

Spatiotemporal Bandits Crime Prediction from Web News Archives Analysis

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Abstract. It is said that prevention is better than cure. Hence the idea of preventing crime from occurring is the best for public safety. This can only be achieved if the law enforcement agencies have a prior knowledge of where and when a crime will occur. A crime is an act that is criminal under the law. It is detrimental to society to comprehend crime in order to prevent criminal action. In order to prevent and solve crime, data-driven research is beneficial. Bandit crime has been on the rise in Nigeria, thereby causing public disorder. In this study, from the perspective of artificial intelligence, a novel hybrid deep learning model for crime prediction is proposed. Bandits crime datasets are obtained online through news archives which are less expensive. Spatial crime analysis was carried out on the novel bandit crime dataset obtained and prediction were made using the newly proposed DeCXGBoost model. A comparative analysis was performed with respect to precision, recall, f-measure, and accuracy with other crime predictions algorithms and the proposed model outperformed the other algorithms with accuracy of 99.9999%.

Keywords. Crime prediction, bandit crime, machine learning, deep learning, spatiotemporal, ensemble methods, artificial intelligence.

1 Introduction

Security is a critical component of a country's long-term stability. For the good of society, it is the obligation of a country's law enforcement institutions to regulate criminal incidences and threats. Crime is a threat to humans posed by other people that is penalized by government legislation

[18]. Crime has always been a persistent and troubling issue in society, resulting in social disparities. Since the evolution of the human race, one of the most serious breaches has remained unsolved is crime.

Crimes have an impact on a country's foreign reputation as well as its economy by putting a financial strain on the government in terms of recruiting more police officers [26]. The government must adopt an optimum approach [25] and long-term e-governance information systems to eradicate crime. Crime has shown intricate relationships with place, time, and surroundings as a long-term worldwide concern.

Extracting effective features to disclose such intertwined links in order to anticipate where and when crimes will occur is becoming a hot topic for researchers as well as a bottleneck [5]. Law enforcement deployment in high-risk areas can be aided by this developed algorithm that are predicting the frequency of crimes with regards to the location-based and time [13].

The number, volume, and coverage of archives news channel and online newspapers are examples of web-based news resources, which has exploded, and they now contain both relevant and authentic data [20]. However, because the data in the archives is not well organized and categorized, extracting relevant information about specific or intriguing criminal incidents might be difficult [26]. The news archives are an excellent source of knowledge.

It has a lot of useful and interesting stuff that has been meticulously recorded by experts and depicts some key characteristics of the specific article [33]. Daily Independent, The Guardian, Nigerian Tribune, The Nation, Daily Trust, The Punch, Blueprint, Leadership, New Telegraph, This Day, Vanguard, Daily Sun are the most popular and authentic newspaper archives in Nigeria. The goal of this study is to use freely available data from news archives to conduct a spatiotemporal analysis for bandit crime prediction.

In a nutshell, the viability of employing geospatial methodologies and a novel deep learning approach called “DeCXGBoost” to predict bandit crime/criminal activities using data from online archives in Nigeria is presented in this work. The experimental assessment results suggest that the approach is successful, with good accuracy in spatial and temporal bandit crime prediction in Nigerian villages.

We also compare the results acquired via our technique to those obtained through other algorithms published in the research, proving that the suggested algorithm is more accurate than other ways suggested as seen from the literature. In order to avoid ambiguity, this research makes numerous original contributions such as the bandit crime dataset gathered from Nigerian online news archives, a proposed new framework dubbed the DeCXGBoost, and a qualitative study of crime as a type.

2 Review of Related Literature

Accurate crime forecasting can aid police resource allocation for crime reduction and prevention. There are two widely used methods for predicting criminal activity: one is based on past crime patterns, and the other is based on environmental characteristics linked to criminal trends [30]. A Convolutional Neural Network (CNN) combined with a Long-Short Term Memory (LSTM) network (hence CLSTM-NN) is proposed in a study by [6] to forecast the existence of criminal events over Baltimore (USA).

The model is used for two different sorts of crimes: larceny and street robbery. The suggested neural network's prediction performance is evaluated using several common metrics in a

variety of controlled plausible scenarios (Accuracy, AUC-ROC, and AUC-PR). However, if the model was used on a single type of crime, a better prediction accuracy will be obtained, never the less our study will adopt the CNN for feature extractions. In a study by [9], the approach of supervised learning was employed to improve the accuracy of crime prediction.

In order to foresee crimes, the proposed system analyses a data collection of crimes previously committed with tendencies as contains in records. The decision tree and k-nearest neighbour algorithms are the foundations of the system. To improve prediction accuracy, the Random Forest method and Adaboost were utilised. Finally, to improve accuracy, oversampling was applied.

The proposed system was fed a twelve-year criminal-activity data collection from San Francisco. However, more advanced machine learning algorithms can be used, which will involve a smaller number of algorithms for a better result. In a study by [3], a prediction technique focused on auto-regressive models and spatial analysis was developed to find dangerous crime hotspots in urban regions automatically.

The technique generates a forecasting model of spatiotemporal crime, which consists of crime-dense regions sets and associated predictors of crime, which each is a predictive model for number of crimes estimated predicted to happen in its connected zone. New York City and Chicago crime datasets were experimentally evaluated on this model.

According to results, the suggested technique has high accuracy in spatiotemporal crime predictions over rolling time horizons. However, machine learning would have produced a more accurate result.

[19] used a Long Short-Term Memory (LSTM) for identifying episodes of crime as regards to safety of the public in the crime prediction context. They were able to achieve 87.84 percent accuracy by employing only five elements from dataset supplied by police from municipal of Chicago.

A Feed Forward Neural Network (FFNN), a Recurrent Neural Network (RNN), a Convolutional Neural Network (CNN), and a combination of Recurring Networks with Convolutions (RNN + CNN) were used in a study by [23]. RNN + CNN was shown to be the best neural network for

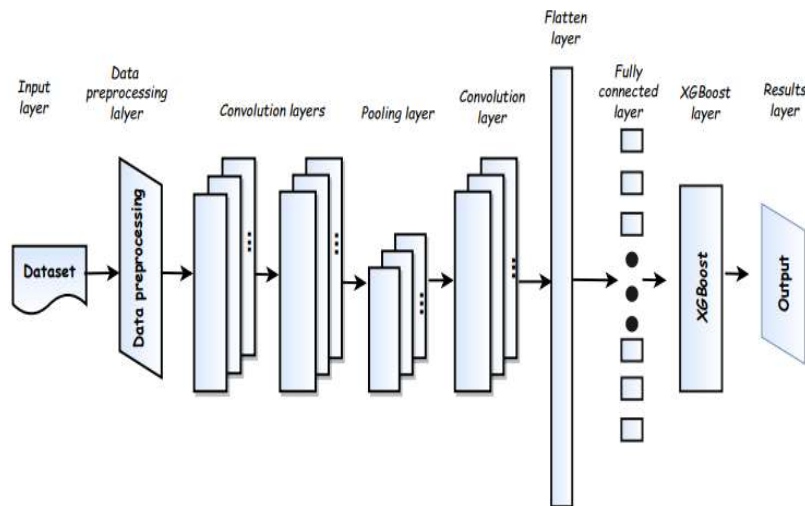


Fig. 1. Proposed frame work

prediction using data from Chicago, with 75.6 percent and 65.3 percent accuracy for Portland.

The study [32] employed algorithms of machine learning of five different types to forecast the type of crime most likely to occur at specific times and locations (locations) in Chicago.

The best result was achieved by a decision tree model, which had a precision of 99.88 percent. In a study by [29], YD county crime events were looked at, ranging from 2012 upto 2015 and several predictions models were used. This included Random Trees, Bayesian networks, and Neural networks. Random Trees had accuracy of 97.4 percent which was the best among the used models in the research.

Several ways to crime prediction have been developed to discover crime patterns and trends, according to the literature. However, because crime is a worldwide issue that is on the rise, there is a pressing need for research that forecasts location-based crimes in Nigeria's neighboring areas using free data from news archives.

Natural language processing methods can be used to turn publicly available data into usable information, and supervised and unsupervised learning can be used to make predictions. Such research can aid in the detection of future crimes in emerging and underdeveloped countries with limited financial resources.

3 Methodology

The new proposed framework called "DeCXGBoost" seen in figure 1, has been proposed with the aim of using deep learning [8] technique and an ensemble learning [31, 28, 11, 35, 7, 14, 21, 27] for the intelligent analysis of crime. It encompasses a convolutional neural network (CNN) which is used for feature extractions with xgboost algorithm which is a very strong classifier is used in the top layer of the CNN for final predictions. We want to be able to use deep learning to predict crime rates and likely hotspots, as well as for proactive policing and prevention efforts, by offering this new framework.

3.1 Data Collection

Data was crawled from the news archives of practically popular and credible newspapers using a Data Miner Tool. These newspapers include Daily Independent, The Guardian, Nigerian Tribune, The Nation, Daily Trust, The Punch, Blueprint, Leadership, New Telegraph, This Day, Vanguard, and Daily Sun.

The data miner tool was chosen for crawling since it collects data from a website and displays it in tabular form.

Table 1. Attributes of the crime dataset

Attribute	Data Type	Description	Example
CrimeType	String	News title	Niger: 20 killed in an attack
Description	String	News description	Army arrest bandits
Location	String	Place of attack	Benue community
Lat	Float	Latitude	10.215539
Long	Float	Longitude	5.393955
Number Killed	Integer	Number of people killed in the attack	5 people lost their lives in Kaduna bandit attack
Number Abducted	Integer	Number of people abducted by the bandits	100 students abducted in Zamfara bandits attack
Property Destroyed	String	Destruction caused during the attack	10 houses burnt in Sokoto bandits attack
Arrest made	Boolean	Bandits arrested by security agency	10 bandits' members arrested by the Nigerian Army
Date	Date	Date of attack	12 October 2021

This further categorizes the news by title, description, date, and URL, among other factors. Crime type, description, location, latitude, longitude, number killed, number abducted, property destroyed, arrest made, and date were among the characteristics of news records used for this study as seen in Table 1.

3.2 Preprocessing

At first, all of the instances were combined, and extraction of properties from the description was carried out. Cleaning of data was done afterwards, thereafter, Description element was eliminated because it was not needed for prediction.

Because there was no requirement to lower the parameter, attributes were chosen based on vast literature, and data reduction techniques were not used. According to the input of our proposed model, RF, KNN, NB, and CNN algorithms, an acceptable format for the bandits data preprocessed and their attributes were presented.

With this in mind, additional data transformations and discretization stages were unnecessary. To convert category qualities to numerical values, we used one-hot encoding. Figure 2 shows the features used in the bandit

crime prediction, also Figure 3 shows the frequency of Number of people killed and abducted during the study time.

3.3 Dataset Training and Testing

Avoiding overfitting and to obtain realistic accuracy more, division of the dataset into two parts is done: training and testing dataset. The training dataset includes all features as well as the target label. The testing dataset only contains the information that a machine learning model uses to predict the target label.

The selection module of Scikit-model learn separates the original dataset into testing and training datasets using a class test train split. The size of the test dataset is set to 20% of the main dataset. The value was utilised in all the trials. The partition of the dataset into train and test data sets is shown in Figure 4.

3.4 Bandits Crime Data Visualization and Hotspot with ArcGIS

For visualising spatial datasets, ArcGIS is a popular application. In this study, the Nigerian shapefile is loaded into ArcGIS along with the

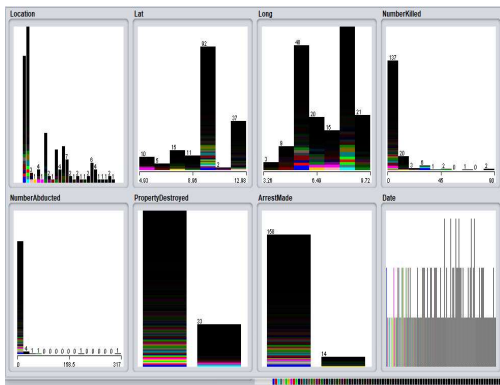


Fig. 2. Features used in the bandits crime prediction as extracted by WEKA tool

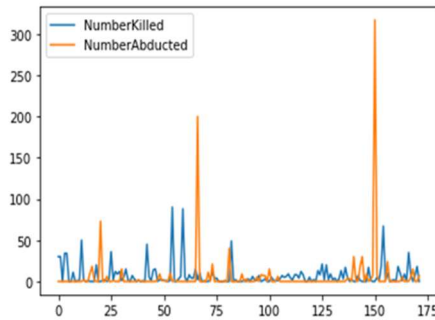


Fig. 3. Shows happening of killings and abductions

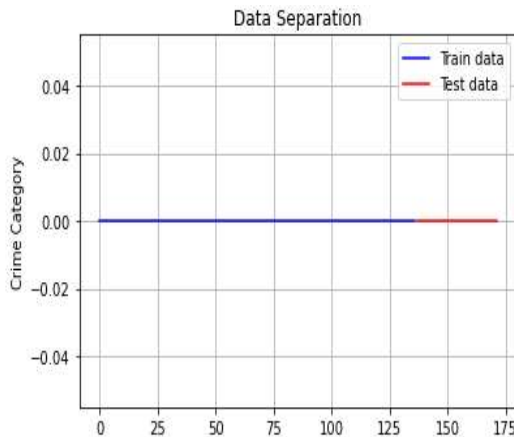


Fig. 4. Data separation of the bandits crime dataset

extracted bandits crime dataset to display records of bandits crime depending on the coordinate (latitude & longitude). ArcGIS representation of the bandits crime dataset in Figure 5 demonstrates

that the bolded points have been particularly prone to banditry offences.

As shown in Figure 5, a hotspot indicates places with a high crime rate and a high likelihood of crime. It refers to the concentration of crime in a certain location [10, 2] as determined by a count that identifies hotspots and cool spots in every aggregation place across the investigative area.

Hotspots creation on maps assists security or law enforcement organisations in identifying areas with high crime rates, thereby forecasting the causes of crime in that region also preventing further crime by raising awareness of the need for security in the region [22, 24].

4 Crime Spatial Analysis

Analysis of crime is described as been the process of identifying trends and patterns of crime from criminal dataset in order to aid in the deployment of plans and strategies for future crime prediction [4].

In order to analyse crime patterns spatially, we conducted a spatial analysis of crime with the spatial data derived from news archives from the web. The term spatial crime analysis means the study of the spatial distribution of the crime rate, which might be clustered, random, or dispersed.

It depicts the spatial relationship between crime feature sites and analyses trends in crime patterns.

4.1 Clustering with k-Means Algorithm

A data mining approach that divides items into groups with similar features or properties, each of which behaves differently is called clustering [1]. It can help forecast crimes based on spatial distribution by analysing clusters [12].

We utilised the k-Means approach to cluster a crime dataset in this study because it is suitable to large datasets and has a lower complexity than other clustering algorithms [24].

In this study, the Weka tool is utilised to conduct k-Means clustering. Based on the nearest mean, k groups are created from n observations in k-Means clustering. The following steps are involved in the k-means clustering process:



Fig. 5. Visualization of bandits crime cases

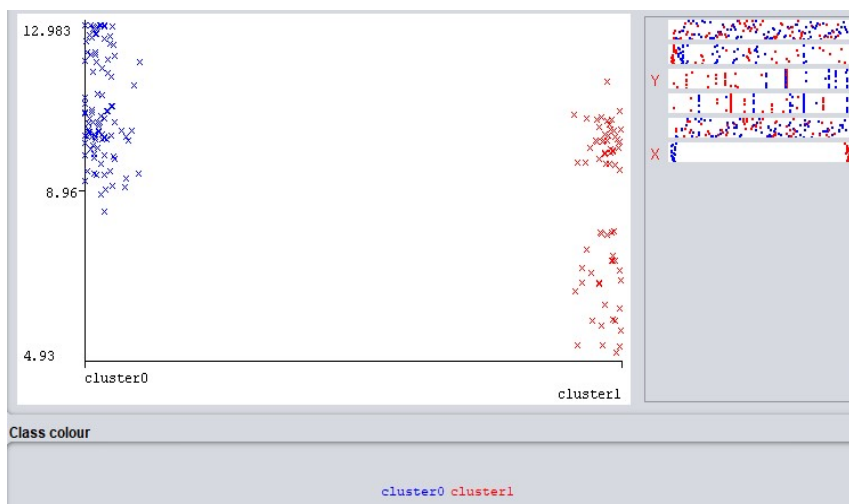


Fig. 6. Bandits crime cases clusters of Nigeria produced using k-Means clustering

- i. k is the number of clusters declared.
- ii. Decide on the cluster's centres.
- iii. The cluster with the least distance between them is assigned to each instance.
- iv. The cluster centroids are recalculated.
- v. The procedure is repeated several times.

The centroids of each cluster produced using the k-Means approach are shown in Table 2.

The data is separated into two clusters with numbers ranging from 0 to 1. Table 3 depicts the

distribution of clusters based on bandit crime locations.

The centroid determines the name of the cluster. Figure 6 shows the crime clusters in terms of their latitude, which was created using the Weka tool.

5 Bandits Crime Prediction

In this section the proposed DeCXGBoost method is used to make predictions from the extracted bandits crime dataset from Nigeria. The results obtained are then compared with other predictions

Table 2. Bandits crime clusters in Nigeria using k-Means algorithm

Clusters	Data Points	Location	LAT	LONG	Date
Centroid	172.0	Kaduna Community	10.0192	6.9944	15 th May 2021
Cluster 0	102.0	Kaduna Community	10.937	7.5816	25 th April 2021
Cluster1	70.0	Niger Community	8.6819	6.1387	30 th Sept. 2021

Table 3. Description of our selected feature

Cluster#	Location
Cluster 0	Kaduna Community
Cluster 1	Niger Community

algorithms used in this studies namely random forest, Naïve bayes, and bagging algorithms.

Any algorithm's performance is measured using a variety of evaluation matrices. F-measure, Accuracy, Recall, Precision, ROC curve, Root Mean Square Error (RMSE), Absolute Error, and other performance criteria are used in evaluations. The capacity to anticipate categorical class labels is defined as accuracy.

This means it estimated the fraction of events that were accurately anticipated [26]. The evaluation matrices used for this study are accuracy, precision, recall, and F-measure.

The formula in Equation (1) was used to calculate the accuracy of the measurements:

$$Accuracy (Acc) = \frac{TP+TN}{TP+TN+FP+FN} \times 100. \quad (1)$$

Precision is the percentage of true positives among all documents that have been positively assigned. It's calculated as given in Equation (2):

$$Precision (Pre) = \frac{TP}{TP+FP} \times 100. \quad (2)$$

Recall is the total number of true positives out of the total number of actual positive documents. It's calculated as shown in Formular (3):

$$Recall (Rec) = \frac{TP}{TP+FN} \times 100. \quad (3)$$

As seen in Equation 4, the F-measure is computed by taking the weighted harmonic mean of the precision and recall:

$$F\text{-measure} = 2 \times \frac{Pre \times Rec}{(Pre + Rec)} \times 100. \quad (4)$$

We have:

- If the dataset contains a positive record but the classification output is negative: False Negative (FN).
- If the dataset contains a negative record but the classification outcome is also negative: True Negative (TN).
- If the instance is positive, but the categorization result is also positive: True Positive (TP).
- A data record that is negative but has a positive categorization outcome: False Positive (FP).

5.1 Predictions with DeCXGBoost

The preprocessed bandits crime dataset is feed into the framework. The implementation was done using python 3.7, tensorflow, keras, and jupyter notebook used as the coding editor. The framework was trained with set parameters as shown in figure 7. Figure 8 (a) shows the loss function from the novel model. Figure 8(b) is the accuracy of both thr train and test dataset.

```
Model: "sequential"
```

Layer (type)	Output Shape	Param #
conv1d (Conv1D)	(None, 9, 32)	64
conv1d_1 (Conv1D)	(None, 9, 64)	2112
leaky_re_lu (LeakyReLU)	(None, 9, 64)	0
max_pooling1d (MaxPooling1D)	(None, 9, 64)	0
conv1d_2 (Conv1D)	(None, 9, 128)	8320
leaky_re_lu_1 (LeakyReLU)	(None, 9, 128)	0
flatten (Flatten)	(None, 1152)	0
my_dense (Dense)	(None, 256)	295168
dropout (Dropout)	(None, 256)	0
dense (Dense)	(None, 1)	257

```
Total params: 305,921
Trainable params: 305,921
Non-trainable params: 0
```

Fig. 7. Build up of our proposed model

5.2 Using Random Forest (RF) for Prediction

Well-known strong supervised machine learning technique is the RF algorithm. Several decision trees are created within a forest by the RF algorithm [15]. Forest with more trees echoes more accurate and reliable predictions. New class are predicted based on prior old tree classes features. Each tree votes for a new tree that is added and the forest chooses the categorisation that receives the most votes from all of the current trees [17].

We used the Weka program to predict bandits crime using RF on the obtained dataset. The following stages were used to implement random forest algorithms [34]:

- i. It selects k features at random from a total of m features, where $m > k$.
- ii. It uses the best split point approach to find the node d among the k characteristics.
- iii. It uses the best split method to split the node into daughter nodes.
- iv. It repeats steps 1–3 till the number of nodes reaches l .

- v. It creates a forest by repeating steps 1 to 4 for n number of times, resulting in an n number of trees.
- vi. It takes the test features and predicts the outcome using the rules of each randomly generated decision tree, then saves the projected outcome (target).
- vii. The votes are calculated for each anticipated class.
- viii. Using the random forest approach, final predictions are created based on the most popular projected class.

5.3 Prediction Using K-Nearest Neighbour (KNN)

The KNN algorithm predicts the test data using the nearest neighbour approach [16]. The Weka tool was utilised in this research to train KNN using a bandits crime dataset, and our test dataset was used to predict the crime occurring at the said location. The distance between features of the training and testing is determined, since distance

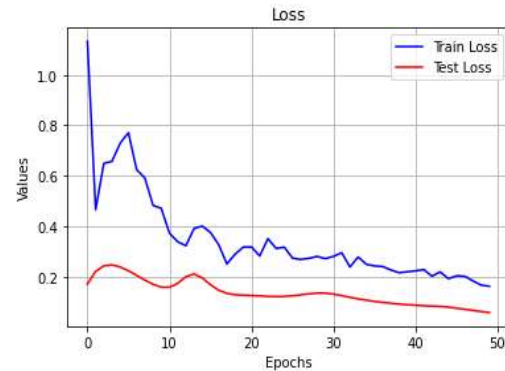
is a factor in KNN. The KNN was put in place in the following way [26]:

- i. Load the data into the program.
- ii. The value of k has been determined.
- iii. Data points are iterated from 1 to the total amount of training to generate the projected class.
- iv. Using the Euclidean distance metric, which measures the distance between the pair of samples p and q in an n -dimensional feature space, calculate the distance between each row of testing data and each row of training data.
- v. Sort the calculated distance values in ascending order.
- vi. The top k rows of the sorted array are returned.
- vii. The most often used class for the specified rows is returned.
- viii. The outcome of the prediction is returned.

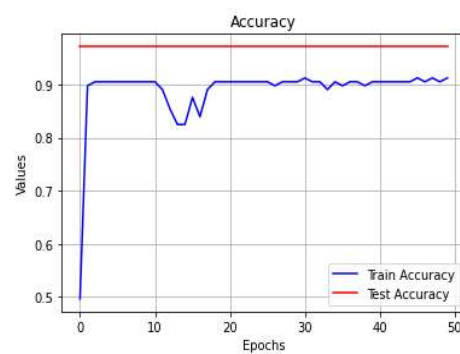
5.4 Prediction Using Naive Bayes (NB)

The Bayes Theorem is used to build the Naive Bayes statistical categorization approach. It's one of the most straightforward supervised learning algorithms on the market. The Naive Bayes classifier is a simple, reliable, and fast approach. Naive Bayes classifiers have high accuracy and speed on huge datasets. The steps that were taken were as follows:

- i. Input the dataset.
- ii. Calculate the prior probability for the provided class labels in step one.
- iii. Calculate the Likelihood Probability for each class using each attribute.
- iv. Use the Bayes Formula to calculate the posterior probability of these values.
- v. Given that the input belongs to the higher probability class, determine which class has the greater probability.
- vi. Return results.



(a)



(b)

Fig. 8. Loss function and accuracy of the proposed model

6 Results and Discussion

The most challenging task is crime prediction, especially when the dataset available from crime reports is insufficient. On bandits crime dataset obtained from archives, we employed our proposed DeCXGBoost model and four other machine learning algorithms that is RF, KNN, NB, and CNN to predict criminal events in this study. With regards to accuracy and prediction, results from the four algorithms used in this study were compared with the proposed model.

The average accuracy of the DeCXGBoost, RF, KNN, NB, and CNN, respectively, was found to be 99.9999%, 91.2791%, 85.4651%, 79.6512%, and 97.1429%. As a result, when compared the proposed novel model to other algorithms used in

Table 4. RF results

Trees	Precision	Recall	F-measure	Accuracy
10 Trees	0.843	0.913	0.877	91.2791
20 Trees	0.843	0.913	0.877	91.2791
30 Trees	0.843	0.913	0.877	91.2791
40 Trees	0.843	0.913	0.877	91.2791

Table 5. KNN results

k	Precision	Recall	F-measure	Accuracy
3-NN	0.849	0.849	0.849	84.8837
5-NN	0.839	0.855	0.847	85.4651
7-NN	0.849	0.849	0.849	84.8837
9-NN	0.839	0.855	0.847	85.4651

Table 6. NB results

k	Precision	Recall	F-measure	Accuracy
3-fold	0.868	0.756	0.802	75.5814
5-fold	0.895	0.797	0.834	79.6512
7-fold	0.877	0.767	0.812	76.7442
9-fold	0.874	0.744	0.796	74.4186

Table 7. Results of the proposed algorithm

Model	Precision	Recall	F-measure	Accuracy
RF	0.843	0.913	0.877	91.2791
KNN	0.839	0.855	0.847	85.4651
NB	0.895	0.797	0.834	79.6512
CNN	0.028	0.028	0.028	97.1429
Ours	1.0	1.0	1.0	99.9999

this study, the proposed novel model prediction remained high and efficient. The outcomes of both algorithms, as well as the parameters, are shown in Tables 4, 5, and 6.

Table 4 compares precision, recall, F-measure, and accuracy values to varying KNN algorithm parameters. The findings show that as the number of trees increases, the matrices' values remain constant, and we get the same maximum values when the number of trees is equal to 40.

When the value of k was increased to 5, we were able to attain higher matrices values, as shown in Table 5. When k is equal to 7, however, it declines, and when k is equal to 5, it returns to the same matrices values.

The number of k folds is shown as a parameter in Table 6, together with precision, recall, F-measure, and accuracy values. We were able to achieve greater matrix values when k equaled 5,

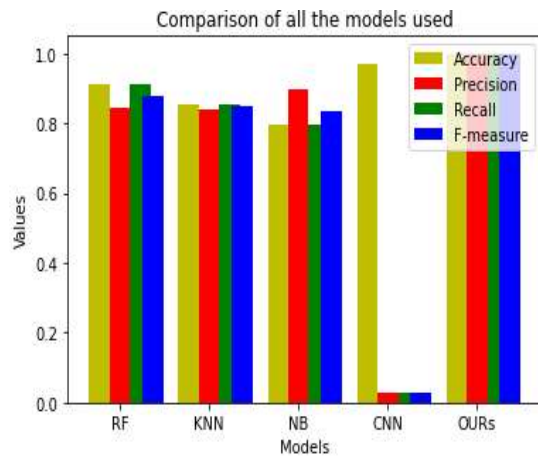


Fig. 9. Comparison of all the models used on bandits crime dataset

but the matrices values continued to plummet after that.

Table 7 shows the comparison of the best matrices values as obtained by each model with CNN performing poorly with respect to precision, recall, and F-measure. However, its Accuracy was higher as compared with RF, KNN, and NB as can be seen in Figure 9.

As seen in figure 9, we were able to achieve higher matrices using our proposed unique hybrid method called DeCXGBoost.

Most accurate result was predicted by the novel DeCXGBoost since it was able to minimize negative consequences of incorrect feature categorization as well as classification mistakes. This was because CNN been a good feature extractor, did the extensive feature extraction and the xgboost ensemble algorithm which is a good a robust classifier did the predictions with great accuracy.

Furthermore, computerised geo-coding technologies for extracting accurate locations can pinpoint the crime's exact site. Such an integrated model can aid law enforcement organisations and decision-makers in predicting specific areas of crimes in order to achieve successful outcomes as see in Table 3, where more of the bandits crime clusters are seen around Kaduna and Niger communities in Nigeria.

7 Conclusions

This paper presents a novel hybrid deep learning frame work which encompassed CNN and xgboost algorithms for spatiotemporal prediction of bandit crime in Nigeria. The proposed DeCXGBoost frame work predicted the number of bandit crimes with good accuracy, according to an experimental evaluation conducted on news archives bandit crime datasets relating to bandit crime data from various parts of Nigeria. In addition, the study also provides fine grained information on where crime is likely to happen through spatial analysis.

We also presented a comparison with other algorithms, demonstrating that the achieved results (to the best of our knowledge) beat those of other systems suggested in literature thus far for crime predictions. Other study topics could be looked into in the future. In real time, we may go deeper into the projections.

References

1. **Agarwal, J., Nagpal, R., Sehgal, R. (2013).** Crime analysis using K-Means clustering. *International Journal of Computer Applications*, Vol. 83, No. 4, pp. 1–4. DOI: 10.5120/14433-2579.
2. **Butt, A., Ahmad, S. S., Shabbir, R., Erum, S. (2017).** GIS based surveillance of road traffic accidents (RTA) risk for Rawalpindi city: A geo-statistical approach. *Kuwait Journal of Science*, Vol. 44, No. 4, pp. 129–134. DOI: 10.5383/swes.7.02.002.
3. **Catlett, C., Cesario, E., Talia, D., Vinci, A. (2019).** Spatio-temporal crime predictions in smart cities: A data-driven approach and experiments. *Pervasive and Mobile Computing*, Vol. 53, pp. 62–74. DOI: 10.1016/j.pmcj.2019.01.003.
4. **Dhaktode, S., Vernekar, N., Vyas, D. (2017).** Crime rate prediction using K-Means. *IOSR Journal of Engineering (IOSR JEN)*, pp. 25– 29
5. **Duan, L., Hu, T., Cheng, E., Zhu, J., Gao, C. (2017).** Deep convolutional neural networks for spatiotemporal crime prediction. *Proceedings of the International Conference on Information and Knowledge Engineering (IKE)*, pp. 61–67.

6. **Esquivel, N., Nicolis, O., Peralta, B., Mateu, J. (2020).** Spatio-temporal prediction of baltimore crime events using CLSTM neural networks. *Journals & Magazines, IEEE Access*, Vol. 8, pp. 209101–209112. DOI: 10.1109/ACCESS.2020.3036715.
7. **Hassan, M., Abdel-Qader, I. (2015).** Performance analysis of majority vote combiner for multiple classifier systems. *IEEE 14th International Conference on Machine Learning and Applications, ICMLA '15*, pp. 89–95. DOI: 10.1109/ICMLA.2015.27.
8. **Hatcher, W. G., Yu, W. (2018).** A survey of deep learning: platforms, applications and emerging research trends. *Journals & Magazines*, Vol. 6, pp. 24411–24432. DOI: 10.1109/ACCESS.2018.2830661.
9. **Hossain, S., Abtahee, A., Kashem, I., Hoque, M. M., Sarker, I. H. (2020).** Crime prediction using spatio-temporal data. In: *Chaubey, N., Parikh, S., Amin, K. (eds) Computing Science, Communication and Security, COMS2 2020, Communications in Computer and Information Science*, Vol. 1235, pp. 277–289. DOI: 10.1007/978-981-15-6648-6_22.
10. **Jana, M., Sar, N. (2016).** Modeling of hotspot detection using cluster outlier analysis and Getis-Ord G_i^* statistic of educational development in upper-primary level. *India. Modeling Earth Systems and Environment*, Vol. 2, No. 60, pp. 1–10. DOI: 10.1007/s40808-016-0122-x.
11. **Joshi, N., Srivastava, S. (2014).** Improving classification accuracy using ensemble learning technique (using different decision trees). Vol. 3, No. 5, pp. 727–732.
12. **Malathi, A., Santhosh-Baboo, S. (2011).** An enhanced algorithm to predict a future crime using data mining. *International Journal of Computer Applications*, Vol. 21, No. 1, pp. 1–6. DOI: 10.5120/2478-3335.
13. **Matijosaitiene, I., Zhao, P., Jaume, S., Gilkey, J. W. (2019).** Prediction of hourly effect of land use on crime. *ISPRS International Journal of Geo-Information*, Vol. 8, No. 1, pp. 1–13. DOI: 10.3390/ijgi8010016.
14. **Narassiguin, A., Bibimoune, M., Elghazel, H., Aussem, A. (2016).** An extensive empirical comparison of ensemble learning methods for binary classification. *Pattern Analysis and Applications*, Vol. 19, pp. 1093–1128. DOI: 10.1007/s10044-016-0553-z.
15. **Ngarambe, J., Irakoze, A., Yun, G. Y., Kim, G. (2020).** Comparative performance of machine learning algorithms in the prediction of indoor daylight illuminances. *Sustainability (Switzerland)*, Vol. 12, No. 11, pp. 1–22. DOI: 10.3390/su12114471.
16. **Padhi, D. K., Padhy, N., Mishra, J. (2020).** Intraday stock prices forecasting using an autoregressive model. *Engineering and Applications (ICCSEA), Gunupur, India*, pp. 1–6, DOI:10.1109/ICCSEA49143.2020.9132927.
17. **Pflueger, M. O., Franke, I., Graf, M., Hachtel, H. (2015).** Predicting general criminal recidivism in mentally disordered offenders using a random forest approach. *BMC Psychiatry*, Vol. 15, No. 62, pp. 1–10. DOI: 10.1186/s12888-015-0447-4.
18. **Raghavendhar, T. V., Joshy, J., Mahalakshmi, R., Ashutosh, S. M. (2018).** Crime prediction and analysis using clustering approaches and regression methods. *IJCAT International Journal of Computing and Technology*, Vol. 5, No. 4, pp. 61–66.
19. **Ramirez-Alcocer, U. M., Tello-Leal, E., Mata-Torres, J. A. (2019).** Predicting incidents of crime through LSTM neural networks in smart city domain. *The Eighth International Conference on Smart Cities, Systems, Devices and Technologies*, pp. 32–37.
20. **Ristea, A., Al Boni, M., Resch, B., Gerber, M. S., Leitner, M. (2020).** Spatial crime distribution and prediction for sporting events using social media. *International Journal of Geographical Information Science*, Vol. 34, No. 9, pp. 1708–1739. DOI: 10.1080/13658816.2020.1719495.
21. **Rojarath, A., Songpan, W., Pong-Inwong, C. (2016).** Improved ensemble learning for classification techniques based on majority voting. *2016 7th IEEE International Conference on Software Engineering and*

- Service Science (ICSESS), pp. 107–110. DOI: 10.1109/ICSESS.2016.7883026.
22. **Rusnák, J., Ondrejka, P., Herman, L., Kubiček, P., Mertel, A. (2016).** Visualization and spatial analysis of police open data as a part of community policing in the city of Pardubice (Czech Republic). *Annals of GIS*, Vol. 22, No. 3, pp. 187–201. DOI: 10.1080/19475683.2016.1200670.
 23. **Stec, A., Klabjan, D. (2018).** Forecasting crime with deep learning. *Machine learning*, pp. 1–20. DOI: 10.48550/arXiv.1806.01486.
 24. **Tabangin, D. R., Flores, J. C., Emperador, N. F. (2008).** Investigating crime hotspot places and their implication to urban environmental design: A geographic visualization and data mining approach. *World Academy of Science, Engineering and Technology*, Vol. 2, No. 8, pp. 210–218.
 25. **Toppireddy, H. K. R., Saini, B., Mahajan, G. (2018).** Crime prediction & monitoring framework based on spatial analysis. *Procedia Computer Science*, Vol. 132, pp. 696–705, DOI: 10.1016/j.procs.2018.05.075.
 26. **Umair, A., Sarfraz, M. S., Ahmad, M., Habib, U., Ullah, M. H., Mazzara, M. (2020).** Spatiotemporal analysis of web news archives for crime prediction. *Applied Sciences (Switzerland)*, Vol. 10, No. 22, pp. 1–16. DOI: 10.3390/app10228220.
 27. **Verma, A., Mehta, S. (2017).** A comparative study of ensemble learning methods for classification in bioinformatics. 2017 7th International Conference on Cloud Computing, Data Science Engineering Confluence, pp. 155–158. DOI: 10.1109/CONFLUENCE.2017.7943141.
 28. **Wan, S., Yang, H. (2013).** Comparison among methods of ensemble learning. *Proceedings - 2013 International Symposium on Biometrics and Security Technologies, ISBAST'13, March*, pp. 286–290. DOI: 10.1109/ISBAST.2013.50.
 29. **Wu, S., Wang, C., Cao, H., Jia, X. (2020).** Crime prediction using data mining and machine learning. *Advances in Intelligent Systems and Computing*, Vol. 905, Springer International Publishing. DOI: 10.1007/978-3-030-14680-1_40.
 30. **Yang, B., Liu, L., Lan, M., Wang, Z., Zhou, H., Yu, H. (2020).** A spatio-temporal method for crime prediction using historical crime data and transitional zones identified from nightlight imagery. *International Journal of Geographical Information Science*, Vol. 34, No. 9, pp. 1740–1764. DOI: 10.1080/13658816.2020.1737701.
 31. **Yang, L. (2011).** Classifiers selection for ensemble learning based on accuracy and diversity. *Procedia Engineering*, Vol. 15, pp. 4266–4270. DOI: 10.1016/j.proeng.2011.08.800.
 32. **Yuki, J. Q., Mahfil Quader Sakib, M., Zamal, Z., Habibullah, K. M., Das, A. K. (2019).** Predicting crime using time and location data. *ACM International Conference Proceeding Series*, pp. 124–128. DOI: 10.1145/3348445.3348483.
 33. **Za'in, C., Pratama, M., Lughofer, E., Anavatti, S. G. (2017).** Evolving type-2 web news mining. *Applied Soft Computing Journal*, Vol. 54, pp. 200–220, DOI: 10.1016/j.asoc.2016.11.034.
 34. **Zakariah, M. (2014).** Classification of large datasets using random forest algorithm in various applications: Survey. *International Journal of Engineering and Innovative Technology*, Vol. 4, No. 3, pp. 189–198.
 35. **Zeng, X., Wong, D. F., Chao, L. S. (2014).** Constructing better classifier ensemble based on weighted accuracy and diversity measure. *The Scientific World Journal*, Vol. 2014, DOI: 10.1155/2014/961747.

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