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TIME SERIES ANALYSIS OF CRIME RATE IN OSUN STATE NIGERIA USING SKELLAM GARCH(1,1) MODELS

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ABSTRACT: *The manifestation of urban crime and other social vices causing anti-moral, anti-social behaviours as well as criminal damage to both public and private properties in Nigeria with the consequential effect of spontaneous and uncontrollable urban growth, high-level poverty rate, distortion of city peace and tranquillity has become an issue of national discourse. The paper employed ARCH and Skellam GARCH models to forecast the likely crime rate trend within the next five years. The Skellam-GARCH model performs better as a crime forecasting model than the ARCH model.*

KEYWORDS: Arch model, Skellam-Garch model, Forecast.

CL: M60

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INTRODUCTION

In the face of the increasing strategies for crime prevention, control and management all over the world, the recent wave of urban crimes in most major cities of the world especially for those in the developing nations has become an increasing source of worry. It has also become a major socio-economic problem and an issue of global discourse in recent times. Sanam et al. (2017) observed that despite the fact that no society desires criminal situations, criminal activities are gradually taking centre stage and hence becoming a blistering subject. The manifestation of this emerging trend is more pronounced in developing nations in spite of the series of policy measures taken by relevant crime control authorities. More so, the exertions of negative impacts of criminal activities on the socio-economic performances in these countries have reached an alarming stage, thus an issue to contend with (Ghani, 2017; Olufolabo, 2015).

Crime is a phenomenal activity that changes over time and across customs and traditions of the people living in a society. As what may be considered legal in one society may be illegal in the other neighbouring society. Adegbola and Oluwole (2018) argued that crime itself is not a new phenomenon anywhere in the world, but more urbanised cities are usually prone to organised criminal activities than less urbanised areas. Bello (2011), just like other scholars who attributed urban crime to the effect of urban expansion, posited that industrialization and technological advancement propel city growth and criminal activity tendencies. The appearance of urban crime and other social vices causing anti-moral, anti-social behaviours as well as criminal damages to both public and private properties in Nigeria today are said to be the consequential effect of the spontaneous and unplanned urbanisation, uncontrolled urban growth pattern and high poverty rate (Ahmed, 2012; Bello, 2011; Aluyor, 2005; Gibbons, 2004).

One of the most recent emerging advances in criminological research though not usually practised by police offices or departments is crime predictions. Obubu et al. (2019) asserted that despite the existence of several econometric researches on crime, police departments or offices hardly make use of forecasting as policing instruments. The prevalence of crime in developing economies of the world increases the unpredictability of the issues of fear of the unknown which is not restricted to class, colour, gender, and age or race of the inhabitants. For instance, the fear of armed robbers often makes most Nigerians, especially those in the cities, to keep vigil. Ahmed (2012) opined that the concentration of violent crimes in major city centres worldwide is heralded as an indicator of the breakdown of urban systems and a prelude to city crime. Ahmed (2010) and Agbola (2000) cited in Ahmed (2012) also observed that the skyrocketing violence and other forms of dangerous criminal tendencies threatening lives and property, the national sense of well-being and coherence, peaceful coexistence, social order and security have become a topical issue of national discourse in recent time in Nigeria.

Bannister and Fyfe (2001) however argued that there exists a close relationship between densely populated, built up environments and the fear of crime. In line with this assertion, Ahmed (2012) opined that there exist unguided population growth and city expansion with inadequate police protection in Nigerian cities. Bello (2012) noted that criminal activities and its fear affect several aspects of daily life which most often promotes insecurity and anxiety. More so, it was observed that residents usually formed opinions concerning levels of urban crime in most developing nations without any empirical evidence as there exists some kind of disconnect between actual rates of crime and neighbourhood safety. Thus, urban area stability and sustainability is said to have connection with the safety of securing and the policing of

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urban areas, while personal safety and security issues are linked with and use as matrix for measuring the quality of life and property values in our urban areas (Tretter, 2013; Ahmed & Salihu, 2013; Bello, 2012; England & Simon, 2010). As an all-embracing issue that cuts across all nations of the world, issues pertaining to the security of lives and properties require careful analysis and prompt action. Hence, this study is therefore considered appropriate and timely as it aims at adopting Skellam Generalised Autoregressive Conditional Heteroscedasticity (SK-GARCH) time series models for the prediction of urban crime in Osun state, Nigeria.

Nigeria is a country with no clear robust study that systematically gauges the internal structure of her crime dynamics. The distorted city growths as well as the prevalence of poverty are pathways that trigger socio-economic misbehaviours that activate crime and conflict. Crime rates in Osun state have been reported to be very low especially when compared to other states in the same geopolitical zone in the past. But the current trending waves of urban insecurities in Osun state are gradual but steadily gaining momentum. The most recent addition to these criminal activities that is, however, alien to the existence of the state but widely reported in the media is kidnapping. The recent trend of urban crimes in the state has taken a serious dimension with huge insecurity challenges on the state, region and the entire nation hence the need for critical analysis of the situation through models that can accurately predict the current trend of crime in the state. In Nigeria, there is thus the need for critical examination of the country's security architecture through crime forecasting and prevention modelling.

THEORETICAL FRAMEWORK

Several theories and concepts on crime prediction and control have been developed by earlier researchers in literature. The common belief that criminal tendencies are inborn were debunked and likened to mirage rather than reality as several factors have been discovered to induce man towards criminalities. Adderley and Bramer (2006) opined that psychologists and sociologists are of the view that criminal occurrences are based on the social configuration of humanities. Hence, Adderley and Bramer (2006) posited that the need for thorough assessment of environmental criminology cannot be overemphasised as the understanding of offenders' behaviour plays a vital role in the understanding and prediction of crime and criminality. These notions have led to the development and propagation of criminological theories that explain causes and trends of crimes in our societies. Some of the theories developed are Routine Activity Theory, Crime Pattern Theory, Rational Choice Perspective Theory, Awareness Theory among others.

The Autoregressive Conditional Heteroscedasticity (ARCH), the Generalized Autoregressive Conditional Heteroscedasticity and Skellam GARCH Models.

The first model of stochastic volatility was the Autoregressive Conditional Heteroscedasticity (ARCH) process which was first proposed by Engle (1982) and later through the separate work of Bollerslev (1986) and Taylor (1986) generalised to make it more robust and realistic. The generalisation was called the Generalised Autoregressive Conditional Heteroscedasticity (GARCH) Model. GARCH is probably considered the most commonly used financial time series model and thus has inspired dozens of other more sophisticated models.

The ARCH effect is concerned with a relationship within the heteroscedasticity, often termed serial correlation of the heteroscedasticity. It often becomes apparent when there is a bunching

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in the variance or volatility of a particular variable, producing a pattern which is determined by some factor. Given the following model:

$y_t = \beta_0 + \beta_1 x_1 + \mu_t$ ……………………………………………………, (1)

$\mu_t \sim N(0, \alpha_0 + \alpha_1 \varepsilon_{t-1})$ ……………………………………………… ., (2)

where μ_t is the error term

σ_t^2 is the conditional variance of the error term. The ARCH effect is then modelled by:

$\sigma_t^2 = \alpha_{0+\alpha_1 \mu_{t-1}^2}$……………………………………………………………, (3)

This is an ARCH (1) model as it contains only a single lag on the squared error term, however it is possible to extend this to any number of lags, if there are q lags, it is termed an ARCH (q) model.

The conditional variance for GARCH (p,q) model is generally expressed as:

$\sigma_t^2 = \beta_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_j \sigma_{t-j}^2$ ……………………………………(4)

where p is the order of the GARCH terms,

δ^2 and q in the order of the ARCH terms, $\mathcal{E}^2$ where $\beta_0 > 0$;

$\alpha_i > 0$; i = 1 ………,q – 1; j = 1,……………,p – 1 and $\beta_p, \alpha_p > 0$.

σ_t^2 is the conditional variance and $\mathcal{E}_t^2$ disturbance term.

The reduced form of equation 3 is the GARCH (1,1) represented as:

$\sigma_t^2 = \beta_0 + \beta_1 \varepsilon_{t-1}^2 + \beta_2 \varepsilon_{t-1}^2$ …………………………………………… (5)

The three parameters ($\beta_0, \beta_1, \beta_2$.) are non negative and $\beta_1 + \beta_2 < 1$, to achieve stationarity.

The family of Autoregressive Conditional heteroskedasticity (ARCH) models, every ARCH or GARCH family model requires two distinct specifications: the mean and variance equations. According to Engel, conditional heteroskedasticity in a return series, y_t can be modelled using ARCH model expressing the mean equation in the form:

$y_t = E_{t-1}(y_t) + \mathcal{E}_t$

Such that $\mathcal{E}_t = \varphi_t \sigma_t$ ……………………………………………………, (6)

Skellam GARCH (1,1) model

Let (Y_t) be an integer valued time series and let F_t be define as σ-field generated by observation up to and including time t. The conditional on the past observations, $(Y_t|F_{t-1})$ are independent and follow symmetric Skellam $\left(\frac{\sigma_{t|t-1}^2}{2}, \frac{\sigma_{t|t-1}^2}{2}\right)$ with conditional variance satisfying

$$\sigma_{t|t-1}^2 = \omega + \alpha y_{t-1}^2 + \beta \sigma_{t-1|t-2}^2, \quad t \geq 2 \text{ ……………………………, 7}$$

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As in GARCH(1,1). The parameters $\omega, \alpha \ and \ \beta$ satisfying the following constraints: $\omega > 0$, $0 < \alpha < 1$, $0 < \beta < 1$ and $\alpha + \beta < 1$ which are necessary and sufficient for stationarity of the process (7). The simplest case of the model with $\beta = 0$ is denoted by Skellam ARCH(1).

Therefore, Skellam GARCH(1,1), is given by

$$P(Y_t = y_t|F_{t-1}) = e^{-\sigma^2_{t|t-1}} I_{yt}(\sigma^2_{t|t-1}), \quad .. \quad y_t = \cdots, -1, 0, 1, \ldots, \ldots \ldots, 8$$
$$E(Y_t|F_{t-1}) = 0 \quad \text{and} \quad Var(Y_t|F_{t-1}) = \sigma^2_{t|t-1}$$

Sources of Data

The study explores secondary data. In order to forecast the current trend of crime rate in Osun, secondary data on monthly occurrence of the selected criminal activities in the state were sourced from the State Police Headquarters in Osogbo for the period covering 2015 to 2022, internet sources, journals and periodicals. The data obtained from the literature search were compared with the data obtained from the Police Headquarters.

For better visual presentation of the occurrence of the prevalent crime rate in the paper, Table 1 portrays a summary of the data while Figure 1 below shows the trend of the prevalent criminal activities in the study area. Theft and other stealing exhibited the highest trend with its peak in 2016. It is however important to note that all the criminal activities reported shows volatile trend with murder though prevalent but not as often reported as the other crime types.

Three years forecast of the trend as shown in Figure 1 revealed that the criminal activities will maintain a consistent trend but with gradual decrease if the current or better policing method is maintained. This is however evident from the trend model that from 2018, crime rate in the state shows a downward trend but that does not mean that the state was free from criminal activities.

Table 1: Summary of the occurrence (2012-2021)

Crime Types	Summary	Percent(%)
Murder	198	1.14
Assault	2931	16.87
Theft and other Stealing	5224	30.07
Burglary	1190	6.85
Armed Robbery	1884	10.85
False Pretence and Cheating	2738	15.76
House Breaking	2170	12.49
Store Breaking	1035	5.96

Cluster Column of Prevalent Crime in Osun State

The visual inspection of Figure 1 shows that at the beginning of the sample period, the trend of most criminal activities except assault was relatively low up to 2016. However, other criminal activities such as false pretence and cheating, burglary among other crimes began to exhibit various levels of volatilities from 2015 with serious spike in 2016 and gradual decline from 2017.

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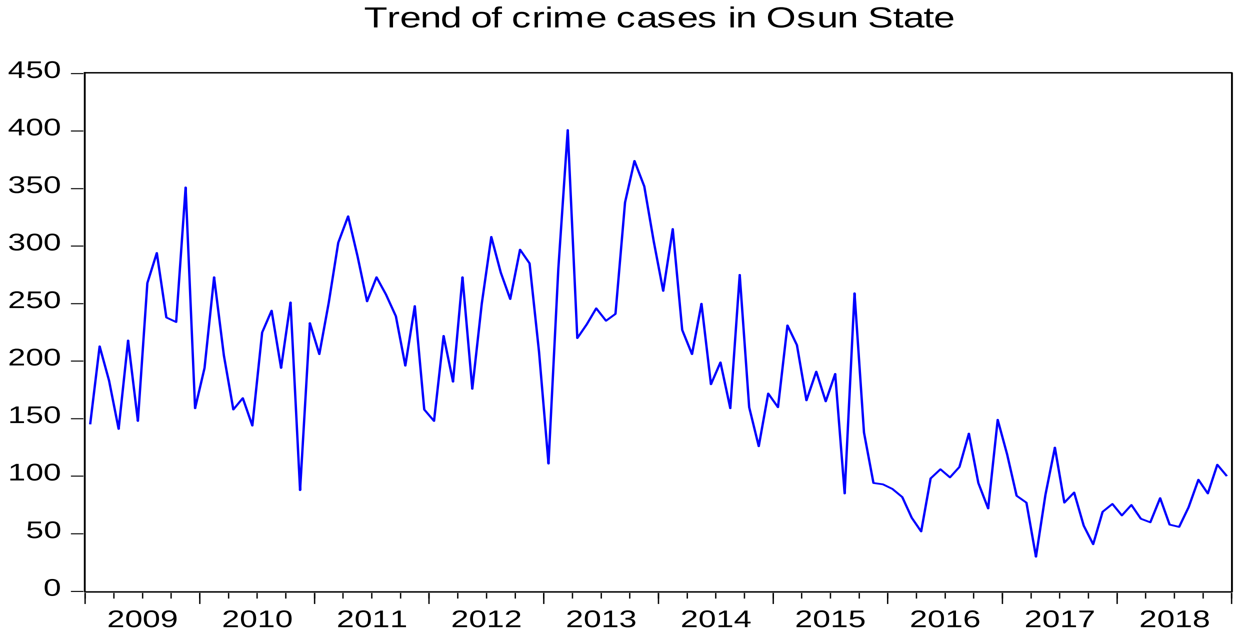

Fig. 1: Time series plot of Crime rate in Osun state

Table 4.2 reported the model estimate of ARCH and Skellam GARCH model. ARCH order 1 was selected owing to the fact that it reported the least AIC and SC, while order 1,1 was selected for Skellam GARCH(1,1) model. The selection was based on the least value of AIC and SC information criteria. More so, the order has the least Log likelihood value of -695.4653 for the ARCH model and Skellam GARCH model reported log likelihood of -666.89.

For the Skellam GARCH model, the one lagged residual has a model effect on the current state of the conditional variance, while the one lagged of the conditional variance has a positive effect on the current conditional variance of the crime cases volatility in Osun State. It shows that the previous level of volatility has a lot of information on the current level of volatility. Similarly, the residual is loaded with innovation on the conditional volatility.

Table 4.2: Parameter Estimate of ARCH Model and Skellam GARCH Model

	ARCH Model	Skellam GARCH Model
Intercept	5464.160	-5.3302
	(7.3644)	(-0.2462)
RESID(-1)^2	0.2109	0.0584
	(3.9094)	(3.9454)
GARCH(-1)		0.9126
		(40.5583)
RESID(-1)^2+ GARCH(-1)		0.9710
Log L	-695.4653	-666.8949
SC	11.7506	11.3143
AIC	11.6577	11.1982
OBS	120	120

Source: Analysis of Field Data (2021)

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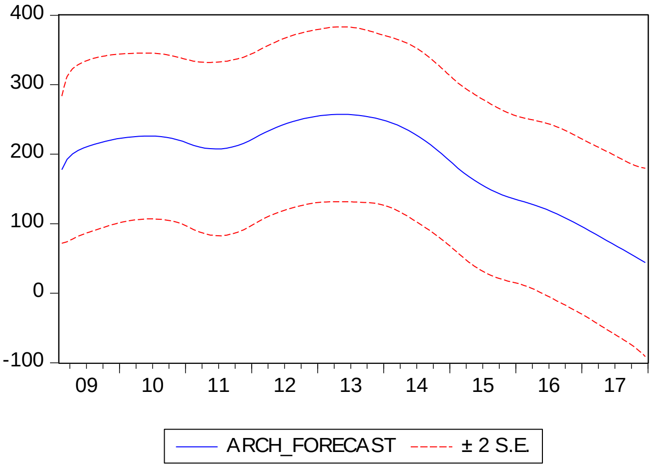
Figure 2 below estimates the raw data before differencing (Non-stationarity) of the conditional volatility of Skellam GARCH Model.

ARCH MODEL

$$ARCH = 1876.12 + 0.39 * \varepsilon(-1)^2 - 0.052\varepsilon(-2)^2$$



Forecast: ARCH_FORECAST	
Actual: CASES	
Forecast sample: 2012M01 2021M12	
Adjusted sample: 2012M02 2020M12	
Included observations: 107	
Root Mean Squared Error	53.70901
Mean Absolute Error	42.75930
Mean Abs. Percent Error	27.22132
Theil Inequality Coefficient	0.131388
Bias Proportion	0.003238
Variance Proportion	0.179940
Covariance Proportion	0.816822
Theil U2 Coefficient	0.719363
Symmetric MAPE	24.15891

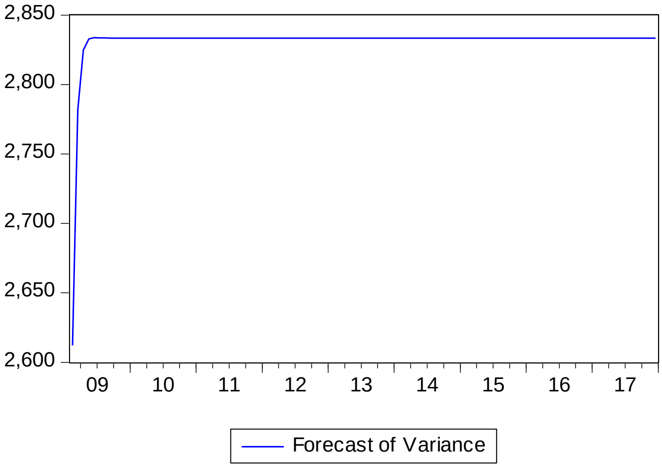


Figure 2: Arch Model for Crime Forecast in Osun state

Skellam GARCH Model

In the case of the Garch model as shown in Figure 2, the model reported a Root Mean Squared Error of 53.71, Mean Absolute Error of 42.11 and Mean Absolute Percent Error of 26.78. The equation used for building the model is as shown below:

$$GARCH = 832.27 + 0.34\varepsilon(-1)^2 + 0.26\varepsilon(-2)^2 + 0.63\delta(-1)$$

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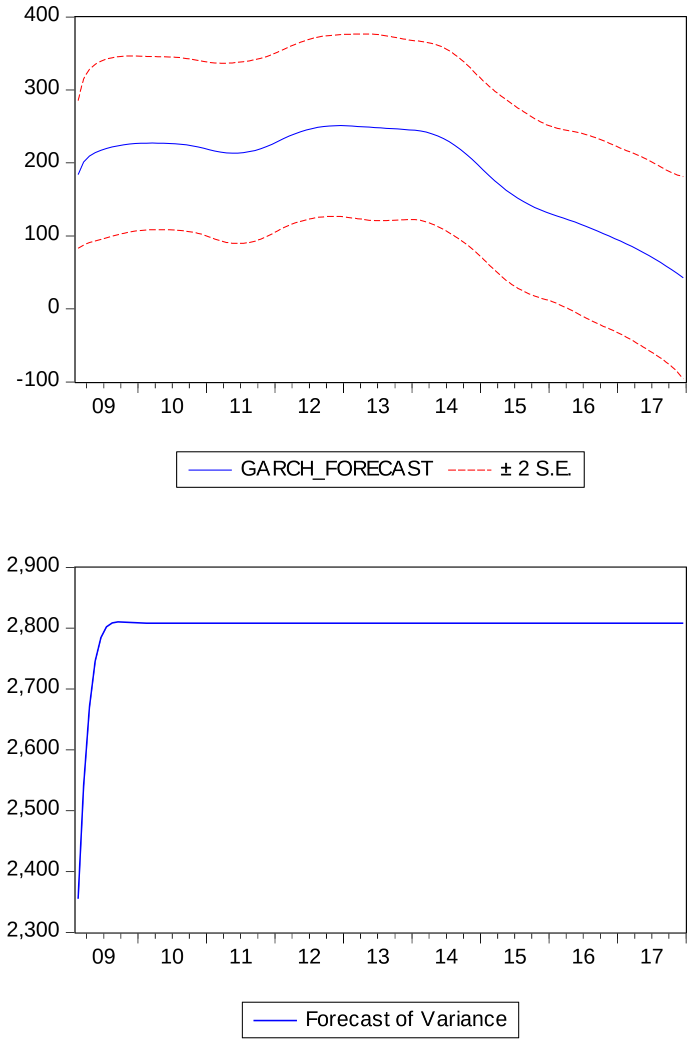

Forecast: GARCH_FORECAST	
Actual: CASES	
Forecast sample: 2012M01 2021M12	
Adjusted sample: 2012M02 2020M12	
Included observations: 107	
Root Mean Squared Error	53.71357
Mean Absolute Error	42.11027
Mean Abs. Percent Error	26.78947
Theil Inequality Coefficient	0.131071
Bias Proportion	0.001630
Variance Proportion	0.170746
Covariance Proportion	0.827625
Theil U2 Coefficient	0.709177
Symmetric MAPE	23.73432

Figure 3: Skellam GARCH Model for Crime Forecast in Osun state

It was therefore discovered from the analysis that the Skellam Garch model reported better results as a crime forecasting tool and performed better than the Arch model. The Skellam Garch models from the above analysis reported the least MAPE, Root Mean Squared Error, Mean Absolute Error which perform better than Arch model and thus a better and preferable tool for crime forecasting.

The result of the forecast, however, negates the submission of Badiora and Fadoyin (2004) who are of the view that residents in Osogbo, the Osun state capital have a good feeling of safety at their place of residence, work and other public areas in the city but congruent with the submissions of Ekoja and Adole (2008), Fajemirokun et al. (2006), and Alemika and Chukwuma (2005) whose studies concluded that Nigeria as a nation is crippled by problems of insecurity and other criminal activities, especially armed robbery, burglary and murder which have become more rampant in recent time. The five years monthly forecasting table and graph is as presented below.

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Table 4.3: Monthly Forecasting Table

Months	Forecast	Months	Forecast	Months	Forecast	Months	Forecast
2022M01	99.91	2023M08	122.47	2025M03	135.52	2026M10	143.07
2022M02	101.43	2023M09	123.35	2025M04	136.03	2026M11	143.36
2022M03	102.91	2023M10	124.21	2025M05	136.53	2026M12	143.65
2022M04	104.34	2023M11	125.04	2025M06	137.01		
2022M05	105.74	2023M12	125.84	2025M07	137.47		
2022M06	107.09	2024M01	126.63	2025M08	137.92		
2022M07	108.41	2024M02	127.39	2025M09	138.36		
2022M08	109.69	2024M03	128.13	2025M10	138.79		
2022M09	110.93	2024M04	128.85	2025M11	139.21		
2022M10	112.14	2024M05	129.55	2025M12	139.61		
2022M11	113.31	2024M06	130.22	2026M01	140.00		
2022M12	114.45	2024M07	130.88	2026M02	140.38		
2023M01	115.56	2024M08	131.52	2026M03	140.75		
2023M02	116.63	2024M09	132.14	2026M04	141.11		
2023M03	117.68	2024M10	132.75	2026M05	141.46		
2023M04	118.69	2024M11	133.34	2026M06	141.8		
2023M05	119.68	2024M12	133.91	2026M07	142.13		
2023M06	120.64	2025M01	134.46	2026M08	142.45		
2023M07	121.57	2025M02	135.00	2026M09	142.77		

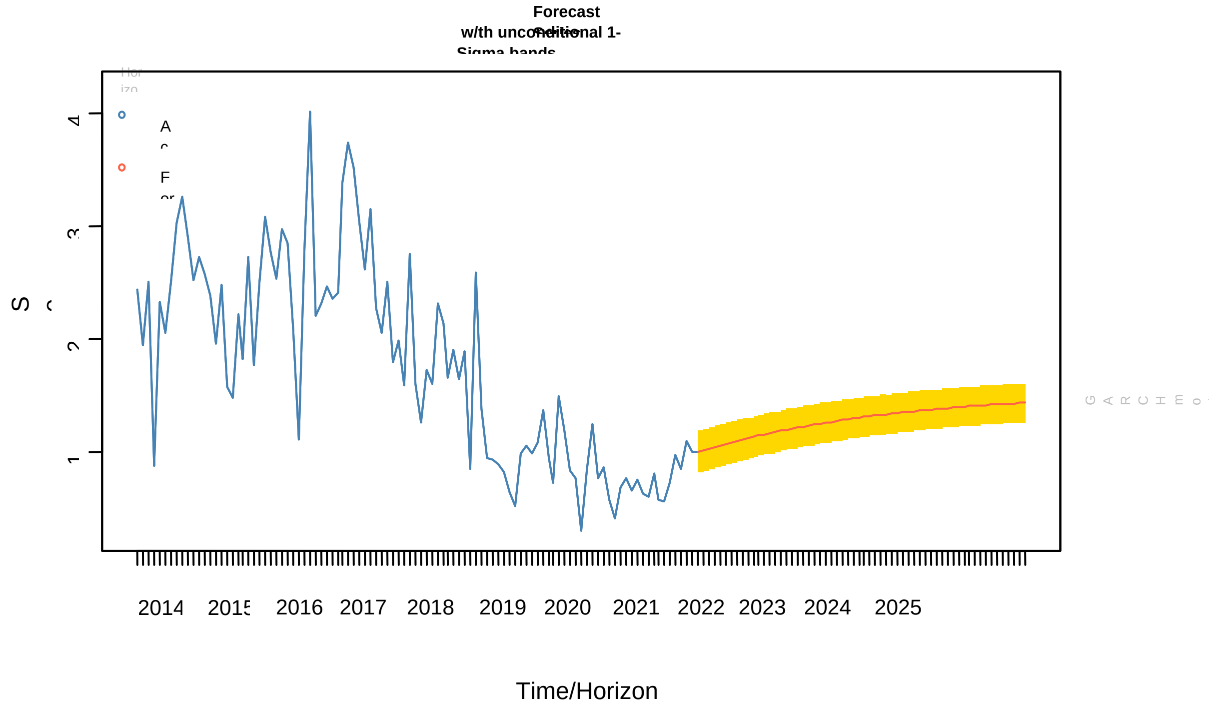

Fig. 4: Monthly Time Series Plot of Crime Occurrences and Forecast in the Study Area

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Visual inspection of Figure 4 reveals that at the beginning of the period under study, most of the reported crimes displayed relatively low volatility up to the first half of 2016 and second half of 2017. Similar trend was observed in the first half of 2019 but a consistent drop in the second quarter of the same year. The five year forecast however shows a gradual upward movement of criminal activities in the study area.

Table 4.4: Five Year Mean and STD Forecasting Table2026

Year	Mean	Standard Deviation
2022	107.5291667	4.764828449
2023	120.9466667	3.370277392
2024	130.3908333	2.351163961
2025	137.1591667	1.687308014
2026	141.5441667	1.247050763

SUMMARY OF FINDINGS

Trend and Skellam Garch(1,1) predictive models were used in order to predict crime trends and forecast crime occurrences. The result of the five year forecast indicated a positive upward movement in crime trend in the state between 2022 and 2026 with GARCH model exhibiting the least MAPE, Root Mean Squared Error, Mean Absolute Error Perform better thus a better forecasting tool.

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