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AN INVESTIGATION OF CRIME IN NIGER REPUBLIC USING REGRESSION KRIGING MODELS

Dodo Boubakar[1]
Umar Usman[2]
B K asare[3]
Y M Ahijjo[4]
A. M. Ndatsu[5]

Revista o Universo Observável
DOI: 10.69720/2966-0599.2025.00035
ISSN: 2966-0599

[1]Department of Statistics, Usman Dan Fodiyo University Sokoto, Nigeria
dboubakar6@gmail.com
[2]Department of Statistics, Usman Dan Fodiyo University Sokoto, Nigeria
uusman07@gmail.com
[3]Department of Statistics, Usman Dan Fodiyo University Sokoto, Nigeria
Mponua2004@yahoo.com
[4]Department of Physics, Usman Dan Fodiyo University Sokoto, Nigeria
yahijjomusa@gmail.com
[5]Department of Statistics, Usman Dan Fodiyo University Sokoto, Nigeria
da6thabdul@gmail.com

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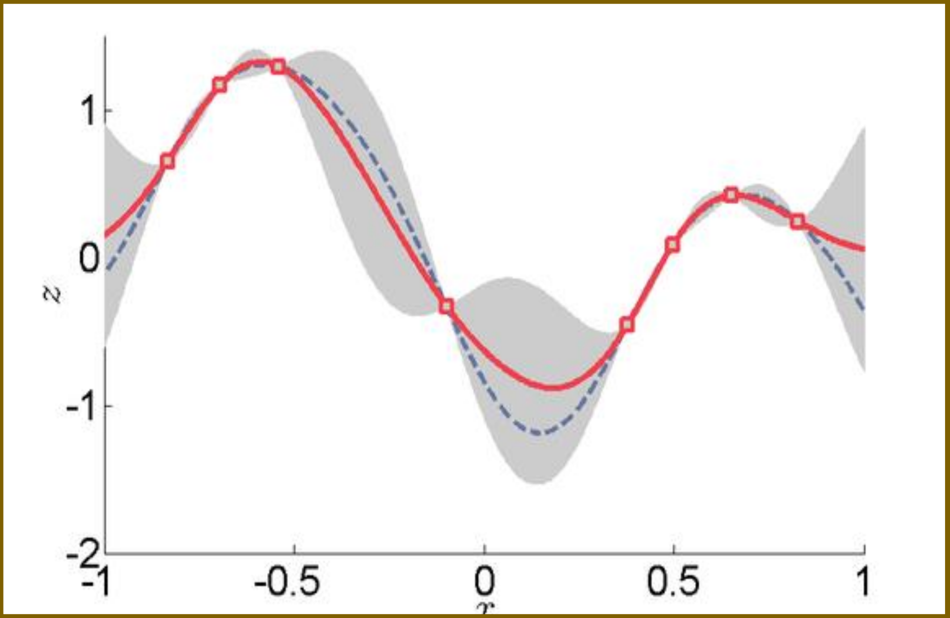

Fonte: https://en.wikipedia.org/wiki/Kriging

PERIÓDICO CIENTIFÍCO INDEXADO INTERNACIONALMENTE

ISSN
International Standard Serial Number
2966-0599
www.ouniversoobservavel.com.br

Editora e Revista
O Universo Observável
CNPJ: 57.199.688/0001-06
Naviraí – Mato Grosso do Sul
Rua: Botocudos, 365 – Centro
CEP: 79950-000

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ABSTRACT

This study investigates crime patterns using regression kriging. The methodology involves determining variogram models for various crime types and fitting multiple regression kriging models. Most variogram models were Gaussian, with some exhibiting smooth transition estimates or spherical structures. The analysis revealed that the majority of crime types exhibit spatial correlation, with range values greater than zero. In the regression kriging models, population size and literacy rate emerged as the most significant predictors. Additionally, the variograms of the kriging residuals indicated trends for certain crime types. However, for most crimes, the residuals displayed spatial autocorrelation, suggesting that the models are suitable for predictive purposes.

Key word: *Variogram, Rgression kriging*

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1. INTRODUCTION

A security crisis refers to a situation that poses a serious threat to the safety, well-being, or stability of a state, region, or the international community. Currently, the Sahel region is grappling with significant security challenges, including armed gang rebellions, jihadist insurgencies, coups d'état, and the illegal trafficking of drugs, weapons, and migrants. The downfall of Libyan leader Muammar Gaddafi in 2011 weakened border security and resulted in a substantial influx of weapons, contributing to the disintegration of the Malian state and exacerbating an ongoing security crisis (Colloque intermasters, 2018).
Generally, crime rates tend to be higher in more developed and densely populated areas, such as large cities or urban regions. A study conducted by Gyamfi (2002) supports this observation, as Southern Ghana—a more developed and densely populated area—exhibits the highest crime rate. Furthermore, Motcho (2004) identifies demographic variables, such as population trends and district density, as significant contributors to the rise of insecurity.

A key emphasis here is on power dynamics and the efforts of dominant groups to limit the diversity of human experiences, language, and culture. Crime is viewed as a public wrong—an act that violates state law and is strongly condemned by society. It is defined as actions or omissions prohibited by law that may lead to penalties such as imprisonment or fines.
According to the Global Organized Crime Index (2021), Niger has a criminality score of 6.02, ranking 41st out of 193 countries, 14th out of 54 countries in Africa, and 3rd out of 15 West African countries. Between 2017 and 2020, the National Gendarmerie reported a decline in crime, noting 5,857 crimes in 2017 compared to 5,175 in 2020.

Geostatistics is a branch of statistics focused on the analysis of spatial or spatiotemporal data sets (Shaltami et al., 2021). It originated in the mining and petroleum industries, starting with Danie Krige's foundational work in the 1950s, which was further developed by Georges Matheron in the 1960s (Zhang, 2011). The main aim of geostatistics was to forecast ore grade probability distributions for mining activities (Krige, 1951).

According to Olea (1991), geostatistics involves the application of statistical methods mainly in geology. It is primarily used in situations where data are gathered as point observations to facilitate predictions. Rossiter (2014) defines geostatistics as the study of populations with known locations (coordinates). Geostatistics is now utilized in a range of disciplines, such as meteorology, forestry, environmental management, time series analysis, and machine learning.

Significant amount of research exists on crime in different regions around the globe, encompassing both regional studies and targeted investigations into crime-related topics, as seen in the works of Gyamfi (2002), Dambazau (2007), Ahmar et al. (2013), Balogun et al. (2014), Numbeo (2015), Umar and Gana (2016), Zakaria and Rahman (2016), Yue (2017), and Denegri and Ley-García (2021). Recent research, such as that by Usman et al. (2021), has utilized regression kriging for spatial analysis of crime rates. Thus, this current paper aims to contribute by mapping crime in Niger using variogram and regression kriging analysis. Additionally, none of the existing crime-related studies have examined crime rates in Niger through regression kriging models. Therefore, this research proposes to analyze crime using variogram analysis and multiple regression kriging techniques on crime data.

2. MATERIAL AND METHODOLOGY

This research relies on secondary data obtained from the Statistics Directorate of the Ministry of Justice, specifically concerning criminal records from nearly all District and High Courts nationwide. The dataset focuses on adjudicated cases—those that have been resolved through judicial decisions—covering the period from 2015 to 2022. It includes variables such as crime origins. Due to data constraints, it features the following crime categories: 3,372 cases of abuse of confidence, 251 criminal associations, 31 corruption cases, 394 illegal arms possession cases, 42 embezzlement cases, 1,965 fraud cases, 357 counterfeit money cases, 19 murders, 218 rebellion cases, 1,242 instances of receiving stolen goods, 8,778 narcotics cases, 1,849 violence or assault cases, and 26,568 thefts. Additionally, the dataset contains information on the unemployment rate, literacy rate,

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school attendance rate, educational level, and population size. The geographical coordinates of the District and High Courts where these crimes were adjudicated served as the basis for the crime analysis.

Variogram

According to Arslan (2012) and Bradai et al. (2016), the variogram, denoted as x, represents the semi-variance of the differences between attribute values at all points separated by a specific distance. The experimental semi-variogram is calculated using the following equation:

Define the spatial variance that is the variance between two spatial data points.

Where $Z(x_i + h)$ and $Z(x_i)$ are the observed values of Z at locations x_i and $x_i + h$

$$var = [\mathrm{Z}(x_i) - \mathrm{Z}(x_i + h)]^2 \quad (1)$$

For all points separate by h, the mean variance will be

$$Mean\ variance = \frac{1}{N(h)} \sum_{i=1}^{N(h)} [\mathrm{Z}(x_i) - \mathrm{Z}(x_i + h)]^2 \quad (2)$$

Finaly the variogram is defined as half of the mean variance

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h) \right]^2 \quad (3)$$

Where $Z(x_i + h)$ and $Z(x_i)$ are the observed values of Z at places x_i and $x_i + h$, and $N(h)$ is the number of paired comparisons at lag h (Webster and Oliver, 2001).

Regression kriging

The summary of the steps involve in regression kriging are:

i. fit a regression model to the spatial data;

$$\mathrm{m}(x) = \beta_0 + \beta_1 X_1(x) + \beta_2 X_2(x) + \cdots + \beta_p X_p(x) \quad (4)$$

$\mathrm{m}(x)$ is the observed value at location x

β_0 , β_1, ….β_p the regression coefficients

$\epsilon(x)$ the residual term

ii. Calculate the residuals from the regression model,

$$r(x_i) = \mathrm{Z}(x_i) - \widehat{m}(x_i) \quad (5)$$

iii. Kriging the residual to obtained the spatial correlation

$$\hat{r}(x_0) = \sum_{i=1}^{n} \lambda_i r(x_i) \quad (6)$$

λ_i is the kriging weigths

iv. Combined the kriged residuals to the regressions model to get the final regression kriging estimate.

$$Z^*(x_0) = \widehat{m}(x_0) + \hat{r}(x_0) \quad (7)$$

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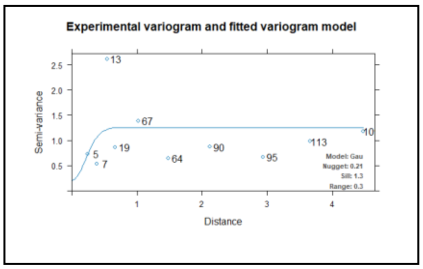
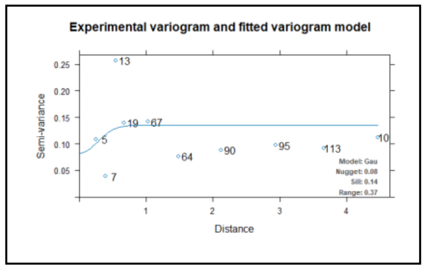
3. RESULTS AND DISCUSSION

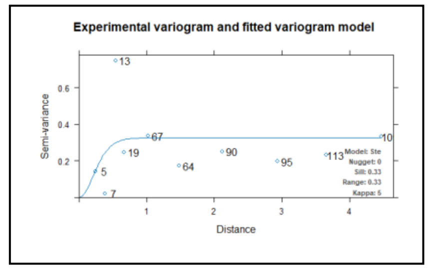
Figure 1: variogram model for all types of crimes



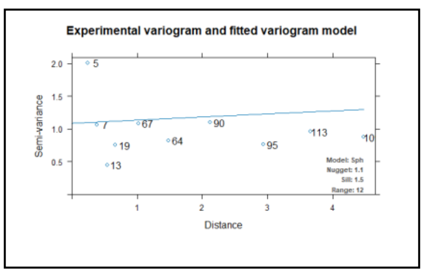
Violence or assault (a)



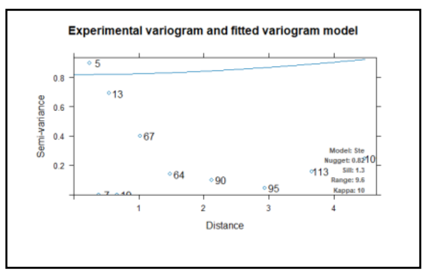
Narcotics (b)



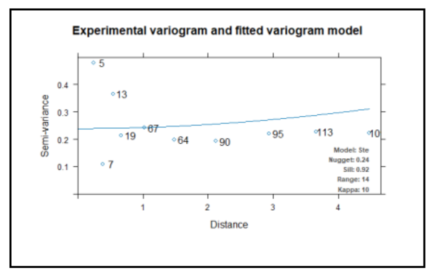
Recels (c)



Rebellion (d)



Murder (e)



Narcotic (f)

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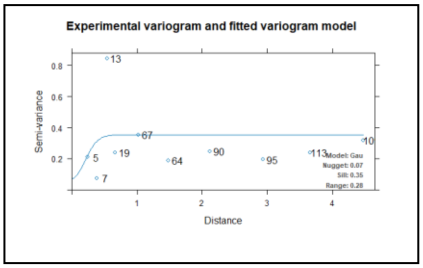
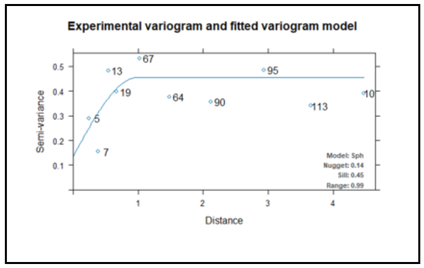
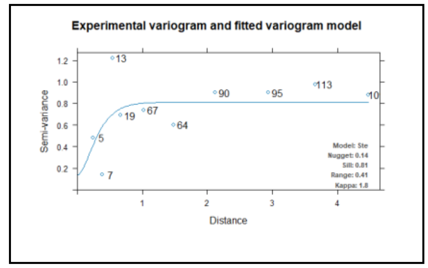


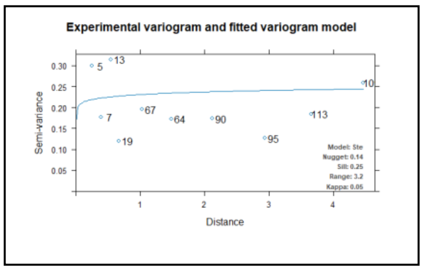
Scam (g)



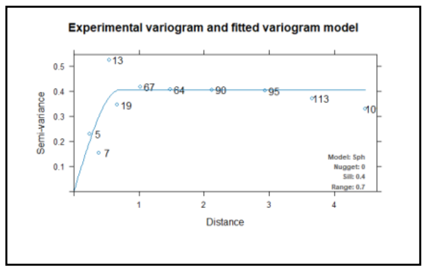
Embezzlement (h)



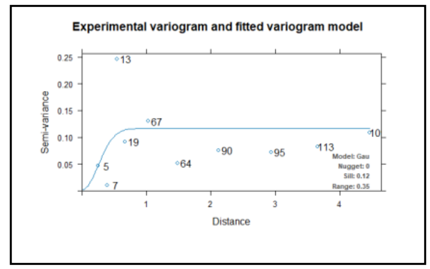
illegal arm (i)



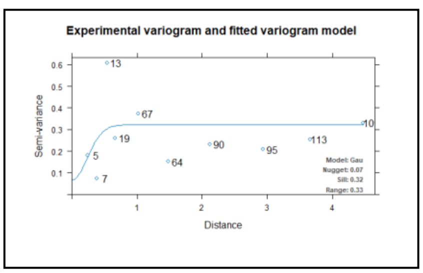
Corruption (j)



criminal association (k)



steal (l)



Abuse of confidence (m)

Table 1: Regression kriging results

Violence or ass	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	2.156e+00	5.796e-01	3.720	0.000641 ***
z1	1.004e-01	9.168e-02	1.095	0.280410
z2	4.204e-02	1.497e-02	2.809	0.007813 **
z3	1.706e-03	6.937e-03	0.246	0.807048
z4	-2.696e-02	1.327e-02	-2.032	0.049165 *
z5	2.143e-06	5.408e-07	3.963	0.000315 ***
Narcotic	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	2.855e+00	7.788e-01	3.666	0.00075 ***
z1	1.906e-01	1.232e-01	1.547	0.13004

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z2	5.303e-02	2.011e-02	2.637	0.01204 *
z3	-6.665e-04	9.321e-03	-0.072	0.94337
z4	-1.800e-02	1.783e-02	-1.010	0.31896
z5	1.496e-06	7.267e-07	2.058	0.04648 *
Recel	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	1.686e+00	7.460e-01	2.261	0.02959 *
z1	1.038e-01	1.180e-01	0.880	0.38449
z2	3.819e-02	1.926e-02	1.983	0.05468
z3	-9.424e-03	8.927e-03	-1.056	0.29780
z4	-2.182e-02	1.707e-02	-1.278	0.20898
z5	2.445e-06	6.960e-07	3.513	0.00116 **
Rebellion	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	-1.903e-01	9.213e-01	-0.207	0.8375
z1	2.697e-02	1.457e-01	0.185	0.8542
z2	4.078e-02	2.379e-02	1.714	0.0946
z3	1.342e-02	1.103e-02	1.217	0.2309
z4	-1.065e-02	2.109e-02	-0.505	0.6166
z5	1.712e-06	8.595e-07	1.991	0.0537
Murder	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	-7.972e+00	1.265e+00	-6.300	2.21e-07 ***
z1	6.141e-01	2.002e-01	3.068	0.00396 **
z2	9.778e-03	3.267e-02	0.299	0.76638
z3	3.463e-02	1.514e-02	2.287	0.02788 *
z4	7.442e-02	2.896e-02	2.569	0.01424 *
z5	6.523e-06	1.181e-06	5.525	2.55e-06 ***
Counterfeit money	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	-1.443e+00	1.128e+00	-1.279	0.20860
z1	2.826e-01	1.785e-01	1.584	0.12155
z2	3.478e-02	2.913e-02	1.194	0.23993
z3	-9.111e-03	1.350e-02	-0.675	0.50390
z4	1.674e-02	2.582e-02	0.648	0.52077
z5	3.557e-06	1.053e-06	3.379	0.00169
Scam	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	8.691e-01	6.903e-01	1.259	0.21570
z1	1.545e-01	1.092e-01	1.415	0.16508
z2	5.827e-02	1.782e-02	3.269	0.00229
z3	-6.215e-03	8.261e-03	-0.752	0.45644
z4	-1.640e-02	1.580e-02	-1.038	0.30583
z5	2.276e-06	6.440e-07	3.534	0.00109
Embezzlement	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	6.850e-01	4.201e-01	1.631	0.1112
z1	-6.314e-03	6.645e-02	-0.095	0.9248
z2	2.001e-02	1.085e-02	1.845	0.0728
z3	-9.103e-04	5.027e-03	-0.181	0.8573
z4	-1.684e-02	9.615e-03	-1.752	0.0879
z5	-1.184e-07	3.920e-07	-0.302	0.7643
Illegal arm possessio	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	5.551e-01	6.139e-01	0.904	0.3716
z1	2.038e-01	9.710e-02	2.099	0.0425

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z2	3.409e-02	1.585e-02	2.151	0.0379
z3	-3.051e-03	7.346e-03	-0.415	0.6803
z4	-3.783e-03	1.405e-02	-0.269	0.7892
z5	2.536e-07	5.727e-07	0.443	0.6604
Corruption	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	-3.588e+00	1.320e+00	-2.719	0.00983 **
z1	1.965e-01	2.088e-01	0.941	0.35262
z2	6.617e-02	3.408e-02	1.942	0.05964
z3	5.493e-03	1.579e-02	0.348	0.72994
z4	2.680e-02	3.021e-02	0.887	0.38066
z5	1.605e-06	1.231e-06	1.303	0.20041
Criminal association	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	2.875e-01	6.992e-01	0.411	0.6832
z1	3.428e-02	1.106e-01	0.310	0.7583
z2	1.953e-02	1.805e-02	1.082	0.2863
z3	-5.666e-03	8.368e-03	-0.677	0.5024
z4	-1.733e-03	1.600e-02	-0.108	0.9143
z5	1.210e-06	6.524e-07	1.854	0.0715
Steal	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	-1.891e+00	5.086e+00	-0.372	0.7121
z1	1.850e+00	8.045e-01	2.300	0.0271 *
z2	3.075e-01	1.313e-01	2.341	0.0246 *
z3	1.335e-02	6.087e-02	0.219	0.8276
z4	-2.446e-02	1.164e-01	-0.210	0.8347
z5	2.880e-05	4.745e-06	6.069	4.58e-07 ***
Abuse of confidence	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	1.791e+00	7.767e-01	2.306	0.02663
z1	1.312e-01	1.229e-01	1.068	0.29240
z2	6.329e-02	2.006e-02	3.156	0.00313
z3	-3.385e-03	9.295e-03	-0.364	0.71775
z4	-2.564e-02	1.778e-02	-1.442	0.15750
z5	2.185e-06	7.247e-07	3.014	0.00457

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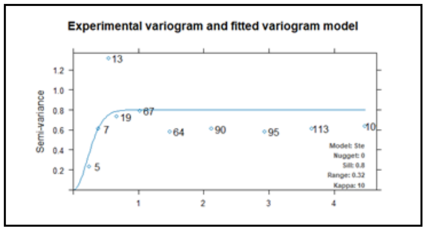
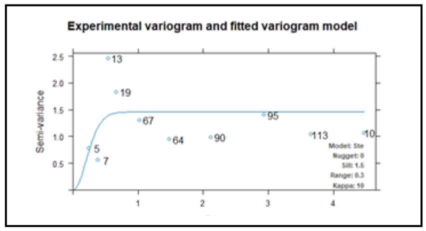
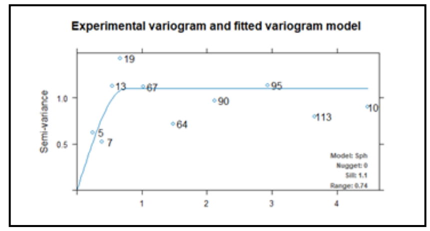


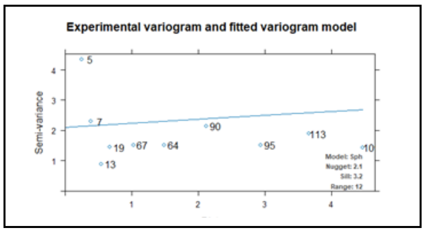
Violence or assault (a)



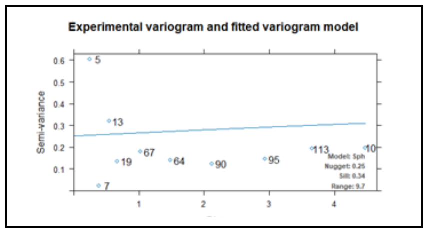
Narcotics (b)



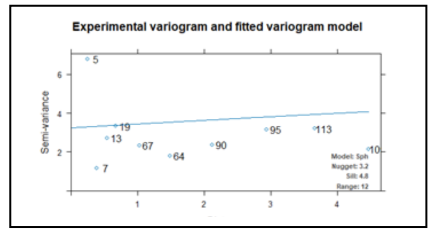
Recels (c)



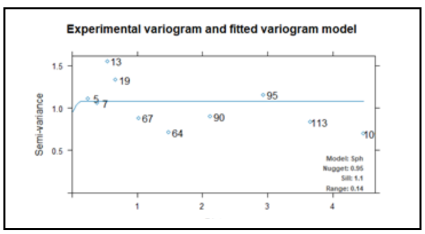
Rebellion (d)



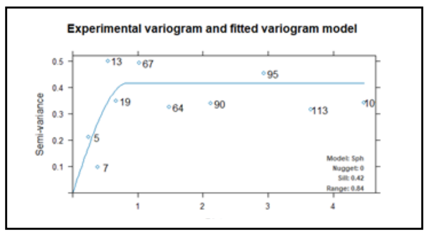
Murder (e)



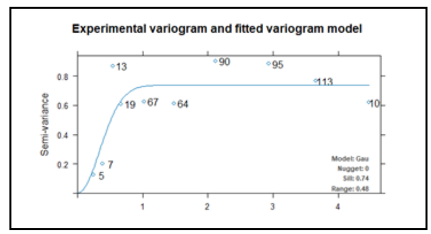
Counterfeit (f)



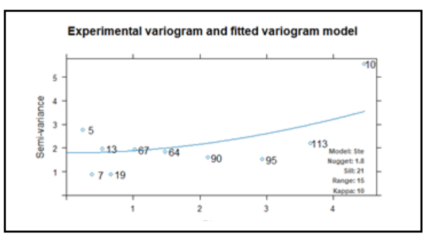
Scam (g)



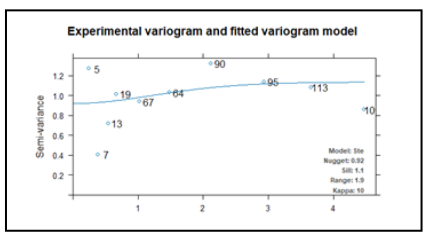
Embezzlement (h)



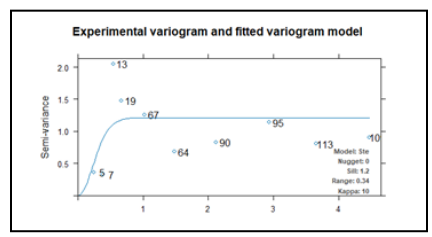
illegal arm (i)



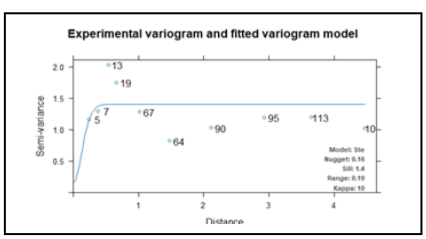
Corruption (j)



criminal association (k)



steal (l)



Abuse of confidence (m)

Figure 2: variogram of the kriging residuals for all types of crimes

DISCUSSIONS

The table 2 below gives an interpretation of the variograms of figure 1 of all the crimes from (a to m) and quantitatively assess the spatial dependence and the correlation between locations across the given space.

Variogram model type (a)	**Parameter of the model**	**Observations**
Gaussian (Gau)	Nugget (0)	implies that at very small distances there is no spatial variability between points. In other word, values measured at very close points to each other (nearly at the same location) are expected to be very similar or even identical.
	Sill (0.19)	Indicates that the total variance in the data is 0.19;
	Range (0.39)	Indicates that the data point up to the distance of 0.39 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (b)	**Parameter of the model**	**Observations**
Gaussian (Gau)	Nugget (0.08)	: indicates some variability that is not due to spatial dependence but can be affect to measurement error or small-scale variability.
	Sill (0.14)	indicated that the total variance beyond which points are no longer spatially correlated
	Range (0.37)	means that data point up to the distance of 0.37 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (c)	**Parameter of the model**	**Observations**
Smooth transition estimator(Ste)	Nugget (0)	implies that at very small distances there is no spatial variability between points. In other word, values measured at very close points to each other (nearly at the same location) are expected to be very similar or even identical.
	Sill (0.33)	Indicates that the total variance in the data is 0.33;
	Range (0.33)	Indicates that the data point up to the distance of 0.33 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (d)	**Parameter of the model**	**Observations**
Gaussian (Gau)	Nugget (1.1)	shows that there are some variabilities that is not due to spatial dependence but can be affected to measurement error or small-scale variability.
	Sill (1.5)	Indicates that the total variance in the data is 1.5
	Range (12)	Indicates that the data point up to a range of 12 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (e)	**Parameter of the model**	**Observations**

Gaussian (Gau)	Nugget (0.82)	shows that there are some variabilities that is not due to spatial dependence but can be affected to measurement error or small-scale variability.
	Sill (1.3)	Indicates that the total variance in the data is 1.3;
	Range (9.6)	Indicates that the data point up to the distance of 9.6 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (f)	**Parameter of the model**	**Observations**
Smooth transition estimator (Ste)	Nugget (0.24)	Indicates that there is some variability at very small distance that is not due to spatial dependence.
	Sill (0.92)	Indicates that the total variance in the data is 0.19;
	Range (14)	Indicates that the data point up to the distance of 0.39 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (g)	**Parameter of the model**	**Observations**
Gaussian (Gau)	Nugget (0.07)	Indicates that there is some variability at very small distance that is not due to spatial dependence.
	Sill (0.36)	Indicates that the total variance in the data is 0.36;
	Range (0.28)	Indicates that the data point up to the distance of 0.28 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (h)	**Parameter of the model**	**Observations**
Spherical (Sph)	Nugget (0.14)	Indicates that there is some variability at very small distance that is not due to spatial dependence.
	Sill (0.45)	Indicates that the total variance in the data is 0.45;
	Range (0.99)	Indicates that the data point up to the distance of 0.99 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (i)	**Parameter of the model**	**Observations**
smooth transition estimator (Ste)	Nugget (0.14)	Indicates that there is some variability at very small distance that is not due to spatial dependence.
	Sill (0.81)	Indicates that the total variance in the data is 0.81;
	Range (0.4)	Indicates that the data point up to the distance of 0.4 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (j)	**Parameter of the model**	**Observations**
Gaussian (Gau)	Nugget (0.14)	Indicates that there is some variability at very small distance that is not due to spatial dependence.
	Sill (0.25)	Indicates that the total variance in the data is 0.25

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	Range (3.2)	Indicates that the data point up to the distance of 3.2 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (k)	**Parameter of the model**	**Observations**
Gaussian (Gau)	Nugget (0)	implies that at very small distances there is no spatial variability between points. In other word, values measured at very close points to each other (nearly at the same location) are expected to be very similar or even identical.
	Sill (0.4)	Indicates that the total variance in the data is 0.4;
	Range (0.7)	Indicates that the data point up to the distance of 0.7 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (l)	**Parameter of the model**	**Observations**
Gaussian (Gau)	Nugget (0)	implies that at very small distances there is no spatial variability between points. In other word, values measured at very close points to each other (nearly at the same location) are expected to be very similar or even identical.
	Sill (0.12)	Indicates that the total variance in the data is 0.12;
	Range (0.35)	Indicates that the data point up to the distance of 0.35 are spatially correlated. The data points are independent of each other beyond this range.
Variogram model type (m)	**Parameter of the model**	**Observations**
Gaussian (Gau)	Nugget (0.07)	Indicates that there is some variability at very small distance that is not due to spatial dependence.
	Sill (0.32)	Indicates that the total variance in the data is 0.32;
	Range (0.33)	Indicates that the data point up to the distance of 0.33 are spatially correlated. The data points are independent of each other beyond this range.

Multiple regression kriging was conducted to investigate the relationship between the response variables (a to m) and the predictors: unemployment rate (Z1), literacy rate (Z2), school attendance rate (Z3), educational level (Z4), and population size (Z5). This method evaluates both the individual and combined effects of the predictors on the response variables.

The findings for each response variable are as follows:

- **Violence or assault cases**: Z2, Z4, and Z5 were significant predictors.
- **Narcotic cases**: Z2 and Z5 were significant predictors.
- **Recel**: Only Z5 was significant.
- **Rebellion**: None of the predictors were significant.
- **Counterfeit money**: Only Z5 was significant.
- **Scam**: Z2 and Z5 were significant.
- **Embezzlement**: None of the predictors were significant.
- **Illegal arms possession**: Z1 and Z2 were significant.
- **Corruption and criminal association**: None of the predictors were significant.
- **Theft**: Z1, Z2, and Z5 were significant.
- **Abuse of confidence** : Z2 and Z5 were significant.

This analysis highlights the varying importance of predictors across different response variables.
The kriging of the residual, figure 2 shows a spatial autocorrelation among the locations for each type of crimes except for Rebellion (d), murder (e), counterfeit money (f) and criminal association where the variogram show a weak trend.

CONCLUSION

Based on the results, it can be concluded that the study successfully achieved its objectives. The variogram model for crime mapping demonstrated spatial correlations across the locations of all crime types. Additionally, the regression kriging models were effectively fitted. This approach proved to be a valuable geostatistical interpolation tool, identifying key predictors—such as population size, unemployment rate, and literacy rate—that significantly explained variations in crime rates. The kriging of residuals, assessed through their variograms, indicated that most of the regression kriging models for different crime types are suitable for predictive purposes.

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