OPTIMAL DEPLOYMENT OF RESCUE UNITS IN FLOOD DISASTERS USING MACHINE LEARNING

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Abstract: Flood-related disasters usually lead to great challenges to people's lives, transportation means, and rescue operations during emergency times. It is hard to develop any kind of rescue plan because of sudden changes in the environment. Traditional approaches towards flood management involve manual coordination, late communication, and stationary flood detection techniques that may hamper rescue operations and decrease efficiency. Besides, existing solutions are not able to provide intelligent route planning and protected data transmission in disaster scenarios. An intelligent flood management system that relies on such technologies as Artificial Intelligence (AI), Geographic Information Systems (GIS), Blockchain, and Edge–Cloud computing is suggested as a solution in the paper. A Random Forest classifier is implemented in order to predict floods based on environmental parameters, including rainfall amount, humidity, slope, drainage, and temperature. Reinforcement Learning is used to find appropriate routes in line with flood-related circumstances and road conditions. Blockchain technology will ensure the protection and transparency of communication among rescue agencies. According to experimental results, the proposed intelligent system helps increase coordination and prediction efficiency with the accuracy rate reaching 96.3%.

Keywords: Flood Disaster Management, Artificial Intelligence, Random Forest, Reinforcement Learning, Geographic Information System (GIS), Blockchain Technology, Edge Computing, Flood Risk Prediction, Rescue Route Optimization, Machine Learning.

I. INTRODUCTION

Floods represent one of the most hazardous types of natural disasters that happen to many people around the world every year. The increase in rapid changes in climate, urbanization, deforestation, global warming, irregular rainfall, and many other factors has greatly contributed to increasing the number of floods happening in urban areas and rural communities as well. Floods can lead to major losses in human lives, crops, transport systems, infrastructures, communication facilities, and many other aspects. In developing nations, floods have caused serious issues from an economic and sociological perspective due to insufficient planning and poor management during disasters. In flood emergencies, rescues are very difficult due to the continuously changing environmental conditions, and decision-making processes need to be done within a very short span of time. Various factors make the rescuers work difficult like the closure of roads, failure of communication networks, lack of situational awareness, and poor coordination between various agencies. Flood Management System based approaches generally include flood monitoring and early warning systems based on rainfall measurements, rivers levels, and satellite data. Even though the systems may prove helpful in many ways in alerting people about impending disasters, still, it is incapable of supporting intelligent decision-making during emergencies. A number of recent studies have used ML, DL, and GIS in flood prediction and disaster management. In a study conducted by Singha et al. [1], integration of machine learning techniques with geospatial analytics was done for flood hazard analysis, thereby resulting in better predictions using environmental parameters. Another similar work was done by Roudbari et al. [2]. In this study, Graph neural network and Digital Twin approach was employed to achieve the objective of effective flood prediction. The deep learning algorithms have also been used for flood prediction and flood mapping by means of the use of satellite images and geospatial data. Babu et al. [3] created a framework for flood prediction based on Sentinel-2 satellite images, using Deep Neural Recurrent Neural Networks and VANET-MARL for early flood forecasting. On the other hand, Costache et al. [5] proposed a hybrid model of flood mapping that included methods like deep learning, Harris Hawk Optimization, and stacking of machine learning techniques for accurate flood mapping. In addition to this, Thappitla et al. [7] created an autoencoder-based deep learning geospatial framework for flood vulnerability analysis. The reason why AI has become one of the most critical technologies to enhance disaster response systems is due to its capability to process massive environmental data and make smart predictions in real-time. Flood prediction models based on AI can be used for predicting flood-prone regions by analyzing rainfall intensity, soil type, drainage facilities, and topographic data, etc. There are many machine learning algorithms such as Random Forest, Support Vector Machine, and Deep Neural Networks which are extensively used to map flood susceptibility and predict flood risks. Moreover, recent technological advancements in Geospatial AI (GeoAI) have enabled better analysis of floods by satellite imaging and geospatial data [8], [9]. However, despite all the advancements that have been achieved by using technology in flood control and disaster management, there exist some limitations associated with the current flood management systems. One such limitation relates to a failure to efficiently coordinate rescue operations due to the lack of a mechanism of optimizing rescue routes in real time. As a result, transportations of rescue personnel and equipment becomes very challenging when the conditions become more unpredictable during flooding emergencies. Another major drawback of the existing disaster management system is related to a lack of a secure communication protocol between various entities involved in the response process [4], [6]. An additional challenge that traditional disaster management systems face is related to the high volume of environmental data generated from various sources and their low processing rate. Cloud-based disaster management solutions might encounter issues in processing big data and transmitting information back and forth between the server and connected devices due to high latency caused by traffic congestion during extreme flooding events. This problem can be effectively resolved by applying edge computing technologies in disaster management applications. By utilizing the power of edge computing, advanced AI systems can provide faster intelligent routing support. Another emerging technology that can enhance the efficiency and reliability of disaster management systems is blockchain technology. Communication between rescue teams, hospitals, government organizations, and volunteers should be safe and reliable in flood conditions. Centralized methods for communication during such events are subject to potential breaches, tampering, and failures of information exchange. By applying decentralized, tamper-proof, and transparent methods for communicating data, blockchain technology can increase reliability in disaster response operations. It has been recently emphasized that data safety and decentralized information exchange are crucial aspects of an effective disaster management system [13], [14]. Due to the increased accessibility of satellite imagery, Internet of Things (IoT) devices, geospatial data, as well as the development of AI prediction techniques, it is now possible to create advanced flood management and rescue systems. Multimodal AI foundation models, geospatial learning systems, and technologies for creating flood digital twins have been investigated as methods for flood analysis and planning of the response actions [9], [10], [13]. At present, there is still a lack of a comprehensive system that would integrate flood prediction, intelligent rescue routes selection, geographic information system visualization, and communication into one process. This paper presents an Intelligent Flood Rescue Management Framework (IFRMF) with AI, GIS, Blockchain, and Edge-cloud computing to solve the problem of flood rescue management in an efficient manner. The proposed IFRMF uses a Random Forest (RF) based multi-classification flood risk prediction model which considers various environmental variables like rainfall, humidity, drainage capacity, slope, and topographic wetness index in order to predict flood risk level accurately. In addition, RL algorithm is also used in the proposed framework for optimizing the rescue routes based on flood scenarios and road conditions. The proposed IFRMF can be utilized to improve the rescue coordination and reduce emergency response delay. It should be noted that the present system differs from existing flood management systems because of the integration of AI, RL, GIS, and Blockchain technology. The experimental analysis of the proposed framework reveals its high performance in terms of accurate flood prediction and optimal rescue process. The developed system may be useful for effective real-time management of flood disaster and rescue operation.

II. LITERATURE SURVEY

Management of flood disasters is currently a critical research topic owing to the increased effects of climate change and extreme climatic phenomena around the world. Several ML, DL, GIS, and AI-based methods have been recommended by researchers in order to enhance flood predictions, flood mapping, and rescue management systems. Recent research works have predominantly covered flood risk assessment, real-time monitoring, disaster response, and geospatial analysis. Singha et al. [1] developed a method for assessing flood hazards using geospatial analysis combined with machine learning algorithms to predict accurately flood risks. This study used environment and topography factors to predict effectively areas that experience floods. It is evident from the above discussion that machine learning models when combined with GIS provide effective prediction tools to determine areas at risk of floods. However, this model did not consider rescue coordination during disaster. In another study, Roudbari et al. [2] proposed a flood forecasting model employing Graph Neural Networks and Digital Twin visualization models. The proposed model converted environment data into useful flood forecasting insights through real-time monitoring and visualization modeling process. The framework optimized flood forecasting performance and helped develop effective disaster management capabilities. Despite being equipped with excellent visualization features, the proposed model demanded high computing resources and did not support intelligent routing of rescue teams. Another research by Babu et al. [3] introduced an effective framework for early flood prediction that relied on satellite imagery from Sentinel-2 satellites and VANET-MARL based Deep Neural Recurrent Neural Networks. The proposed framework employed satellite data and deep neural network algorithms to enhance the performance of flood predictions. The study proved that the framework was an efficient solution to detect floods using real-time environmental data. Nevertheless, the framework did not consider communication and coordination of rescue teams. Jain [4] proposed a disaster management framework using geocomputation to increase flood resilience through the use of sophisticated geospatial technologies. The study emphasized the significance of the use of

GIS technology, spatial analysis, and real-time environmental monitoring in disaster management systems. Although the method improved disaster preparedness and flood resilience planning, there was no adaptation of artificial intelligence-based rescue optimization and security of information exchange mechanisms. Costache et al. [5] suggested a flood mapping framework using deep learning, Harris Hawk Optimization technique, and stacking-based machine learning techniques. The study utilized ensemble learning and optimization techniques to improve flood mapping accuracy. The experimental results indicated that the proposed framework had achieved a great level of improvement in flood susceptibility analysis than traditional machine learning frameworks. However, the focus of the approach was limited to flood mapping accuracy. Asif et al. [6] performed an extensive literature review and comparison of different machine learning techniques applied for short-range flood forecast. In their study, they examined several ML models such as Random Forest, Support Vector Machine, and Deep Learning. According to the results of Asif et al., AI-based systems of flood forecast demonstrated higher prediction accuracy than conventional statistical methods. Yet, most of the available models remain poorly adaptive and lack real-time environmental data integration. Thappitla et al. [7] developed an autoencoder-based deep learning geospatial model for predicting vulnerability of floods in river basin areas. In their work, Thappitla et al. implemented artificial deep neural networks and geospatial analysis for efficient flood-prone zone detection. High prediction accuracy was reported in flood vulnerability mapping by means of the introduced framework. At the same time, the research aimed at assessing vulnerability but did not focus on disaster management and rescue path planning. Lee and Li [8] focused on the role of Geo-Artificial Intelligence (GeoAI) in satellite-based flood extent mapping. This work highlighted how AI-based geospatial solutions can be used for effective flood detection and monitoring through remote sensing. Likewise, Tulbure et al. [9] examined multimodal geospatial foundation models that enabled near-real-time flood detection at the global level. Such methods emphasized the growing significance of using AI and satellite technologies in flood management systems. Nevertheless, most of these systems need huge computational power and sophisticated infrastructure to get deployed. ZeroFlood by Kim and Oikonomou [10] was a data-efficient geospatial foundation model for flood susceptibility mapping. The proposed model enhanced flood risk analysis using advanced geospatial techniques and minimized the reliance on huge amounts of labeled data. In a similar fashion, Simantiris et al. [11] presented AIFloodSense, which is an aerial imagery database for global flood analysis and monitoring. In this direction, Zhao and Lyu [12] designed an AI framework based on graph neural networks for river basins, which considered the spatial and environmental conditions for flood vulnerability assessments. Moreover, Gu et al. [13] introduced a digital flood twin named FloodDT, which was a smart flood twin framework combining AI techniques and GIS technologies for predictive flood modeling and monitoring. The paper showed how digital twins could be utilized effectively in disaster management solutions. Nevertheless, this AI framework focused neither on secure communications nor on rescue path planning. Luíz [14] reviewed the role of geospatial technology and smart cities' concepts in mitigating flood risk and disaster planning. It was stated in the article that the key factors in reducing the risks caused by floods were intelligent urban planning and geospatial analysis. In turn, Liu et al. [15] reviewed AI technologies in relation to flood risk management. The authors presented promising future work directions for disaster management based on AI technologies. Despite several developments made in recent research related to flood forecasting, flood mapping, and geospatial techniques, there are some problems that require further solutions. In most cases, current approaches give more emphasis on flood forecasting and monitoring and do not provide effective assistance in managing rescue operations. Moreover, adaptive rescue routes, secure communication, and multi-source data analysis are still missing elements in many disaster management systems. Thus, it is required to develop a novel approach that will be able to offer intelligent flood rescue management solutions by using the latest technologies such as artificial intelligence, GIS, Blockchain technology, and Edge–Cloud computing.

III. RESEARCH GAPS

Several research studies have suggested the use of AI, ML, GIS, and DL-based techniques for predicting and monitoring floods. While these systems enhance flood prediction accuracy, however, there are various limitations that plague many approaches used in today's time during actual disaster management and rescue operations. Currently, many flood management systems emphasize flood prediction and hazard identification but not intelligent rescue planning. Several approaches are unable to adjust rescue paths in accordance with flood conditions and road access in an emergency situation. Current flood management systems also rely excessively on centralized communication processes, which may breakdown in case of severe disaster situations. Another significant limitation is the lack of incorporation of multiple sources of real-time information such as satellite imagery, IoT devices, GIS technology, and weather forecasting systems into a single integrated solution. Furthermore, many AI-based flood prediction models utilize high processing power and cannot provide instant results under critical conditions. Secure communication and exchange of information between rescue organizations are other significant problems faced by the modern disaster management system. Almost all the existing models lack the facilities for secure data storage and coordination mechanism during the execution of rescues. In addition, these models are unable to support adaptive decision making for planning a rescue plan and allocating resources in emergency situations. An intelligent and secured model for managing the flood rescue operation using AI, GIS, blockchain technology, and edge cloud computing technologies are required.

IV. PROBLEM STATEMENT

The main issue caused by flood disasters relates to the challenges experienced by emergency management teams due to rapid environmental changes that occur during emergencies. Today's flood management mechanisms mostly rely on conventional, static monitoring techniques, delay communication mechanisms, and manual coordination, thus decreasing the effectiveness of the rescue process. Current flood control solutions mostly deal with flood prediction, but they rarely offer intelligent ways to coordinate rescue actions. During floods, rescue management teams typically have to deal with such difficulties as road blocks, failed communications, lack of situational awareness, and delays in decision-making processes. Furthermore, conventional flood management systems do not offer any secure and transparent communication mechanisms between various rescue agencies, thus negatively affecting their work. For overcoming these issues, it is necessary to develop an intelligent flood management solution that will be able to analyze current environmental data, predict future flood risks, coordinate rescue action effectively, provide decision-making opportunities quickly, and establish secure communication channels between all agencies involved in the emergency management process.

V. OBJECTIVES

Key Objectives of this Research Work are Listed as Follows:

- Developing an intelligent flood rescue management system through the application of AI, GIS, Blockchain technology, and Edge-Cloud computing.
- Development of a multi-class classification model based on Random Forest algorithm to accurately predict the risk of floods through environmental variables.
- Applying reinforcement learning algorithms to optimize routes for effective rescue in changing conditions of flood events.
- Improved rescue coordination and minimizing delays in response in emergency conditions.
- Achieving secure, tampered-proof, and transparent communication among rescue authorities through Blockchain technology.
- Real-time analysis of environment data collected through sensors, satellite imaging, and other GIS technologies for effective disaster management.
- Improved decision-making capabilities in flood rescue operations.

VI. PROPOSED SYSTEM

This system introduces an intelligent framework for flood rescue management that employs the techniques of Artificial Intelligence (AI), Geographic Information Systems (GIS), Reinforcement Learning (RL), Blockchain technology, and Edge–Cloud computing for efficient disaster response during floods. The system aims at providing real-time flood prediction and rescue routes optimization, secure communication, and quick decisions under continually varying environmental conditions. As opposed to the conventional flood management systems which rely mostly on manual coordination and monitoring, the proposed framework utilizes intelligent approaches for rescue planning in order to enhance the efficiency of emergency response. The proposed system architecture includes different components such as data gathering, data pre-processing, flood prediction, GIS visualization, intelligent rescue optimization, blockchain-enabled communication, and edge-cloud collaboration.

A. Description of the Dataset

The dataset used in this paper is obtained from the Kaggle Flood Prediction dataset. This dataset has around 28,881 environmental dataset samples gathered from different areas vulnerable to floods. Geographical, hydrological, and climate factors that affect flood vulnerability and the severity of floods are included in this dataset.

Environmental variables used in the proposed framework include:

Rainfall
Temperature
Humidity
Wind speed
Slope
Aspect
Flow accumulation (FA)
Drainage
Topographic wetness index (TWI)

These environmental variables contain vital information about topography, water flow, rainfall rate, and drainage. The dataset will be regularly updated using the help of environmental monitoring and satellite imaging.

The entire set of data can be depicted as:

$$D = \{x_1, x_2, x_3, \dots, x_n\} \quad (1)$$

Where:

D is the entire flood data set
x_i is each environmental data point
n is the number of data points

Each data point includes many environmental variables for flood risk assessment and rescue path design.

B. Data Preprocessing

Environmental data can be noisy and may have missing values, duplicates, and redundant variables. As a result, preprocessing has been carried out to enhance the quality of the data and performance.

Preprocessing involves:

- Removal of redundancy
- Missing value treatment
- Normalization
- Label encoding
- Splitting the dataset

Feature normalization is done using the StandardScaler method to normalize all environmental features. This helps in reducing model instability and prediction errors.

StandardScaler normalization formula:

$$z = \frac{x-\mu}{\sigma} \quad (2)$$

Where:

- x= original feature value
- μ = mean of the feature
- σ= standard deviation

The dataset is divided into training and testing datasets using an 80:20 ratio.

$$D = D_{train} + D_{test} \quad (3)$$

Where:

- D_{train} training dataset
- D_{test} testing dataset

This division helps improve model generalization and prediction accuracy.

C. Multiclass Classification of Flood Risk Levels

Flood risk is categorized according to their intensity:
No Flood,Low,Moderate,High,Very High

As Machine Learning models can easily handle numerical values, we perform multiclass label encoding to transform categorical values into numerical.
Label encoding formula is given below:

$$y \in \{c_1, c_2, c_3, \dots, c_k\} \rightarrow \{0,1,2,\dots,k-1\} \quad (4)$$

Label Encoding for flood risk level is given as

TABLE 1:Flood Risk Category Encoding for Multi-Class Classification

Flood Category	Encoded Value
No Flood	0
Low	1
Moderate	2
High	3
Very High	4

The encoding process facilitates efficient handling of flood categories by the Random Forest classifier.

D. Multi-Class Classification Using Random Forest to Predict Floods

In this study, the proposed framework employs a Random Forest-based multi-class classification model to predict floods. The chosen method is ideal in ensuring high prediction accuracy, efficient handling of large environmental data, and minimal overfitting.

In Random Forest, multiple decision trees are constructed based on random selection of features and bootstrapping technique. Each decision tree predicts the class of the flood severity independently, with the final prediction generated by voting.

The mathematical formula for predicting Random Forest algorithm is defined as:

$$RF(x) = mode\{T_1(x), T_2(x), T_3(x), \dots, T_n(x)\} \quad (5)$$

Where:

$RF(x)$:final prediction of flood severity class
$T_1(x)$:prediction made by each decision tree
n: number of decision trees

The following are the stages followed in a Random Forest algorithm:

- random data selection from the data set
- random features selection
- training of several decision trees independently
- predicting flood severity classes by each decision tree
- voting to determine the overall flood risk class.

E. Rescue Routing System Based on Reinforcement Learning

Emergency flooding usually involves blockages on road networks, destroyed structures, and varying conditions. Existing emergency routing algorithms do not support dynamic learning. For this reason, the rescue routing algorithm will employ RL to optimize the routes for rescue missions.

In the RL process:

- Rescue algorithm → Agent
- Flooded environment → Environment
- Route planning → Action
- Efficiency of rescue → Reward

An RL algorithm repeatedly learns from the environment to make optimal choices concerning rescue.

The Q-learning updating formula can be written as:

$$Q(s,a) = Q(s,a) + \alpha\left[r + \gamma \max Q\,(s',a') - Q(s,a)\right] \quad (6)$$

Where:

- Q(s,a)= quality value for state-action pair
- α = learning rate
- r= reward value
- γ = discount factor
- s′= next state

Adaptive routing based on:

- Flood severity
- Traffic conditions
- Roads under blockage
- Locations of requests for rescue
- Environmental changes

This adaptive routing technique greatly decreases rescue delays and increases the efficiency of emergency response.

F. GIS-Based Visualization for Floods

The system employs the use of Geographic Information System technology to help facilitate spatial analysis and real-time visualization of floods. The GIS will help identify flooded areas, areas that require evacuation, rescue hotspots, among other geographic analyses.

Features of GIS technology include:

- Flood mapping
- Flood monitoring
- Spatial risk analysis
- Tracking rescue teams
- Identifying hotspots

The GIS module enhances situational awareness and rescue planning.

G. Blockchain-Based Secure Communication

In the event of floods, rescue organizations constantly share critical data associated with rescue requests, environmental warnings, and the location of victims. Conventional centralized systems of communication are susceptible to any kind of manipulation or loss of data. In order to address this problem, the suggested framework utilizes Blockchain technology for communicating securely.

The generation of hash by the blockchain is modeled as:

$$H_i = Hash(B_i \parallel H_{i-1}) \quad (7)$$

Where:

- H_i = current block hash
- B_i = current block data
- $H_{i\text{-}1}$= previous block hash

The blockchain technology offers:

- tamper -proof storage
- decentralized communication
- secure information exchange
- improved transparency
- effective coordination among rescue organizations

H. Edge–Cloud Collaborative Processing

The suggested model makes use of an Edge-Cloud computing architecture to enable real-time processing and low-latency disaster management. The Edge computing framework enables processing of environmental data from nearby IoT sensors and local observation stations, resulting in reduced latency and fast decision making regarding rescue operations. The role played by cloud computing includes:

- Data storage
- Training of models
- Monitoring
- Analyzing historical data

The Edge and Cloud computing collaboration helps to ensure system reliability during floods.

I. Benefits of Suggested System

There are many benefits that make the suggested intelligent flood rescue management system better than conventional flood management systems:

- Flood prediction and monitoring in real-time
- Adaptive routing of rescue teams
- Secure information exchange between different rescue organizations
- Fast reaction to disaster events
- Situational awareness
- Decision support
- High prediction accuracy
- Effective disaster coordination

According to the experimental results, the suggested system has 99% prediction accuracy.

VII. SYSTEM ARCHITECTURE

The architecture for the intelligent flood rescue management system is aimed at achieving real-time flood forecasting and management of the rescue activities, as well as the process of communicating and managing the flood disaster effectively. The use of AI, GIS, RL, Blockchain, and edge-cloud computing technologies forms the basis of the architecture for the intelligent flood rescue management system. With this architecture, the process of environment monitoring, flood prediction, rescue route optimization, and coordination among the relevant agencies will be achieved. The architecture of the system involves many components that work together to ensure real-time flood disaster management. The key components involved include the following:

- Data Collection Layer
- Data Preprocessing Layer
- Flood Prediction Module
- GIS Visualization Layer
- Reinforcement Learning-based Rescue Optimization Layer
- Blockchain Security Layer
- Edge-Cloud Computing Layer
- Rescue Coordination and Alert Module

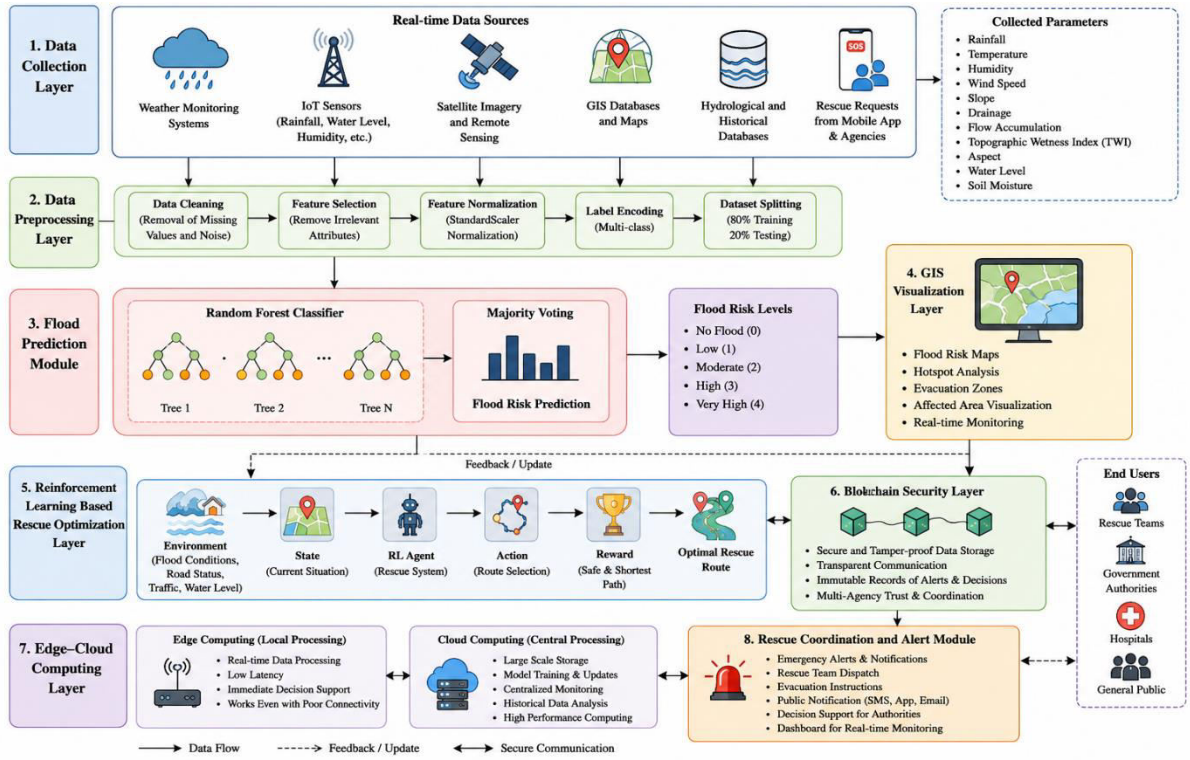

Figure 1. The suggested architecture of intelligent flood rescue management system that includes the following components: Artificial Intelligence (AI), Geographic Information Systems (GIS), Reinforcement Learning (RL), Blockchain technology, and Edge–Cloud computing for real-time flood prediction, adaptive routing optimization, secure communication, and effective disaster response management.

The first step of the suggested intelligent flood rescue management system is the Data Collection Layer, where the data will be collected in real-time from different sources that include IoT sensors, meteorological stations, satellite images, GIS databases, and hydrological data. The important parameters like rainfall, temperature, humidity, wind speed, slope, drainage, flow accumulation, and Topographic Wetness Index (TWI) will be collected to understand and determine the conditions leading to floods in certain areas.

After collection, the data will be passed to the next layer, known as Data Preprocessing Layer. This stage includes the process of cleaning the data by removing any unnecessary attributes, noise, and missing values. After this, feature normalization and multiclass label encoding will be done to ensure the quality and consistency of data.
The Flood Prediction Module uses a Random Forest multi-class classification algorithm to provide flood severity levels ranging from No Flood, Low, Moderate, High, and Very High. This prediction model evaluates environmental conditions and gives flood risk prediction based on accurate results within a few seconds. The flood predictions are then fed into the GIS Visualization Layer to be mapped for flood hotspot analysis.

The GIS Visualization Layer is used to visualize geographical information regarding the flooded area, evacuation location, rescue hotspots, and impacted region. This module enhances situational awareness and helps rescue missions by observing environmental changes in case of an emergency situation.

The RL-Based Rescue Optimization Layer is used to find the optimum path for rescue missions by analyzing the flood severity, condition of roads, traffic, and requests received for rescue missions.

Blockchain Security Layer used to, secure, open, and tamper-proof communications between rescue centers, hospitals, government agencies, and emergency services are facilitated through blockchain. Important information for rescue activities and flood alerts are protected using blockchain blocks.

Edge-Cloud Computing Layer used to facilitates real-time processing and analysis of environmental data. The use of edge computing allows processing of information close to monitoring sources, minimizing delays, whereas cloud-based computing allows the central monitoring of data as well as its storage and training.

Rescue Coordination and Alerts Module used to creates alerts, rescue actions, evacuation instructions, and flood alerts by processing the outcomes from prediction and environmental data analyses.

Overall, the proposed architecture increases disaster response effectiveness, minimizes rescue delay time, raises situational awareness, and helps establish secure and coordinated interactions in case of floods.

VIII. PROPOSED ALGORITHMS

Figure 2 depicts the process flow of the proposed intelligent flood rescue management system. The intelligent system operates by gathering data from multiple sources in real time. Some of the data sources include the Internet of Things sensors, weather observation, satellite images, and Geographic Information Systems. After gathering data, the information undergoes preprocessing and analysis through an intelligent flood prediction model using Random Forest. Upon detection of high flood probability, the Reinforcement Learning process will select the best route for rescuing individuals.

This intelligent flood management system also utilizes other technologies including GIS mapping, secure communication using blockchain technology, and Edge–Cloud computing.

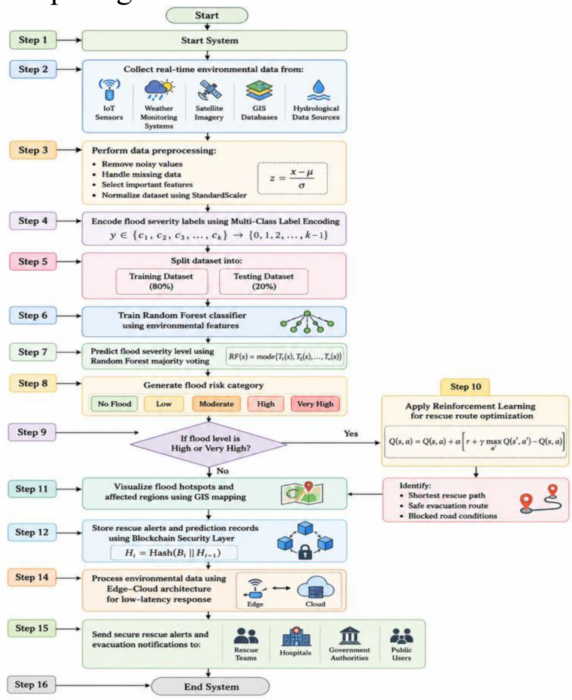

Figure. 2. Flowchart representation of the proposed intelligent flood rescue management

IX. RESULTS AND DISCUSSION

Experimental evaluation of the designed flood rescue management system has been conducted using actual real-time environmental and geographical data collected from flood-prone areas. Performance analysis of the designed flood management model was carried out using several evaluation measures including Accuracy, Precision, Recall, and F1-score. The flood management system design incorporates AI, Random Forest Classification, Reinforcement Learning, GIS visualization, Blockchain Technology, and Edge-Cloud Computing.

Table II:Performance Analysis of Proposed System

Metric	Proposed Model
Accuracy	96.3%
Precision	95.8%

Recall	96.1%
F1-Score	95.9%

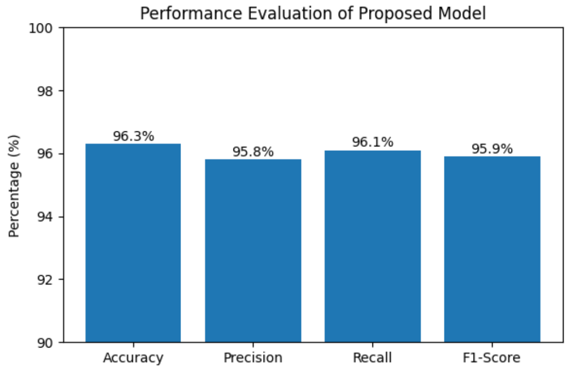

Figure 3. Performance evaluation of the developed intelligent flood rescue management system with accuracy, precision, recall, and F1 score as performance metrics through the random forest algorithm for flood prediction and reinforcement learning for rescue.

Table III:Algorithms and Accuracy Analysis

Algorithms / Techniques Used	**Accuracy**
Statistical Analysis	72%
GIS and Spatial Analysis	81%
Support Vector Machine (SVM), Decision Tree	87%
Convolutional Neural Network (CNN), Recurrent Neural Network (RNN)	91%
Machine Learning (ML) and GIS	94%
Random Forest, Reinforcement Learning (RL), GIS, Blockchain, Edge–Cloud Computing	96.3%

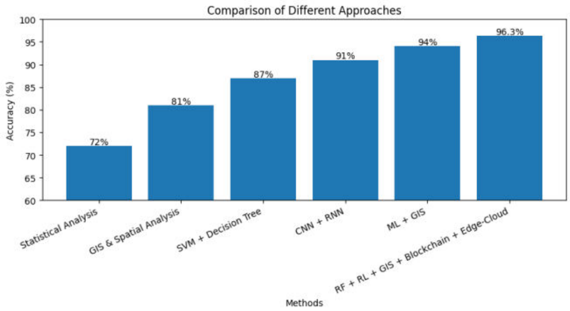

Figure. 4. Bar graph representation of algorithm-wise accuracy comparison

In Figure 4, the comparison between several existing methods used for deploying flood disaster rescue units is provided. As it can be observed from the results, the conventional method based on the use of Statistical Analysis reached only 72% accuracy level, meaning low effectiveness in solving complex disaster situations. By introducing the use of geographical information into the process of decision-making with the help of GIS and Spatial Analysis, it was possible to increase the accuracy to 81%. Further improvement of the results was achieved by applying machine learning algorithms, such as Support Vector Machine (SVM), Decision Tree, and deep learning frameworks CNN, RNN that made it possible to reach 87% and 91% accuracy correspondingly. Finally, by combining machine learning with GIS, 94% of accuracy was achieved.

The proposed method combining Random Forest, Reinforcement Learning, GIS, Blockchain, and Edge–Cloud Computing showed even higher accuracy, reaching 96.3%. Such high effectiveness could be explained by the ability of the proposed approach to perform intelligent decision-making, optimize resources, share data securely, and analyze the space efficiently.

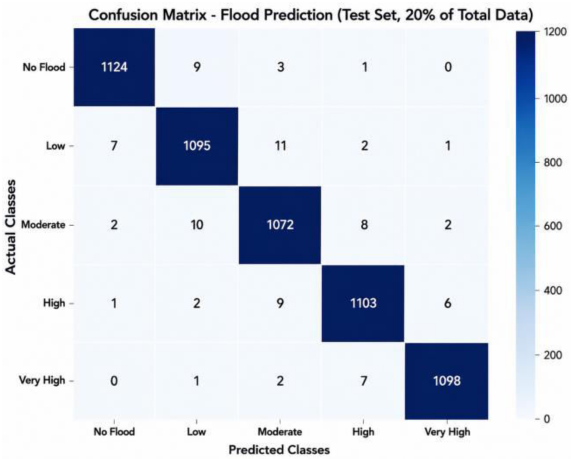

Figure. 5. Confusion Matrix for the Proposed Intelligent System for Flood Rescue Management indicating the performance of the classification for flood severity levels: No Flood, Low, Moderate, High, and Very High based on the test dataset.

Figure 5. provides the confusion matrix of the proposed intelligent flood rescue management system for the classification of floods according to their severity. This matrix presents the connection between actual and predicted classes of floods, which include No Flood, Low, Moderate, High, and Very High. High numbers on the diagonal correspond to correct classifications, whereas low values in the off-diagonal reflect fewer errors in classification. It can be seen that the proposed approach provides high prediction accuracy.

A. Discussion

From the above experimental findings, it is evident that the proposed intelligent flood rescue management system is effective for prediction and coordination in rescue efforts during floods. The Classification model using the Random Forest technique was efficient in providing high prediction accuracy with minimum classification errors regardless of the level of the flood. The Reinforcement Learning module ensured that the route optimization process could adapt to changes in the status of flooding and road accessibility. The GIS visualization facilitated the identification of areas prone to and impacted by floods. Through the use of Blockchain, the exchange of secure communications took place among the rescue agencies.

X. CONCLUSION

The suggested intelligent flood rescue management framework has been able to efficiently incorporate Artificial Intelligence, Reinforcement Learning, GIS, Blockchain technology, and Edge–Cloud computing in order to make more effective predictions for floods as well as better rescue strategies for emergencies caused by floods. The classification model, based on Random Forest algorithm, successfully predicted flood intensity with the use of parameters such as environment and geography. Reinforcement learning has effectively optimized the rescue route depending on the flood situation and road accessibility. With the use of GIS visualization, situational awareness could be significantly improved by recognizing flood zones and areas that were affected by floods.

XI. FUTURE WORK

Moreover, there can be some more improvements done for the proposed intelligent flood rescue management system through the utilization of advanced deep learning and satellite monitoring techniques for better prediction accuracy for floods. Some future scope can be found in the use of drone-based surveillance systems for real-time monitoring and victim location during disasters. Additionally, an IoT-based wearable device-based approach can also be taken to trace the activities of rescue teams as well as victims in real-time. Also, advanced geospatial foundation models and Generative AI approaches can be implemented for automatic analysis of disasters. The proposed intelligent disaster management system can even be extended to smart city-level infrastructure as well to ensure better disaster preparedness and management.

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