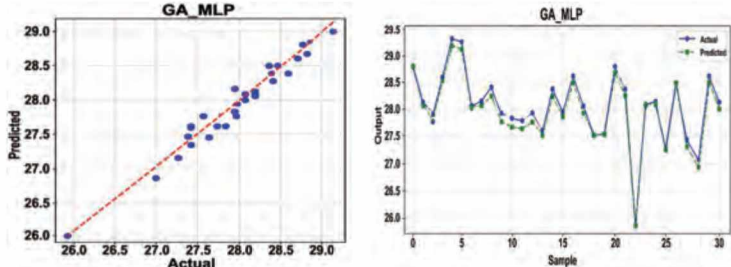


Figure 6. Relationship Between Predicted and Observed Air Temperatures on the Testing Dataset for the GA - MLP

5.4. BO - MLP Model

In this study, the BO - MLP (Bayesian Optimization–Multilayer Perceptron) model was developed using the training dataset to predict air temperature in underground coal mines. The MLP network was constructed with the ReLU activation function and a two - hidden - layer architecture. To improve prediction accuracy, Bayesian Optimization (BO) was employed to identify the optimal hyperparameter configuration of the MLP model. The optimization process focused on several key hyperparameters, including the number of neurons in the hidden layers, the regularization coefficient (alpha), and the learning rate. Bayesian Optimization constructs a surrogate model based on previously evaluated hyperparameter configurations to approximate the relationship between the hyperparameters and model performance. Based on this surrogate model, an acquisition function is utilized to select the most promising hyperparameter configuration for the next evaluation, thereby balancing the exploitation of high - performing regions and the exploration of unexplored regions within the search space. The Root Mean Square Error (RMSE), defined in Equation (4), was adopted as the objective function, and the optimal hyperparameter configuration was determined as the one corresponding to the minimum RMSE value. After the optimization process was completed, the optimal hyperparameter set obtained from Bayesian Optimization was used to construct the final MLP model. The optimized model was subsequently trained using the backpropagation algorithm and applied to predict air temperature in the underground mining environment. The prediction performance of the BO - MLP model on the testing dataset is presented in Figure 7.

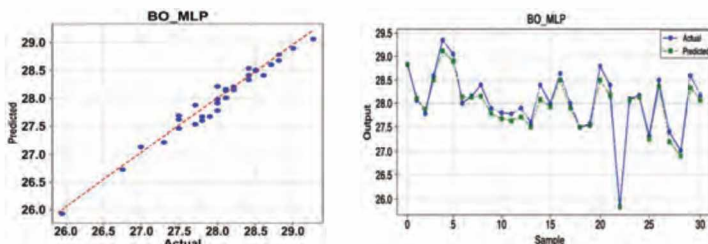


Figure 7. Relationship Between Predicted and Observed Air Temperatures on the Testing Dataset for the BO – MLP

5.5. Performance Evaluation of the Developed Models

After obtaining the optimal parameters for the four models, 30 test datasets were used to validate the accuracy of the developed models. Table 3 presents the results of the 4 models on the testing datasets. The model evaluation results based on three criteria—RMSE, R^2 , and MAE—are shown in Table 1

Table 1. Results of the 4 models on the testing datasets.

Model	Testing dataset		
	RMSE	R2	MAE
MLP	0.19	0.91	0.15
PSO - MLP	0.12	0.97	0.1

GA - MLP	0.12	0.96	0.1
BO - MLP	0.13	0.96	0.11

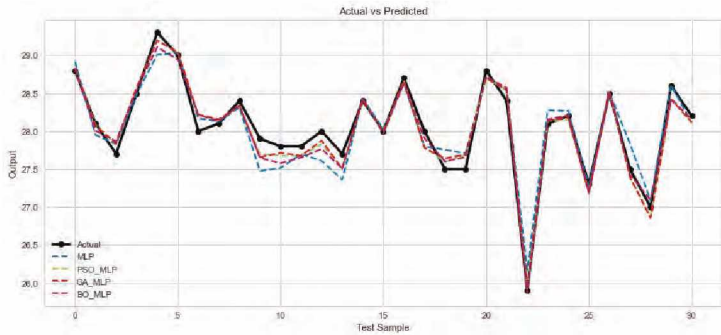


Figure 8. Comparison of predicted and actual results across the models.

Based on the results in Table 1 and Figure 4, the performance of the MLP, PSO - MLP, GA - MLP, and BO - MLP models on the testing dataset was evaluated using the RMSE, R^2 , and MAE metrics. The results show that all models achieved high prediction accuracy, with R^2 values greater than 0.90. However, the hybrid models incorporating optimization algorithms consistently outperformed the traditional MLP model.

The MLP model obtained RMSE, MAE, and R^2 values of 0.19, 0.15, and 0.91, respectively. These results indicate that the model has relatively good predictive capability; however, the prediction error remains relatively high due to the hyperparameters being selected using a conventional approach. The traditional MLP model also shows larger deviations at locations with strong temperature fluctuations, particularly in the sample ranges from 8 to 13 and from 27 to 29. This suggests that the model's generalization ability is limited when its hyperparameters are not properly optimized.

When the Particle Swarm Optimization (PSO) algorithm was applied, the predictive performance improved significantly. The PSO - MLP model achieved RMSE = 0.12 and MAE = 0.10, representing reductions of approximately 36.8 % and 33.3 % compared to the MLP model, respectively. At the same time, the coefficient of determination increased from 0.91 to 0.97, indicating that the model can explain up to 97 % of the variability in the observed temperature data. Among all evaluated models, this is the best - performing model.

Similarly, the GA - MLP model also produced strong results, with RMSE = 0.12, MAE = 0.10, and $R^2 = 0.96$. Compared to the MLP model, the prediction errors were significantly reduced and the coefficient of determination increased, demonstrating that the genetic algorithm effectively supports the search for optimal MLP hyperparameters. However, the performance of GA - MLP is still slightly lower than that of PSO - MLP.

For the BO - MLP model, the RMSE, MAE, and R^2 values were 0.13, 0.11, and 0.96, respectively. Although the predictive performance is considerably better than that of the original MLP model, it is still marginally lower than that of the PSO - MLP and GA - MLP models. This indicates that Bayesian Optimization improves the predictive capability of the MLP network, but does not achieve the same level of optimality as PSO for this dataset.

Overall, integrating optimization algorithms into the MLP network significantly reduces prediction errors and improves the coefficient of determination. The hybrid models PSO - MLP, GA - MLP, and BO - MLP demonstrate strong predictive performance, with predicted values closely matching the actual data across most testing samples. Among them, the PSO - MLP model shows the highest degree of agreement, particularly at the peak and trough points of the dataset. This is consistent with the quantitative evaluation results using RMSE, MAE, and R^2 , where PSO - MLP achieved RMSE = 0.12, MAE = 0.10, and $R^2 = 0.97$. Therefore, PSO - MLP is considered the most suitable model for predicting underground mine air temperature in this study dataset.

6. Conclusion

Artificial Intelligence (AI) has been increasingly applied in engineering fields due to its ability to process complex data and improve the accuracy of predictive tasks. In underground mining, air temperature prediction plays a crucial role in ventilation design, microclimate control, and ensuring safe working conditions for miners. In this study, the MLP, PSO - MLP, GA - MLP, and BO - MLP models were developed and evaluated to predict air temperature in the longwall face based on mining and ventilation parameters.

The main conclusions of this study can be summarized as follows:

(1) Machine learning models based on MLP neural networks are capable of effectively predicting underground air temperature. However, integrating hyperparameter optimization algorithms significantly improves prediction performance compared to the traditional MLP model.

(2) The optimization algorithms PSO, GA, and BO all contribute to reducing prediction errors and improving the coefficient of determination. Compared to the MLP model, the hybrid models achieve lower RMSE and MAE values and higher R^2 values, demonstrating a better ability to model the nonlinear relationships between influencing factors and longwall air temperature.

(3) Among the evaluated models, the PSO - MLP model achieved the best performance with RMSE = 0.12, MAE = 0.10, and $R^2 = 0.97$ on the testing dataset. This indicates that Particle Swarm Optimization (PSO) is more effective in searching for optimal hyperparameters compared to GA and BO for this dataset, thereby significantly enhancing the accuracy and stability of the predictive model.

(4) The study confirms the potential of AI - based models, particularly PSO - MLP, for underground mine air temperature prediction. The model can be used as a supportive tool for ventilation system design, management, and microclimate control in underground coal mining operations.

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СМЕНА НАУЧНОЙ ПАРАДИГМЫ В НАУКАХ О ЗЕМЛЕ: ОТ ГЕОЛОГО - ГЕОФИЗИЧЕСКОГО РЕДУКЦИОНИЗМА К СИСТЕМНОЙ ГЕОКИБЕРНЕТИКЕ

Аннотация. В условиях постиндустриального общества анализируется исчерпание классической парадигмы в науках о Земле и обосновывается переход к системной геокибернетике, синтезирующей большие данные, искусственный интеллект и цифровые двойники планеты. Показано, что этот сдвиг — закономерный этап эволюции научной рациональности в антропоцене, где знание становится фактором управления планетарным гомеостазом.

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