Prediction of earthquake and its magnitude using Machine Learning

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***Abstract*—Earthquakes are one of the most devastating natural disasters causing a serious threat to life and infrastructure all over the world. Earthquake prediction before its occurrence is the very important as it can alert people about the earthquake before it's occurrence so that people can prepare well for its post effects and can save their lives as well. This paper reviews various methodologies for the prediction of earthquake and its magnitude, the major challenges that we face in the precise prediction of earthquake and various strategies and improvements that can contribute in handling the post-event scenario efficiently. Using various machine learning algorithms, we have developed a model which can predict earthquake and its magnitude. For developing this, we have used Sci-kit Learn Library. We have obtained data set through USGS (United States Geological Survey) website for implementing machine learning algorithms. Both classification and regression algorithms are implemented on our data set.The classification algorithms used on our data set to predict earthquakes include Random Forest , K-nearest-neighbour (KNN) ,Decision tree and logistic regression , Support Vector Classifier and Naive Bayes. Out of all the classification algorithms, the Random Forest turned out to be the best classifier.For predicting the magnitude of earthquake , Regression algorithms like Multi-linear Regression is used .**

Keywords: Machine Learning, Earthquake prediction, SVM, Random Forest

I. INTRODUCTION

An earthquake is the shaking of ground which is caused due to movement or break down of rocks inside earth's surface. Large earthquakes are among the most destructive and unpredictable natural phenomena, yet our ability to rapidly and accurately estimate their impacts remains limited [1]. In earth's outer layer stress builds due to which rocks begin to break. This leads to release of energy which is in the form of waves travelling through the earth's crust and further causing the shaking of earth. This shaking is termed as an earthquake. Magnitude of earthquakes depend on area of fault on which they occur. This implies that larger the area , larger will be the earthquake and similarly smaller the area, smaller will be the earthquake. The magnitude of earthquake below 3 is not felt by humans as these earthquakes don't cause enough shaking which can be felt by humans. But Richter scale can predict the earthquakes which have magnitude less than 3. Predicting earthquake and its magnitude before its actual occurrence is complicated mechanism in itself. But this goal is not impossible as this research paper will help us in achieving this goal in which we will be able to predict earthquake and its magnitude using machine learning.

A. *Destruction caused by Earthquakes*

It is very significant to predict earthquake in order to prevent people, buildings, different infrastructure and other monuments from massive damage. Many people die due to earthquake. Animals also have to suffer a lot due to earthquake as they too die. Various diseases and health issues are caused to humans and animals due which they both have to suffer a lot. This hazardous situation is dangerous for all. Earthquake can also occur in oceans which leads to tsunami and the people living near these oceans have their lives in danger. This tsunami which is caused by earthquake can also affects the life of aquatic animals too. Recently in April 2024, a massive earthquake of magnitude 6.3 occurred in Taiwan's eastern country of Hualien but there was minor damage reported. In January,2024 a powerful earthquake of magnitude 7.6 occurred in Japan due to which over a dozen people have lost their lives and it also led to the washing of houses and cars. One-metre-high tsunami waves also affected Japan's western seaboard at that time.

B. *Ancient approach used for predicting earthquakes*

A classical approach to determining that an earthquake may be looming is based on the inter event time (recurrence interval) for characteristic earthquakes, earthquakes that repeat periodically [1]. So, it's not easy to predict earthquake a few years back before its occurrence. Predicting magnitude of earthquake in ancient time is itself a challenging task. Ancient methodologies like animal behavior, geological changes and hydro-logical observations are used but these processes for earthquake's prediction are not more accurate .

C. *Modern approach for predicting earthquake*

1) **Statistical Methods:**

- Historical Data Analysis: It means that by Analyzing past earthquakes helps scientists find patterns that could help predict future ones.
- Risk Assessment: It involves figuring out the likelihood of earthquakes and their impacts.

2) **Collaborative and Multi-Disciplinary Approaches:**

- Combining Data: It implies that Scientists can use data from various sources like GPS, and satellite information for enhanced risk assessment.
- Working Together: is also a major factor in which countries and scientists share data to improve earthquake prediction and safety.

D. *Machine learning approach for predicting earthquake*

This research paper uses machine learning for predicting earthquake and its magnitude. We will train our model using machine learning techniques like classification and regression. After learning our model can predict earthquake and its magnitude.

II. LITERATURE REVIEW

In today's modern era there a lot of modern and advanced techniques or methodologies for predicting an earthquake. Many people, animals, buildings, monuments and other infrastructures are being devastated due major earthquakes that occurred all over the world. This research aims to predict earthquake before it's actual outbreak. So that before earthquake's outbreak people can take safety measures, find the shelters which are safe and collect the basic necessities like food which is utmost important at the crucial time of disaster. Also, if earthquakes are predicted then government can also aware the population about the upcoming earthquake and can take precautions. People and animals all over the world will save their lives as they can know the earthquakes which will occur in their future.

A study conducted by Joshua Pwavodi et al. (2024) [2] used Artificial Intelligence and Internet of things for predicting the magnitude of earthquake. They algorithms used by then are ANN (Artificial Neural Network), SVM (Support Vector Machine) and FL (Federated Learning) etc. But the gap that is addressed from their study is that all the techniques that can be used to predict earthquakes (like Random Forest) are not implemented by them. Sumanth Kalavakunta et al. (2024)[3] proposed that we can predict earthquakes using linear regression technique .They also compare linear regression's prediction with K-Nearest neighbors (KNN) prediction and concluded that accuracy is more using linear regression as compared to KNN.The gap that is addressed from their research is Other Machine learning algorithms like Decision Tree and Naive Bayes are not implemented by them.

Papiya Debnath et al. (2021) [4] addressed that supervised machine learning techniques can be used for prediction of earthquakes. It includes techniques like Random Forest, Decision Tree and Logistic Regression. Their model can classify 3 categories (Mild, Fatal and Moderate earthquake). Mustafa Abdul Salam .et al (2021) [5] used seismic indicator and hybrid machine learning techniques for predicting earthquake. 7 seismic indicators including time taken during the occurrence of n seismic events (T), average magnitude of the n events(M_mean) etc and two hybrid machine learning techniques namely FPA-ELM (which is a hybrid of Flower Pollinating Algorithm (FPA) and extreme learning machine (ELM)) and FPA-LS-SVM (which is a hybrid of FPA and Least Square- Support Vector Machine (LS-SVM)) were used by them.

Javed N. Rashidi et al. (2023) [6] proposed that injection induced earthquakes can be predicted using machine learning They used 3 machine learning techniques which are Support Vector Machine, Probabilistic Neural Network and Ada Boost Algorithm. The gap that is addressed from their study is that only injection induced earthquake can be predicted using their model and other earthquakes like natural earthquakes can't be predicted using their model.

Yanwei Wang et al. (2023) [7] showed in their research that earthquakes can be predicted using a new deep learning approach which is EEWNet (Earthquake Early Warning Network) for the prediction of earthquake in EEW (Earthquake Early Warning). EEWNet is based on convolutional neural network.

Dr. V. Vijaya Kumar et al. (2024) [8] developed an earthquake prediction model by training their data set through Artificial Neural Network (ANN). They used Recurrent Neural Network (RNN) for the prediction of various details on an earthquake. Their model can predict the magnitude and depth of an earthquake.

Maher Ali Rusho et al. (2024) [9] proposed that earthquakes forecasting model can be formed using Long Term Short Memory (LSTM). They have worked on the data which has been taken from Indonesia. Their model is based on standard analytical methods which are used for formalizing the principles of LSTM networks mathematically.

Pan Xiong et al. (2021) [10] proposed that earthquakes can be predicted using machine learning by using satellite data. They also used Ada Boost ensemble technique for forecasting of earthquakes. Their results supported the coupling of lithosphere - atmosphere - ionosphere coupling during the earthquakes.

III. METHODOLOGY

For the successful prediction of earthquake and its magnitude, a well-defined methodology is required. Methodology includes the steps, instructions and the procedures that should be performed sequentially on the data for achieving our desired goal. There are two phases Training phase (in which data is trained using algorithms) and testing phase (where the model is tested to give predictions).

A. Data Collection

The very first step of building a machine model that predicts earthquake is Data Collection which is a very essential step in the formation of machine learning model. It means to find relevant data which can help us in building models which can give accurate predictions. We have built our model by using data set through USGS (United States Geological Survey) website. We have manually selected data by choosing an option '2.5+' from magnitude, by choosing 'world' option from geographic region and manually selecting the area of world by drawing rectangle on map and choosing 'csv' option from output options to download the csv (comma separated value) file of data set. Our data set consists of 9714 rows and 22 attributes. Our dataset has

attributes as “time”, “latitude”, “longitude”, “depth”,” “mag” , “magType”,” “nst” ,” “gap” and “dmin” etc.

A. *Data preprocessing*

Data preprocessing means the transformation of raw data into a format which can be used for training and testing of our models. The steps that we have used for data preprocessing of our model are:

1) **Exploratory Data Analysis (EDA):** EDA is the initial and crucial step of data preparation and preprocessing. Firstly, we have removed some unnecessary attributes from the data set such as “id”, “updated”, “status”, “locationSource” and “magSource” etc. Then we added an attribute named “earthquake” which has binary values 0 and 1.0 in “earthquake” column represents that earthquake will not occur (as it has a magnitude less than 3) and 1 represents that earthquake will occur (as it has a magnitude greater than equal to 3). After that we handled null values in our model and our data set has 3 columns with null values. These attributes are “nst”,“gap” and “dmin” (they all have float as datatype).So we have replaced these null values with the mean of that particular column.

Then we modified the “time” column (which shows date and time of the earthquake occurred) **to** “month” column (which denotes the month number in which earthquake occurred). Then we removed “time” column.

All the values in “place” attribute of our data set show some unnecessary information along with information of the place. So, we have made some changes in “place” column. For example “56 km N of Lae , Papua New Guinea” is a value present in place column. This example has “56 km N of Lae” as unnecessary information and “Papua New Guinea” as necessary information. So, we have modified all the values present in this column in such a way that each value represents necessary information only.

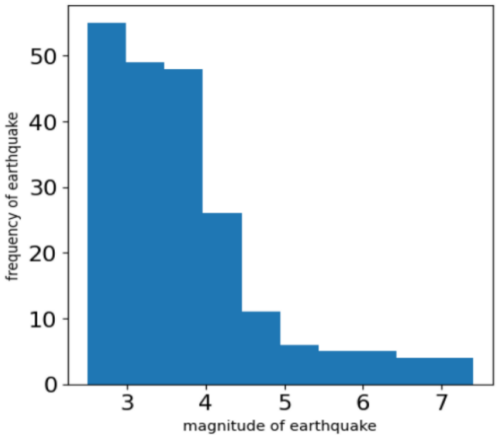

Fig. 1. A histogram plot

Fig. 1. represents a histogram plot which is plotted using matplotlib. It shows the frequency of each magnitude of earthquake present in the data set.So we have analyse that earthquakes with magnitude less than 3 (approximately) are maximum.Those earthquakes with magnitude greater than 6.5 (approximately) and less than 8.5 (approximately) are minimum in our data set.

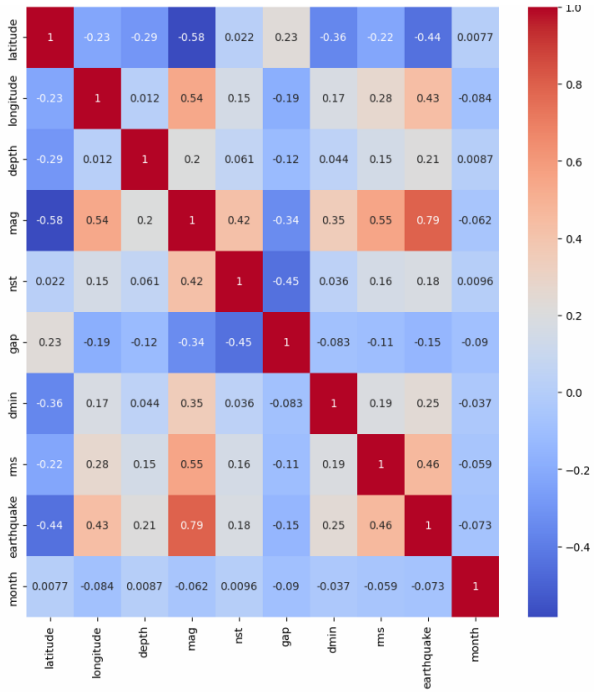

Fig. 2. Correlation Matrix

Fig. 2. shows a correlation matrix which is formed through seaborn and matplotlib libraries. Correlation matrix displays the Karl Pearson’s correlation coefficient. The cells in above correlation matrix which show value as 1 denote that a perfect positive correlation exists between the two variables associated with that particular cell . So every variable has a perfect positive correlation with itself. According to the figure blue colour and it’s shades represent that two variables are less correlated. Similarly, the orange colour and it’s shades represent that two variables are highly correlated.So, we observe that “mag” and “earthquake” are highly correlated with each other as it has value 0.79.

2) **Labeling of Data using Label Encoder:** Label Encoding refers to conversion of categorical features into labeled or numerical data so that accuracy of our model can enhance.Label encoding has been done through LabelEncoder() function which has been imported through sklearn.preprocessing library for the prediction of earthquake. Label Encoding has applied on 3 categorical columns (“net”, “magType” and “place”) which have data types as object so we have converted their data types from object to integer.

3) **Feature Selection**:After that Feature Selection is implemented for extraction of best features from our data for the prediction of earthquake. For implementing Feature Selection, we have used SelectKBest (K refers to the number of best features that we want to get selected by our model). So we have given K as 11 so that our model can select 11 best features.

4) **Splitting of data into training and testing set:**We split our data into training and testing sets by using train_test_split which is imported through sklearn.model_selection. We have taken size of testing set as 1/3 so that $(1/3)^{rd}$ of the data is in testing set and $(2/3)^{rd}$ of the data is in training set.

5) **Feature Scaling:**Then Feature Scaling is done on our data for the prediction of earthquake and for implementing this we have used StandardScaler which has been imported through sklearn.preprocessing. Feature scaling is a method of standardizing those features which are independent in our data. So, this technique has been implemented on the independent variables or features of the data which has been selected through feature selection technique.

B. *Implementation of machine learning algorithms on data*
We have implemented both classification and regression techniques on the data . Classification techniques are used for prediction of earthquake and regression technique is used for the prediction of magnitude of an earthquake.

1) **Prediction of earthquake**

For predicting whether an earthquake will occur or not, Classification Techniques are implemented on data which will predict earthquake and classify the data into two categories 0 and 1 (0 represents that earthquake will not occur and 1 represents that earthquake will occur).

The following classification techniques are used :

a) Logistic Regression: Logistic regression is a method which basically gives a binary outcome (an outcome with two values) based on one or more independent variables.We imported LogisticRegression through sklearn.linear_model . In our model binary outcome has two values (0 & 1). So if earthquake occurs then our model will give 1 as outcome and if earthquake will not occur then it will give 0 as outcome. Equation For Logistic Regression :

$$\ln(P/(1-P))=\beta 0 + \beta_1 * X_1 + \beta_2 * X_2 + \ldots + \beta_n * X_n$$

where, P is the probability of Y (outcome to be predicted) being success (1) ,

$\beta 0$, β_1 , β_2 , ….. ,β_n are coefficients ,

X_1 , X_2 , ……..,X_n are the independent features.

b) Support Vector Machine (SVC): Support Vector Classifier(SVC) is basically used for creating the decision boundary that can separate out the 'n' dimensional space into 'm' categories. In our model m has value of 2 as there are two classes 0(non occurrence of earthquake) and 1(occurrence of earthquake).For implementing it, SVC (Support Vector Classifier) is imported through sklearn.svm .

c) Random Forest: Random Forest ,as it's name suggests , consists of collection of decision trees where every tree is trained on a different subset of data. Each decision tree in Random Forest gives it's vote or it's prediction so, Random Forest gives outcome on the basis of majority of votes. For implementing Random Forest,we have imported RandomForestClassifier from sklearn.ensemble.

d) Naive Bayes: It's a powerful classifier used in machine learning which uses Bayes theorem for classifying the data into different categories.According to naive Bayes all the features are independent.This assumption is called Naive Assumption.For implementing it in our model we have imported GaussianNB through sklearn.naive_bayes .

The equation for the Bayes Theorem is:

$$P(A|B)=(P(B|A).P(A)) / P(B)$$

where, P(A|B) is probability of hypothesis A being true given that B has been already occurred , P(B|A) is the probability of evidence B given that hypothesis A is true ,

P(A) is the initial probability of hypothesis A being true before considering the evidence ,

P(B) is total probability of evidence B .

e) Decision Tree:A decision tree is machine learning algorithm basically used for classification.At it's top,root node is there and at it's bottom there exist leaf nodes. There are internal nodes in between the root node and leaf nodes.These nodes are connected with each other through branches.For it's implementation we have used DecisionTreeClassifier which is imported through sklearn.tree .

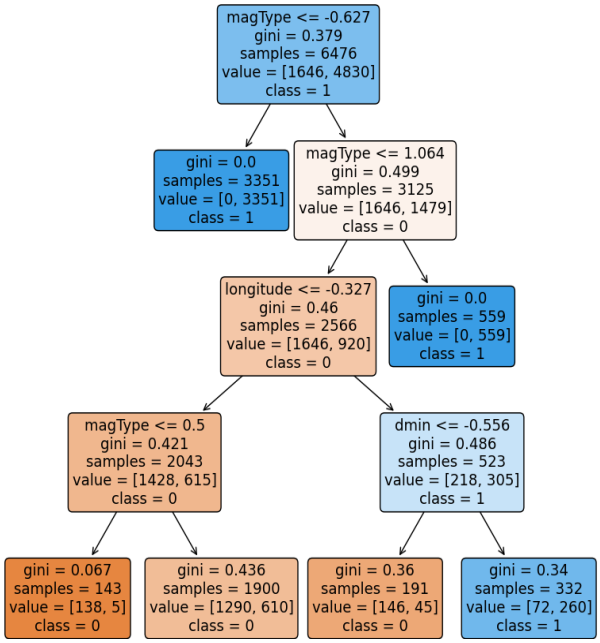

Fig. 3. A decision tree

Fig. 3. shows a decision tree which is formed using plot_tree(which is imported through sklearn.tree) and matplotlib .This decision tree classifies data into two classes 0(earthquake will not occur) and 1(earthquake will occur).We observe that it is making decisions on the basis of attributes like magType and dmin etc.

f) K-Nearest-Neighbor(KNN):'K' in KNN represents the number of nearest neighbors of a data point. For predicting the value or class of a particular data point using KNN, the values or classes of it's nearest neighbors in feature space are considered . For implementing it in our model, KNeighborsClassifier is imported through sklearn.neighbors.

2) **Prediction of magnitude of earthquake**

If the value predicted through earthquake is 1 then our model will predict the magnitude of earthquake.It means that if earthquake will occur then our model will predict the magnitude of earthquake using Multi Linear Regression.

Multi Linear Regression: Multi Linear Regression is basically an expansion of Linear Regression.In this ,there are 2 or more independent variables and 1 dependent variable (or target variable). For implementing it LinearRegression is imported through sklearn.linear_model in our model.The mathematical equation for the multi-linear regression is :

$$Y = \beta 0 + \beta_1 * X_1 + \beta_2 * X_2 + \ldots + \beta_n * X_n + \varepsilon$$

Where,

Y : Dependent variable(or the target variable). β0:Intercept(value of Y when all values of X are 0(zero)).
β_1 , β_2 ,…, β_n : Coefficients.
X_1 , X_2 ,…, X_n : Independent variables. .
ε : ε is error term .

IV. RESULTS

In this section we are representing the model's performance after the training of our model .

A. *Results for the Prediction of earthquakes*

For the prediction of earthquake we have achieved the following results:

TABLE I. RESULTS FOR EARTHQUAKE PREDICTION

Name of classifier	Accuracy	class	precision	recall	F1-score
Logistic Regression	86.35	0	0.70	0.82	0.75
		1	0.93	0.88	0.91
Support Vector Machine	88.42	0	0.70	0.95	0.81
		1	0.98	0.86	0.92
Decision Tree	87.09	0	0.74	0.73	0.74
		1	0.91	0.91	0.91
Random Forest	89.47	0	0.75	0.89	0.81
		1	0.96	0.90	0.93
Naive Bayes	85.15	0	0.64	0.94	0.76
		1	0.98	0.82	0.89
KNN (K Nearest Neighbor)	87.49	0	0.72	0.82	0.77
		1	0.94	0.89	0.91

From TABLE I. , we observe that all the algorithms have accuracy greater than 85% which implies that they all are performing very well.

Decreasing order of accuracy of different algorithms used : Random Forest(89.47) >Support Vector Machine(88.42) >K Nearest Neighbor(87.49) >Decision Tree(87.09) >Logistic Regression (86.35) >Naive Bayes(85.15)

For precision ,recall and F-1 Score , TABLE II. shows 2 classes for each .So class 0 represents non occurrence of earthquake and class 1 represents occurrence of earthquake.

1) **Precision**=True Positive/(True Positive + False Positive) Precision describes that how many correctly predicted cases turned out positive.We also observe that for class 0, more than 60 % and for class 1,more than 90% correctly predicted cases emerged out to be positive for all the classifiers that were used.
2) **Recall**=True Positive/(True Positive + False Negative) Recall states that basically how many actual positive cases are predicted correctly by our model.We observe that for class 0 more than 70% and for class 1 more than 85% actual positive cases are predicted accurately by all of the models that were used.
3) **F-1 Score**=2*Precision*Recall / (Precision + Recall) F-1 Score is basically harmonic mean of the precision and recall values.So it gives combined idea of both of them.We observe that for class 0 ,all models have f-1 score more than 0.70 and for class 1 all models have f-1 score greater than or equal to 0.89 which indicates that all the classifiers are performing good for both the classes (0 and class 1).

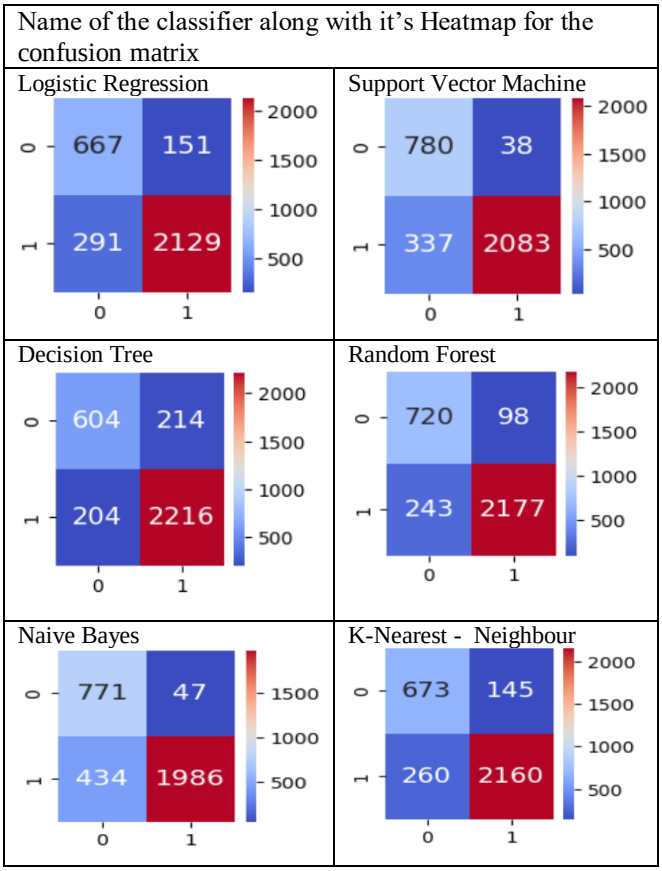

Fig. 4. Algorithms with their heatmaps

From Fig. 4, we see the heat maps for confusion matrices which are formed using matplotlib and seaborn . We observe that more than 1980 positive and more than 600 negative class data points were classified accurately by all the models used. Less than 340 negative and less than 220 positive data points are not classified accurately by all the models.

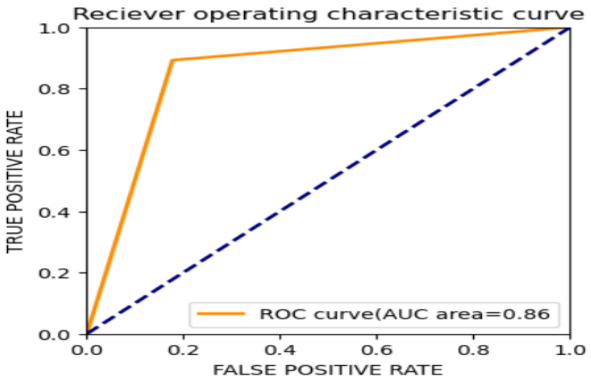

Fig. 5. Receiver operating curve

Fig. 5. represents a Receiver Operating Curve (ROC) is the plot of Total Positive Rate (TPR) vs False Positive Rate (FPR). In above figure , AUC (Area Under Curve) represents the area under the ROC curve.We observe from the figure that the ROC curve is above the diagonal and AUC area is 0.86 which implies that our model is performing well.

B. *Results for the Prediction of magnitude of earthquakes*

For the prediction of magnitude of earthquake if earthquake occurs then we have achieved the following results:

- Our model's accuracy on whole data is 87.07%.
- Our model's accuracy on training set is 87.18%.
- Our model's accuracy on testing set is 86.82% .

TABLE II. RESULTS FOR EARTHQUAKE'S MAGNITUDE PREDICTION

Regression technique	Mean squared error	R squared
Multi-linear regression	0.09580	87.07

From TABLE II. , MSE(Mean Squared Error) is 0.09580 implies that the predicted values are nearly close to actual values of our model as MSE measures the mean of squared difference between the actual and the predicted value.R squared is 87.07 which shows that our model explains 87.07% variance in target variables based on independent variables and Our model is close to a perfect fit.

V. DISCUSSION

Here, we will discuss about results of our model,will discuss comparisons between our findings and the existing literature and discuss about the discrepancies of our model.

A. Discussion about Results

1) **Discussion about Results of prediction of earthquake:**
We observe that Random Forest has the maximum accuracy of 89.47 and Naive Bayes has the minimum accuracy 85.15 among all the classification algorithms. For class 0(non occurrence of earthquake) Random Forest has highest Precision(0.75),Support Vector Machine has highest Recall(0.95) and Random Forest as well as Support Vector Machine both have highest F-1 Score(0.81).It implies that these both classifiers are performing well.
For class 1(occurrence of earthquake), Support Vector Machine as well as Naive Bayes have highest Precision(0.98) , Decision Tree has highest Recall(0.91) and Random Forest has highest F1-score(0.93). It means that Random Forest has highest F-1 score for both class 0 and class 1.

2) **Discussion about results of prediction of magnitude of Earthquake:**
Decreasing order of accuracy on different sets:Accuracy due to training data(87.18) > Accuracy due to all the data set values(87.07)> Accuracy due to the testing data(86.82). So Accuracy obtained due to Training data is the greatest and accuracy obtained due to testing data is the least among all the accuracy calculated.
Mean Squared Error (0.09580) is less and R squared(87.07) is high ,it implies that our model is performing good **.**

VI. CONCLUSION

In this research, we have successfully demonstrated that we can predict the earthquakes and it's magnitude using various classification and regression techniques of machine learning. Our findings indicate that all the machine learning techniques which we have used in our research have an accuracy greater than 85%, which indicates the reliability and the effectiveness of our predictive model. Through this research we have implications for the earthquake's risk mitigation and it's preparedness. For the future scope, we suggest the below techniques for earthquake's prediction:

- Neural Network Architecture: Various deep learning techniques such as CNN (convolutional neural network) and LSTM (Long Short Term Memory) networks can be used for finding the complex patterns in earthquake.
- IOT (Internet Of Things): IOT can be used for enhancing the prediction of earthquakes by deploying network for the real time sensors that can monitor temperature and ground movements etc .IOT can also be used as early warning systems which can be used for sending alerts before an earthquake hits.
- Computer Vision (CV) : CV techniques can be used for analyzing satellite images which can help to detect the changes in the earth's surface such as ground deformation along fault lines which can detect more risk of earthquake.

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