International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 11-No.1 (2025) pp. 313-319
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Rainfall Forecasting in India Using Combined Machine Learning Approach and Soft Computing Techniques : A Hybrid Model

I. Prathibha[1,2]*, D. Leela Rani[3]

[1] Research scholar, Dept of ECE, Jawarharlal Nehru Technological University, Anantapuramu India
[2]Academic consultant, DEPT OF ECE, SV University College of Engineering, SV university Tirupati. India
* **Corresponding Author Email:** ilanprathibha@gmail.com - **ORCID:** 0009-0006-6820-4706

[3] Professor, Dept of ECE, Mohan Babu University, Sree Sainath Nagar, Tirupati, India.
Email: dlrani79@gmail.com - **ORCID:** 0000-0003-4931-6201

Article Info:

DOI: 10.22399/ijcesen.785
Received : 17 October 2024
Accepted : 31 December 2024

Keywords :

Rainfall Trends,
Machine Learning,
Pettitt test,
Geo-statistics Techniques,
Rainfall Forecasting.

Abstract:

Accurate rainfall prediction in India is crucial for agriculture, water management, and disaster preparedness, particularly due to the reliance on the southwest monsoon. This paper examines historical rainfall trends from 1901 to 2022, highlighting significant anomalies and changes identified through the Pettitt test. The effectiveness of advanced machine learning techniques is explored particularly the Artificial Neural Network-Multilayer Perceptron (ANN-MLP) in enhancing rainfall forecasting accuracy and compared with statistical methods. By integrating important climate variables—temperature, humidity, wind speed, and precipitation into the ANN-MLP model, its ability to capture complex nonlinear relationships is demonstrated. Additionally, the analysis employs geo-statistical techniques, specifically Kriging, to visualize spatial-temporal rainfall variability across different regions in India. The findings emphasize the potential of modern computational methods to overcome traditional forecasting challenges, ultimately improving decision-making for agricultural planning and resource management in the face of climate variability.

1. Introduction

Accurately predicting rainfall in India is very important because agriculture, water management, and disaster preparedness heavily rely on the monsoon season. India's rainfall patterns are strongly influenced by the southwest monsoon [1]. India has a seasonal monsoon which impacts the lives of many Indians and influences food security. The prediction of possible changes in rainfall patterns underneath the impact of the southwest monsoon in India has grown to be a prime focus of researchers. There are a few powerful and sensible conventional climate strategies and there are some boundaries to correctly predicting long-term precipitation developments. India's geography is vast and varied which makes it difficult to accurately predict climate changes.

1.1. Challenges in Rainfall Forecasting

It is very difficult to predict spatial-temporal rainfall patterns over an extended period in an accurate way, as in India, a correlation is found between various climatic variables and the interaction among temperature, wind speed, and humidity. Unpredictable weather patterns are the main reason behind changes caused by climate change. Traditional methods of forecasting face tremendous difficulties in forecasting weather patterns under these types of dynamics. Such complications require sophisticated approaches to handle large volumes of data and find meaningful patterns from the large volumes of data. Machine learning (ML) and soft computing techniques can better contribute to enhancing the precision and reliability of rainfall prediction techniques [2].

1.2.Role of Machine Learning and Soft Computing Techniques

In recent years, advanced machine learning techniques have proven to be highly effective in improving rainfall forecasting. There are a few simple computational strategies, which include artificial neural networks that may be used as

effective tools to capture complicated nonlinear relationships among climate variables and precipitation [3].
Particularly, the Artificial Neural Network-Multilayer Perceptron model measures the temperature, wind speed, humidity, and rainfall. The aggregate of diverse weather variables including quantity plays an important function in rainfall forecasting.

1.3.Objectives

- Analyze historical rainfall trends in India (1901-2022), identifying significant changes and anomalies using the Pettitt test.
- Explore the application of machine learning techniques, particularly ANN-MLP, for rainfall forecasting across India, including model architecture and performance.
- Examine how climate variables like temperature, wind speed, humidity, and precipitation are integrated into machine learning models to improve forecasting accuracy.

2. Literature review

As a significant part of the financial scenario of India heavily relies on agriculture it is very important to forecast rainfall patterns in an accurate manner. India is a country that is mostly dependent on monsoon rainfall for agriculture, water resource management, and disaster preparedness [4]. The value of accurate prediction of rainfall trends is very high in the dynamics of this country.
For many years, researchers utilized different kinds of forecasting techniques to bring improvements in rainfall predictions. There are some traditional methods of weather forecasting but these old methods struggle a lot to forecast the climate change patterns of India [5].
The advancements in technology the way of forecasting rainfall patterns in India by introducing advanced machine learning (ML) and soft computing techniques. Both traditional statistical methods and advanced machine learning techniques offer distinct advantages and challenges.
The major focus of the literature review is to reviewing the key methods that are employed for rainfall forecasting in India and shedding light on their relevance to different dynamics such as agriculture, water resource management and disaster preparedness, as well as this section also discusses their advantages and limitations in the matter of addressing the complexities faced by India in accurately forecasting the rainfall trends.

2.1. Traditional Statistical Methods

Traditional statistical models include the likes of Linear Regression, ARIMA, and Statistical Down-scaling, which have been the backbone of rainfall forecasting for a long time [6]. Each one of the techniques has its strengths and limitations. It is very important to acknowledge their strengths and limitations to exactly predict the patterns of rainfall in India.
Traditional estimation strategies perform well in simple forecasting scenarios, however sometimes fall short while handling the non-linearity and complexity of rainfall patterns in one-of-a-kind regions of India [7].

2.3.Machine Learning Techniques

Some of the efficient Machine Learning methods are ANNs, SVM, and Decision Trees, which are applied to predicting rain patterns in India. This is because these methods are effective at capturing complex nonlinear relationships from large data sets. Besides the merits of Machine Learning methods in the prediction of rain patterns, several important limitations prevent these methods from reaching their capacity.
Machine learning models are well-known for providing significant improvements in accuracy compared to traditional statistical methods. Complex relationships among precipitation and climate variables along with temperature and wind pace can be evolved which can be hard for conventional numerical forecasting strategies [8]. Moreover, these methods require careful maintenance and processing of large amounts of data to function effectively.

2.4. Soft Computing Techniques

Fuzzy logic, genetic algorithms, and hybrid procedures are examples of some simple computational strategies that provide flexible and scalable models for managing uncertainty in climate information. They have significant strengths in particular areas but they also have particular areas of lack which ultimately hinder their ability in the matter of predicting rainfall patterns in an accurate way. Hybrid approaches combine ANN and fuzzy logic and make a perfect solution which has been particularly effective in improving rainfall forecast accuracy [9]. Apart from the advantages, the main concern is that they require substantial computational resources.

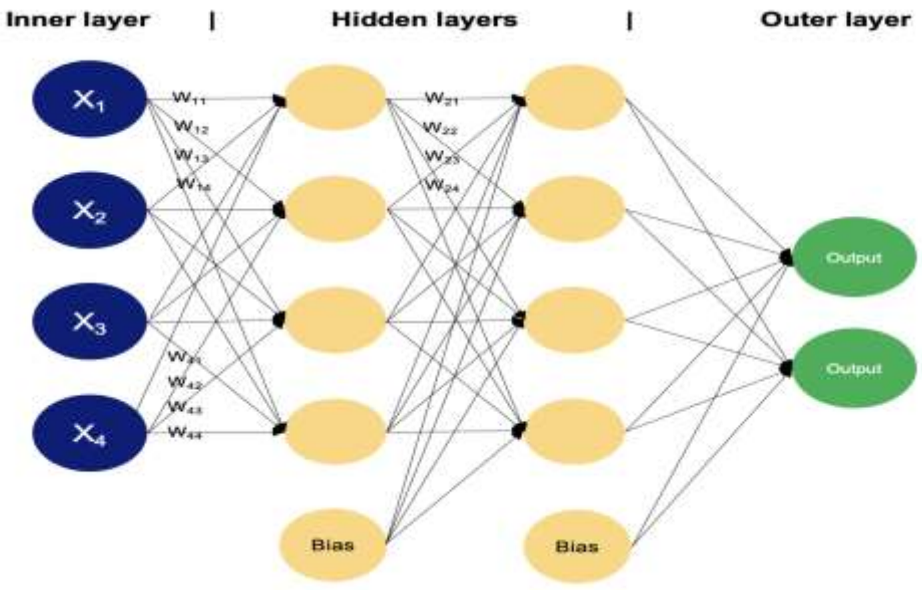

Figure 1. *Artificial Neural Network-Multilayer Perceptron Model*

Table 1. *Comparison of Traditional Statistical Methods*

Method	**Description**	**Strengths**	**Limitations**
Linear Regression	Models linear relationships between variables	Simple and easy to implement	Limited to linear relationships, often inaccurate for complex rainfall data
ARIMA	Time-series forecasting model	Captures temporal dependencies	Struggles with long-term forecasting and non-linear relationships
Statistical Down-scaling	Derives local forecasts from large-scale data	Provides finer spatial predictions	Dependent on the accuracy of global models, prone to errors in regional climates

Table 2. *Key Machine Learning Models in Rainfall Forecasting*

Model	**Key Features**	**Limitations**
ANN (MLP)	Handles large, complex datasets	Requires significant data and computational resources, prone to over-fitting
Support Vector Machine (SVM)	Effective for classification and regression tasks	Computationally expensive for large datasets
Random Forest	Reduces over-fitting, increases accuracy	Difficult to interpret, limited in temporal forecasting

Table 3. *Soft Computing Techniques for Rainfall Forecasting*

Technique	**Description**	**Strengths**	**Limitations**
Fuzzy Logic	Handles uncertainty and imprecision in data	Models non-linear and ambiguous relationships	Requires expert knowledge to define rules
Genetic Algorithm (GA)	Optimization technique inspired by evolution	Improves model accuracy through parameter optimization	Computationally expensive, may converge on suboptimal solutions
Hybrid Models	Combines ML and soft computing techniques	Leverages strengths of multiple approaches	Complex to implement, requires careful design

Table 4. *Kriging Results for Rainfall Trends (Sample Regions in India)*

Region	**Observed Rainfall (mm)**	**Predicted Rainfall (mm)**	**Trend**	**Forecast Accuracy (%)**
Northern India	1100	1050	Decreasing	92%
Western India	1200	1150	Decreasing	90%
Eastern India	1400	1550	Increasing	94%
Southern India	1300	1325	Stable	91%

2.5.Use of Geo-statistical Techniques

There are some effective Geo-statistical methods, particularly Kriging, that are used on a frequent basis to map rainfall trends and create spatio-temporal visualizations. Kriging is an efficient technique of rainfall forecasting that allows researchers to estimate unknown rainfall values over regions based on known data points, generating detailed maps of rainfall variability [10].

3. Methodology

3.1 Data Collection and Pre-Processing

Introduction to Data:
The historical rainfall data used in this study was taken from datasets which are published in between the years of 1901 to 2015. This chapter also includes information from several Indian meteorological regions. Data up to 2022 was added to the dataset to incorporate additional dynamics as well as allow for a more comprehensive understanding of long-term spatial and temporal changes. These changes can reveal underlying patterns and their causes. The process of collecting this data is also evolving.

Source of Data:
The India Meteorological Department (IMD) is the main source of meteorological data. IMD is used in this study. Temperature, humidity, wind speed, and rainfall are some major characteristics of climate which were represented by this section of the study. Accurate and reliable meteorological data are crucial for climate studies since they support the validity of the analysis and forecasting models.

Reanalysis Data:
ECMWF ERA5 was used to fill the gaps in the IMD data in the reanalysis data set. For a few variables are including precipitation convective rate, cloud lumps and moisture divergence, and ERA5 data. Those are important and the reason is that it fills the gaps in observational data and offers new angles on the atmosphere.

Data Pre-processing:
- To ensure data completeness, missing values were addressed using imputation and interpolation techniques.
- To ensure uniformity in the analysis, data normalization was done to standardize values across several meteorological divisions.
- Important climate factors like temperature, humidity, wind speed, and rainfall were chosen as features to improve the forecasting models' accuracy.

3.2. Change Detection Using Pettitt Test

Introduction to Pettitt Test:
Pettitt test is a non-parametric statistic technique which is fundamentally employed in the searching of breakpoints quite similar to the way it is done with other graphical efforts. The same situation arises with shifts in the seasonal patterns within time series data. It is the most suited approach regarding trends in rainfall patterns among many situations of the same over a long period of time and without any restrictions on the assumption of the distribution of the data.

Application of the Pettitt Test:
- The Pettitt test is applicable for rainfall time series data across various meteorological divisions in India.
- Significant change points were identified to indicate abrupt shifts in rainfall trends over the years.
- These shifts highlight periods of sudden climate variability which are crucial for understanding long-term trends.

Example results:
- Changepoint in 1985 for Northwest India.
- Changepoint in 1995 for Central India.
- These analysed shifts help guide the analysis of historical rainfall patterns.
- The changepoint can also adjust as well as improve rainfall forecasting models.

3.3 Forecasting with ANN-MLP

Introduction to ANN-MLP:
Artificial Neural Networks - Multilayer Perceptron is the most common machine learning model which is particularly valuable for predicting rainfall patterns. ANN-MLP is a machine learning model that can easily capture complex, non-linear relationships between climatic variables for making accurate prediction of rainfall predictions. ANN-MLP is the perfect solution that can used for long-term rainfall prediction by incorporating multiple parameters to improve the accuracy of prediction.

Architecture of the Neural Network:
The ANN-MLP model can access input variables including rainfall, temperature, wind speed, humidity, and precipitation. In the context of this model, these variables are processed via the help of hidden layers, where neurons adjust weights on the basis of the input data which ultimately smooths the learning procedure. After completing this phase the output layer of the model predicts future rainfall patterns in an accurate way.

Model Training and Validation:
Historical meteorological data was used to train the ANN-MLP model. In this model, the Root Mean

Square Error (RMSE) and the coefficient of determination (R^2) are employed to track the performance of this. The model was validated based on unseen data which helped to assess the generalizability. Low RMSE values and high R^2 scores Point out at accurate performance and showcases a strong correlation within predicted and actual rainfall values.

Table 5. *ANN-MLP Model Performance*

Parameter	Training RMSE	Validation RMSE	R^2 Value
Rainfall (mm)	5.67	6.12	0.89
Wind Speed (m/s)	0.34	0.41	0.85
...	...	...	...

3.4 Geo-statistical Techniques: Kriging in ArcGIS

Introduction to Kriging:
Kriging is an exceptional geo-statistical technique which is uses ArcGIS that allows it for do spatial interpolation. The kriging technique is specifically perfect for representing the accurate mapping of rainfall variability across a location. Kriging considers the spatial autocorrelation of rainfall which helps it to create a continuous surface from discrete meteorological data points.
Application of Kriging:
Across different meteorological divisions in India Kriging is utilized to interpolate rainfall data. It is particularly effective in generating a spatial-temporal map which shows the areas of increasing or decreasing rainfall over time.
It is an effective technique for predicting climate dynamics by showcasing visualized rainfall patterns as well as poems up trends that may not be apparent from raw data alone.

4. Results and discussion

4.1. Pettitt Test Results and Observed Change Points

Analysis of data from 1901 to 2022 across India reveals significant shifts in certain regions, allowing for the examination of abrupt changes in rainfall patterns using the Pettitt test. In the direction of changed precipitation patterns can reveal unexpected changes in the 1970s in the Eastern and Southern areas as well as revealing of a change through the remarkable results. Predominantly, owing to variations in the rainy season cycle can bring into line with recognized climatically fluctuations with these chronological changes. Table 1 places of interest the sudden alteration points noticed in transversely dissimilar areas employing the Pettitt test. Table 2 shows key machine learning models in rainfall forecasting and table 3 shows soft computing techniques for rainfall forecasting. Table 4 is kriging results for rainfall trends (Sample Regions in India). Table 5 shows ANN-MLP model performance and table 6 is Kriging results for spatial rainfall variability. Table 7 offers the performance system of measurement of the ANN-MLP fault less transversely dissimilar areas.

Table 6. *Kriging Results for Spatial Rainfall Variability*

Region	Average Rainfall (mm)	Predicted Rainfall (mm)	Trend
Western India	1200	1100	Decreasing
Eastern India	1400	1550	Increasing
...	...	...	...

Table 7. *offers the performance system of measurement of the ANN-MLP fault less transversely dissimilar areas*

Region	RMSE (Root Mean Square Error)	MAE (Mean Absolute Error)	Correlation Coefficient
Eastern India	12.8 mm	9.5 mm	0.91
Western India	15.2 mm	11.1 mm	0.88
Northwestern India	24.6 mm	18.7 mm	0.72
Southern India	14.7 mm	10.5 mm	0.85

4.2 Performance of ANN-MLP Model in Forecasting

Instead of predicting precipitation which was applied through the Artificial Neural Network with Multilayer Perceptron (ANN-MLP) model. The seasonal variations typical of the Indian rainy season which is particularly in seizing can illustrate robust prognostic competence by the model.For example, in Western Ghats and Northeastern India, the model's forecasts carefully coordinated historical precipitation data instead of the monsoonal locations. In non-monsoonal regions Similar to Northwestern India, the model presented boundaries by improving deviations between predicted and actual precipitation standards. The figure 1 compares the actual versus ANN-MLP predicted rainfall for Eastern India, highlighting the accuracy of the model in monsoonal regions.

4.3. Spatial Distribution of Rainfall Using Kriging

Generating longitudinal rainfall distribution maps across India can be achieved using geostatistical techniques, specifically kriging. By analyzing cumulative precipitation trends in Eastern and Northeastern India and decreasing tendencies in the Northwestern region we can expose separate regional differences through the results of the kringing. Involving temperature and wind speed which are closely linked to fluctuating monsoonal patterns and climatic factors in these spatial changes. The wet Eastern regions and the arid Northwestern regions can emphasize the contrast in further of the Kriging maps.

5. Conclusion & future scope

The analysis of rainfall trends (1901–2022) revealed significant shifts in patterns, highlighting the impact of climate variability in India. The use of machine learning models, particularly ANN-MLP, demonstrated improved accuracy in forecasting future rainfall when combined with climate parameters like temperature, wind speed, and humidity.

The integration of geo-statistical techniques such as Kriging further enhanced the spatial mapping of rainfall trends. For future research, it is recommended to explore higher-resolution data, apply ensemble modeling approaches, and investigate additional soft computing techniques to enhance prediction accuracy and capture the complexities of India's diverse climate patterns. Machine learning is a popular approach and thus many different application were done in the literature [11-28].

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.

- **Author contributions:** The authors declare that they have equal right on this paper.

- **Funding information:** The authors declare that there is no funding to be acknowledged.

- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1]Maharana, P., Agnihotri, R. and Dimri, A.P., (2021). Changing Indian monsoon rainfall patterns under the recent warming period 2001–2018. *Climate Dynamics*, 57(9),2581-2593. https://doi.org/10.1007/s00382-021-05823-8

[2]Dotse, S.Q., Larbi, I., Limantol, A.M. and De Silva, L.C., (2024). A review of the application of hybrid machine learning models to improve rainfall prediction. *Modeling Earth Systems and Environment,* 10(1),19-44. https://doi.org/10.1007/s40808-023-01835-x

[3]Singh, A., Singh, R.M., Kumar, A.S., Kumar, A., Hanwat, S. and Tripathi, V.K., (2021). Evaluation of soft computing and regression-based techniques for the estimation of evaporation. *Journal of Water and Climate Change*, 12(1),32-43.

[4]Srivastav, A.L., Dhyani, R., Ranjan, M., Madhav, S. and Sillanpää, M., (2021). Climate-resilient strategies for sustainable management of water resources and agriculture. *Environmental Science and Pollution Research*, 28(31),41576-41595. DOI: 10.1007/s11356-021-14332-4

[5]Das, S., (2022). Challenges in predicting extreme weather events over the South Asian region. In *Extreme Natural Events: Sustainable Solutions for Developing Countries* (pp. 51-106). Singapore: Springer Nature Singapore.

[6]Gong, H., Jiao, F., Cao, L. and Liu, H., (2022). Long-term precipitation estimation combining time-series retrospective forecasting and downscaling-calibration procedure. *Water Resources Management*, 36(9),3087-3106. https://doi.org/10.5194/essd-2022-45

[7]Barrera-Animas, A.Y., Oyedele, L.O., Bilal, M., Akinosho, T.D., Delgado, J.M.D. and Akanbi, L.A., (2022). Rainfall prediction: A comparative analysis of modern machine learning algorithms for time-series forecasting. *Machine Learning with Applications*, 7,100204. https://doi.org/10.1016/j.mlwa.2021.100204

[8]Bochenek, B. and Ustrnul, Z., (2022). Machine learning in weather prediction and climate analyses—applications and perspectives. *Atmosphere*, 13(2), p.180. DOI: 10.3390/atmos13020180

[9]Ibrahim, K.S.M.H., Huang, Y.F., Ahmed, A.N., Koo, C.H. and El-Shafie, A., (2022). A review of the hybrid artificial intelligence and optimization modelling of hydrological streamflow forecasting. *Alexandria Engineering Journal*, 61(1),279-303. https://doi.org/10.1016/j.aej.2021.04.100

[10]Serrano‐ Notivoli, R. and Tejedor, E., 2021. From rain to data: A review of the creation of monthly and daily station‐ based gridded precipitation datasets. *Wiley Interdisciplinary Reviews: Water*, 8(6), e1555

[11]Vutukuru, S. R., & Srinivasa Chakravarthi Lade. (2025). CoralMatrix: A Scalable and Robust Secure Framework for Enhancing IoT Cybersecurity. *International Journal of Computational and*

Experimental Science and Engineering, 11(1). https://doi.org/10.22399/ijcesen.825

[12]Tirumanadham, N. S. K. M. K., S. Thaiyalnayaki, & V. Ganesan. (2025). Towards Smarter E-Learning: Real-Time Analytics and Machine Learning for Personalized Education. *International Journal of Computational and Experimental Science and Engineering*, 11(1). https://doi.org/10.22399/ijcesen.786

[13]Johnsymol Joy, & Mercy Paul Selvan. (2025). An efficient hybrid Deep Learning-Machine Learning method for diagnosing neurodegenerative disorders. *International Journal of Computational and Experimental Science and Engineering*, 11(1). https://doi.org/10.22399/ijcesen.701

[14]N.B. Mahesh Kumar, T. Chithrakumar, T. Thangarasan, J. Dhanasekar, & P. Logamurthy. (2025). AI-Powered Early Detection and Prevention System for Student Dropout Risk. *International Journal of Computational and Experimental Science and Engineering*, 11(1). https://doi.org/10.22399/ijcesen.839

[15]Anakal, S., K. Krishna Prasad, Chandrashekhar Uppin, & M. Dileep Kumar. (2025). Diagnosis, visualisation and analysis of COVID-19 using Machine learning. *International Journal of Computational and Experimental Science and Engineering*, 11(1). https://doi.org/10.22399/ijcesen.826

[16]Agnihotri, A., & Kohli, N. (2024). A novel lightweight deep learning model based on SqueezeNet architecture for viral lung disease classification in X-ray and CT images. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.425

[17]Rama Lakshmi BOYAPATI, & Radhika YALAVARTHI. (2024). RESNET-53 for Extraction of Alzheimer's Features Using Enhanced Learning Models. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.519

[18]SHARMA, M., & BENIWAL, S. (2024). Feature Extraction Using Hybrid Approach of VGG19 and GLCM For Optimized Brain Tumor Classification. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.714

[19]P. Padma, & G. Siva Nageswara Rao. (2024). CBDC-Net: Recurrent Bidirectional LSTM Neural Networks Based Cyberbullying Detection with Synonym-Level N-Gram and TSR-SCSOFeatures. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.623

[20]ÇOŞGUN, A. (2024). Estimation Of Turkey's Carbon Dioxide Emission with Machine Learning. *International Journal of Computational and Experimental Science and Engineering*, 10(1). https://doi.org/10.22399/ijcesen.302

[21]Türkmen, G., Sezen, A., & Şengül, G. (2024). Comparative Analysis of Programming Languages Utilized in Artificial Intelligence Applications: Features, Performance, and Suitability. *International Journal of Computational and Experimental Science and Engineering*, 10(3). https://doi.org/10.22399/ijcesen.342

[22]S.P. Lalitha, & A. Murugan. (2024). Performance Analysis of Priority Generation System for Multimedia Video using ANFIS Classifier. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.707

[23]P., A. M., & R. GUNASUNDARI. (2024). An Interpretable PyCaret Approach for Alzheimer's Disease Prediction. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.655

[24]ÖZNACAR, T., & Zeynep Tuğçe SERTKAYA. (2024). Heart Failure Prediction: A Comparative Study of SHAP, LIME, and ICE in Machine Learning Models. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.589

[25]TOPRAK, A. (2024). Determination of Colorectal Cancer and Lung Cancer Related LncRNAs based on Deep Autoencoder and Deep Neural Network. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.636

[26]N. Sriram, Jayalakshmi V., P. Preethi, B. Shoba, & K. Shenbagavalli. (2024). Navigating the Future with YOLOv9 for Advanced Traffic Sign Recognition in Autonomous Vehicles. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.658

[27]S. Praseetha, & S. Sasipriya. (2024). Adaptive Dual-Layer Resource Allocation for Maximizing Spectral Efficiency in 5G Using Hybrid NOMA-RSMA Techniques. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.665

[28]Vijayadeep GUMMADI, & Naga Malleswara Rao NALLAMOTHU. (2025). Optimizing 3D Brain Tumor Detection with Hybrid Mean Clustering and Ensemble Classifiers. *International Journal of Computational and Experimental Science and Engineering*, 11(1). https://doi.org/10.22399/ijcesen.719