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Deciphering Stability Dynamics of the Banditry Menace Model in Niger State.

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Abstract

Niger State has experienced recurrent bandit attacks, kidnapping, and mobility restrictions across vulnerable communities. In response, this study develops a deterministic nonlinear mathematical model to investigate the dynamics of banditry activities, incorporating repentant bandits and government intervention efforts. The model further examines the stability properties governing banditry dynamics in Niger State. The population is partitioned into seven classes, with preventive and reactive control measures that include detention of captured bandits, rehabilitation of repentant bandits, and government interventions aimed at preventing susceptible individuals from being recruited or kidnapped. The bandit-free equilibrium and bandit-persistence equilibrium states are established. The effective reproduction number, which serves as the threshold parameter, is derived using the next-generation matrix approach and used to quantify the level of banditry activities. When the effective reproduction number is less than one, banditry activities die out from the dynamical system, whereas values greater than one indicate persistence of banditry within the system. The local asymptotic stability of the bandit-free equilibrium is characterized using the Jacobian matrix method, while the local asymptotic stability of the bandit-persistence equilibrium is similarly established through the Jacobian matrix method. Numerical results demonstrate that banditry is effectively curbed when the effective reproduction number is below one and persists otherwise. The model provides a mathematical basis for evaluating integrated security, socioeconomic, and rehabilitation interventions in Niger State. Furthermore, detention of captured bandits, reinforced by rehabilitation of repentant bandits, significantly outperforms lethal measures in preventing susceptible individuals from being kidnapped under the specified preventive and reactive intervention strategies considered.

Keywords

Banditry,
Deterministic Mathematical Model,
Effective Reproduction Number,
Government Efforts,
Repentant Bandits,
Stability Analysis.

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INTRODUCTION

Banditry activities in Nigeria is a phenomenon that has become devastatingly worrisome in several northern States. This complex form of organized criminal violence involves activities like kidnapping for ransom, armed robbery, cattle rustling, destruction of legitimate property and murder (Tasiu et. al., 2024). In 2024, fatalities from criminal gangs in the North-West surpassed those tied to militant Islamist groups in the North-East, with an estimated 7,400 people abducted in mass attacks and roughly 700,000 displaced (Adeleke & Adegbami, 2024; Umar et. al., 2026). The violence has crippled several socio-economic sectors ranging from the agricultural sector, to the education sector and much more, thus causing severe food crises, and undermined economic stability in this region (Ajiboye, 2023). This in turn makes it difficult to address through single intervention mechanism.

In Niger State, the growth of banditry is fueled by poverty, youth unemployment, weak governance, and porous borders (Akogwu et al., 2025). Marginalized young men are lured with financial rewards, weapons, or livestock, while kinship and peer networks sustain recruitment pipelines. Specifically, documented attacks include the Ajata-Aboki ambush in Shiroro LGA (June 2022) where 48 people were killed, and the Madaka market attack in Rafi LGA (March 2024) which claimed 21 lives (Ifabiyi et. al., 2026; Umar et. al., 2026). International Organization for Migration (IOM) reports confirm continuing displacement into IDP camps across Shiroro, Rafi, and Munya LGAs (Umar et. al., 2026).

These observations simply suggest that banditry can be conceptualized as a dynamic system and not just a sequence of isolated criminal incidents. Consequently, it implies that individuals are recruited to become active participants in the banditry activities while others may leave through arrest, rehabilitation or other mechanisms.

Mathematical modelling offers a structured, quantitative framework for understanding complex health, economic, and social phenomena such as epidemiology, banditry, and financial challenges. By framing banditry as a "social infection" that spreads through recruitment and transmission mechanisms, compartmental models can quantify threshold conditions such as the reproduction number that determine whether criminal activity will persist or decline Tasiu et al., 2024; Afolabi, 2025; Tasiu et al., 2025). These models allow policymakers to simulate intervention scenarios including job creation, intensified policing, rehabilitation, and community engagement.

The primary objective of this study is to understand and investigate the stability dynamics of the banditry model in Niger state to be precise, using the deterministic modeling approach. The importance of investigating this model cannot be over emphasized, as persistence of banditry has presented a multidimensional challenge, and socio-economic conditions continue to generate new recruitment. Although, several mathematical models have been developed to address insecurity in Nigeria, see for instance (Adamu and Ibrahim (2020); Akanni and Abidemi (2022); Tasiu et al. (2024); Tasiu et al., 2025).

However, these models did not fully capture the role of repentant bandit, i.e., former bandits who provide intelligence on bandit operations, nor did they explicitly incorporate government effort as a dynamic variable. This provides a literature gap and a contribution to the field of knowledge.

The present study extends this line of investigation, focusing on the framework of Niger state-oriented deterministic model. The nexus of the study is specifically designed to decipher the stability analysis of the banditry dynamics. Further, the model incorporates the repentant bandit compartment (B_R) and modelling government effort (G) as a logistic growth variable influenced by rehabilitation outcomes. The central aim is not just to analyze the threshold quantity, but to establish mathematically how changes in incorporating the repentant bandits and government intervention affect the long-term behavior in curbing banditry in Niger State.

MATERIALS AND METHODS

Model Formulation and Description

The model is sub-divided into mutually exclusive sub-populations as follows: the susceptible individuals (S), the bandits (B), the captives (C), individuals undergoing detention (B_D), the freed captives who regain freedom from captivity (C_F), repentant bandits who undergo rehabilitation (B_R), and government effort to eradicate banditry (G). The total population size at time (t) denoted as $N(t)$ is given by

$$N(t) = S(t) + B(t) + C(t) + B_D(t) + C_F(t) + B_R(t) + G(t). \quad (1)$$

The population of the susceptible (S) is generated from daily recruitment through birth or immigration at the rate Λ; it decreases due to movement into the captive class (C) at the rate ψ, and into the bandit class (B) at the rate λ, and also by natural death μ. The population of the bandit class (B) is generated from the susceptible class and diminishes by the death of bandits at the hands of the government at the rate $\delta_3 G$, natural death at the rate μ, or progression into the detention class (B_D) at the rate α. The captives (C) are generated through migration from the susceptible class at the rate ψ, and decrease by the death of captives by bandits at the rate δ_1 and collateral damage $\delta_2 G$; the class also reduces through progression to the freed-captive class (C_F), at the rate τ_1 and $\tau_2 G$, and through natural death at the rate μ. The freed captives $(C_F)$are those that regained freedom from captivity either by paying ransom at the rate τ_1, or through government effort to rescue the captives at the rate $\tau_2 G$; the class diminishes by natural death at the rate μ and may relapse to the susceptible class at the rate γ.

The detention class $(B_D)$is generated by the progression of bandits at the rate α, and diminishes due to natural death at the rate μ and from detained bandit to repentant bandit (B_R) through rehabilitation by government effort at the rate τ_3 G. Government effort (G) follows a logistic-type growth, bounded by a carrying capacity of 100, that is reinforced by the presence of repentant bandits who provide actionable intelligence and depleted at a constant attrition rate n. From the description given above, the flow chart is depicted in Figure 1

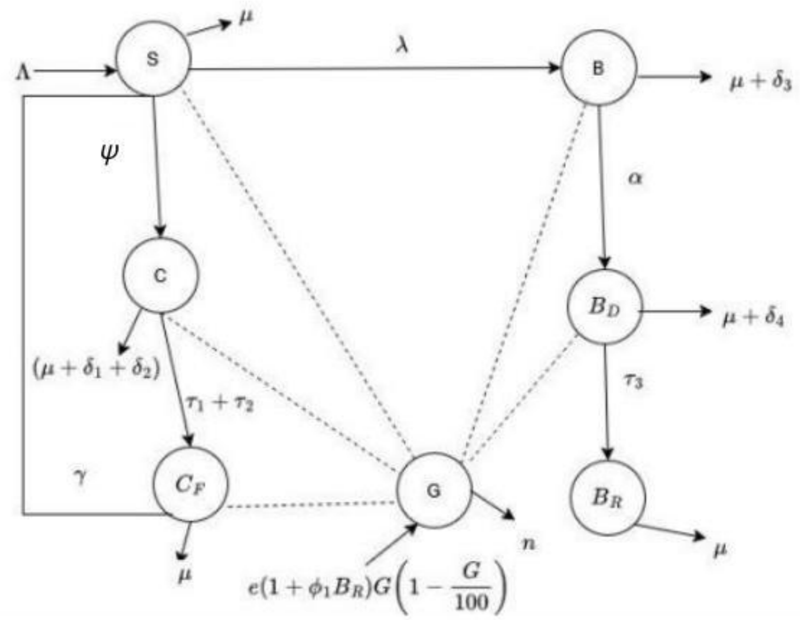

Figure 1: Schematic diagram of banditry activity model

Subsequently, the following system of non-linear differential equation for the banditry menace model is obtained:

$$
\begin{aligned}
\frac{dS}{dt} &= \Lambda + \gamma C_F - (\lambda + \mu + \psi)S \\
\frac{dB}{dt} &= \lambda S - (\alpha + \mu + \delta_3)B, \\
\frac{dC}{dt} &= \psi S - (\tau_1 + \tau_2 + \mu + \delta_1 + \delta_2)C, \\
\frac{dC_F}{dt} &= (\tau_1 + \tau_2)C - (\gamma + \mu)C_F, \\
\frac{dB_D}{dt} &= \alpha B - (\tau_1 + \delta_4 + \mu)B_D, \\
\frac{dB_R}{dt} &= \tau_3 B_D - \mu B_R, \\
\frac{dG}{dt} &= e(1 + \phi_1 B_R)G\left(1 - \frac{G}{100}\right) - nG,
\end{aligned} \tag{2}
$$

where, $\lambda = \beta(1 - \varepsilon_1 G)B$ and $\psi = \kappa(1 - \varepsilon_2 G)B$.

Positivity of the Solution.

It is very important to analyze the basic properties of the model (2). The model needs to be positive and bounded in an invariant region, which proves that it is mathematically well-posed, thus leading to certainty in the future predictions (Tasiu et al., 2024, Sulayman, et. al., 2023).

***Theorem 1*:** Let $\Theta_{bandits}$ be a positive invariant region and also suppose; $\{S(0) > 0, B(0) \geq 0,, C(0) \geq 0, B_D(0) \geq 0, C_F(0) \geq 0, B_R(0) \geq 0\} \in \Theta_{bandits}$, then all the solution set $\big(S(t), B(t)0, C(t), B_D(t), C_F(t), B_R(t)\big) > 0$ of the model (2) are positive and for subsequent time (t) (Sulayman, et. al., 2023).

Proof

Given the equation from the susceptible compartment of the banditry menace model (2);

$$
\begin{aligned}
\frac{dS}{dt} &= \Lambda + \gamma C_F - (\lambda + \mu + \psi)S \\
&\geq -(\lambda + \mu + \psi)S \\
\frac{dS}{dt} &\geq -(\lambda + \mu + \psi)S \\
\int \frac{1}{S} dS &\geq \int -(\lambda + \mu + \psi)dt \\
S(t) &\geq S(0)e^{-(\lambda+\mu+\psi)t} \\
S(t) &\geq 0
\end{aligned}
$$

This can also be shown for other compartments of the banditry model (2), and as such the solution is positive for all $t > 0$. This completes the proof.

Invariant Region

The invariant region is the region that shows that the solution of the model is bounded. Considering the basic banditry model, it can be seen that

$$
\frac{dN}{dt} = \frac{dS}{dt} + \frac{dB}{dt} + \frac{dC}{dt} + \frac{dB_D}{dt} + \frac{dC_F}{dt} + \frac{dB_R}{dt}
$$

$$\leq \Lambda - \mu(S + B + C + B_D + C_F + B_R) - (\delta_3 B + \delta_1 C + \delta_2 C_F + \delta_2 B_D). \qquad (3)$$

Assuming that there is no death due to other causes aside natural death, then (3) becomes

$$\frac{dN}{dt} \leq \Lambda - \mu N - (\delta_3 B + \delta_1 C + \delta_2 C_F + \delta_2 B_D)$$
$$\leq \Lambda - \mu N$$

So that $N \leq \frac{\Lambda}{\mu}$. The positive invariant region is obtained considering the following theorem

Hence all feasible solution set of the population of the model system enters the region

$$\Theta_{bandits} = \left\{(S, B, C, C_F, B_D, B_R) \in \mathbb{R}_+^6 : N \leq \frac{\Lambda}{\mu}\right\}. \qquad (4)$$

Hence it is positively invariant set under the flow induced by the model, hence the model is sociologically well posed in the domain. Hence the result satisfies the existence, continuity and uniqueness of the system.

Stability Analysis

This section presents the stability analysis of the banditry model (2) where the behavior of the model is examined after obtaining the equilibrium points. Accordingly, the investigation will explain clearly if the equilibrium points are either asymptotically stable or unstable. An important threshold parameter considered when studying the dynamic behavior of the banditry model is the effective reproduction number denoted $R_C = \rho(FV^{-1})$, which determines if the banditry menace will persist or be completely eradicated. The next generation matrix method is used to obtain R_c, which is given by

$$\mathcal{R}_c = \frac{\beta\Lambda\left(1 - \varepsilon_1 \frac{m}{n}\right)}{\mu(\alpha + \mu + \delta_3)}. \qquad (5)$$

Equilibrium Solution

The equilibrium solution for the banditry model is obtained in this section, where the solutions for the bandit-free scenario and bandit persistent scenario are considered respectively. These solutions are obtained by equating the model system to zero, i.e.,

$$\frac{dS}{dt} = \frac{dB}{dt} = \frac{dC}{dt} = \frac{dB_D}{dt} = \frac{dC_F}{dt} = \frac{dB_R}{dt} = 0. \qquad (6)$$

Bandit-free Equilibrium (E^0)

The bandit-free equilibrium (BFE)is the state where there are no bandits in the population. As a result, every affected class will be zero and every individual in the population will be susceptible. This implies that

$$E^0 = (S^0, B^0, C^0, {B_R}^0, {C_F}^0, {B_D}^0) = \left(\frac{\Lambda}{\mu}, 0, 0, 0, 0, 0\right) \qquad (7)$$

For non-linear differential equation systems, the asymptotic stability of equilibrium is established using the Jacobian Matris. It gives the necessary and sufficient conditions for all roots of the characteristic polynomial to contain negative portions.

Theorem 2: The bandit-free equilibrium of the model (2) is locally asymptotically stable if $R_C < 1$ and unstable if otherwise.

Proof: The Jacobian matrix of the BFE is given by;

$$\begin{pmatrix} -\mu & -(A_1+A_2)\frac{\Lambda}{\mu} & 0 & \gamma & 0 & 0 \\ 0 & A_1\frac{\Lambda}{\mu}-(\alpha+\mu+\delta_3) & 0 & 0 & 0 & 0 \\ 0 & A_1\frac{\Lambda}{\mu} & -(\tau_1+\tau_2+\mu+\delta_1+\delta_2) & 0 & 0 & 0 \\ 0 & 0 & \tau_1+\tau & -(\gamma+\mu) & 0 & 0 \\ 0 & \alpha & 0 & 0 & (\tau_3+\mu+\delta_4) & 0 \\ 0 & 0 & 0 & 0 & \tau_3 & -\mu \end{pmatrix} \quad (8)$$

Where, $A_1=\beta\left(1-\varepsilon_1\frac{m}{n}\right)$ and $A_2=\kappa\left(1-\varepsilon_2\frac{m}{n}\right)$.

The characteristic equation is

$$\left|J\left(E^0\right)-\lambda I\right|=0,$$

$$(-\mu-\lambda)^2\left[-(\gamma+\mu)-\lambda\right]\left[-(\tau_3+\mu+\delta_4)-\lambda\right]\left[-(\tau_1+\tau_2+\mu+\delta_1+\delta_2)-\lambda\right]\left[\left(A_1\frac{\Lambda}{\mu}-(\alpha+\mu+\delta_3)\right)-\lambda\right]=0$$

Thus, five all eigenvalues are negative. Furthermore, we have that

$\lambda_6=A_1\frac{\Lambda}{\mu}-(\alpha+\mu+\delta_3)$, such that $A_1\frac{\Lambda}{\mu}-(\alpha+\mu+\delta_3)<0$. Then, it implies that

$$\frac{A_1\Lambda}{\mu(\alpha+\mu+\delta_3)}<1.$$

Therefore, $\mathcal{R}_c=\frac{A_1\Lambda}{\mu(\alpha+\mu+\delta_3)}$.

Thus, the bandit-free equilibrium is locally asymptotically stable if $\mathcal{R}_c<1$ and unstable if $\mathcal{R}_c>1$.

Bandit-persistence Equilibrium (E^*)

The bandit-persistence equilibrium (BPE)is the point that indicates the persistence of the bandits in the population at steady state. The E^* for the model (2) based on equation (5) is given by

$$E^*=(S^*,B^*,\ C^*,B_R{}^*,C_F{}^*,B_D{}^*)$$

$$S^*=\frac{\alpha+\mu+\delta_3}{A_1},\ B^*=\frac{\lambda(\Lambda+\gamma A_3)}{(\lambda+\mu+\psi)(\alpha+\mu+\delta_3)},\ C^*=\frac{\psi(\Lambda+\gamma A_3)}{(\lambda+\mu+\psi)(\mu+\delta_1+\delta_2+\tau_1+\tau_2)},$$

$$C_F{}^*=\frac{\psi(\Lambda+\gamma A_3)(\tau_1+\tau_2)}{(\gamma+\mu)(\lambda+\mu+\psi)(\mu+\delta_1+\delta_2+\tau_1+\tau_2)},\ B_D{}^*=\frac{\alpha\lambda(\Lambda+\gamma A_3)}{(\lambda+\mu+\psi)(\alpha+\mu+\delta_3)(\mu+\delta_4+\tau_3)},$$

$$B_R{}^*=\frac{\alpha\lambda(\Lambda+\gamma A_3)\tau_3}{\mu(\lambda+\mu+\psi)(\alpha+\mu+\delta_3)(\mu+\delta_4+\tau_3)}.$$

Where $A_3=\frac{\tau_1+\tau_2}{\gamma+\mu}C*$

Local Stability of Endemic Equilibrium, (E^{**})

The Routh–Hurwitz criteria is used to establish the asymptotic stability of equilibrium for nonlinear systems of differential equations. The Routh–Hurwitz criteria provide the necessary and sufficient conditions for all roots of the characteristic polynomial to have negative real parts, thereby ensuring asymptotic stability.

The local stability of the endemic equilibrium point is determined from the Jacobian matrix of the system evaluated at E^{**}. The Jacobian matrix is given by

$$J(E^{*}) = \begin{pmatrix} -(\mu+(A_1+A_2)B^{**}) & -(A_1+A_2)S^{**} & 0 & \gamma & 0 & 0 \\ A_1B^{**} & A_1S^{**}-(\alpha+\delta_3+\mu) & 0 & 0 & 0 & 0 \\ A_2B^{**} & A_2S^{**} & -(\tau_1+\tau_2+\mu+\delta_1+\delta_2) & 0 & 0 & 0 \\ 0 & 0 & \tau_1+\tau_2 & -(\gamma+\mu) & 0 & 0 \\ 0 & \alpha & 0 & 0 & (\tau_3+\mu+\delta_4) & 0 \\ 0 & 0 & 0 & 0 & \tau_3 & -\mu \end{pmatrix} \quad (9)$$

Using elementary row operations, the matrix reduces to

$$J(E^{*}) \approx \begin{pmatrix} m_1 & m_2 & 0 & 0 & 0 & 0 \\ m_3 & m_4 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_5 & 0 & 0 & 0 \\ 0 & 0 & 0 & -(\gamma+\mu) & 0 & 0 \\ 0 & 0 & 0 & 0 & \tau_3+\mu+\delta_4) & 0 \\ 0 & 0 & 0 & 0 & 0 & -\mu \end{pmatrix}$$

where

$$m_1 = -(\mu+(A_1+A_2)B^{**}),\ m_2 = -(A_1+A_2)S^{**},\ m_3 = A_1B^{**},$$
$$m_4 = A_1S^{**}-(\alpha+\delta_3+\mu),\ m_5 = -(\tau_1+\tau_2+\mu+\delta_1+\delta_2).$$

The characteristic equation is obtained as

$$\left|\begin{pmatrix} m_1-\lambda & m_2 \\ m_3 & m_4-\lambda \end{pmatrix}\right|(m_5-\lambda)(-(\gamma+\mu)-\lambda)(-(\tau_3+\delta_4+\mu)-\lambda)(-\mu-\lambda)=0$$

Thus, four eigenvalues are clearly negative given by:

$$\lambda_3 = m_5 < 0,\ \lambda_4 = -(\gamma+\mu) < 0,\ \lambda_5 = -(\tau_3+\delta_4+\mu) < 0,\ \lambda_6 = -\mu$$

The remaining eigenvalues are obtained from the quadratic equation

$$\lambda^2 - (m_1+m_4)\lambda + m_1m_4 - m_2m_3 .$$

Theorem 3: The endemic equilibrium E^{*} is locally asymptotically stable if

$$m_1+m_4 < 0 \text{ and } m_1m_4 - m_2m_3 > 0$$

Hence, all eigenvalues have negative real parts provided the above conditions are satisfied. Therefore, the endemic equilibrium E^{*} is locally asymptotically stable. The sociological implication of this result is that banditry persists in the population at a stable level whenever the system satisfies the stability conditions, and the initial population lies within the basin of attraction of the endemic state.

RESULTS AND DISCUSSION

Numerical Simulation

Numerical simulation for the analytical results of the banditry model (2) is presented. This is a crucial step in ensuring the accuracy and reliability of the model (2). The simulations were presented to monitor the dynamics of the model, for different values of the effective reproduction number in order to verify the analytical results of both bandits-free and bandit persistence. The time series analysis was carried out in *Maple* software which was more convenient and easy to depict the behavior of the bandit which tend to be logically an infection in the population, and for illustrating which of the parameters tend to either spike or reduce the unity of the effective reproduction number $(\mathcal{R}_c)$ the *Mathematica* software is used which is also much convenient.

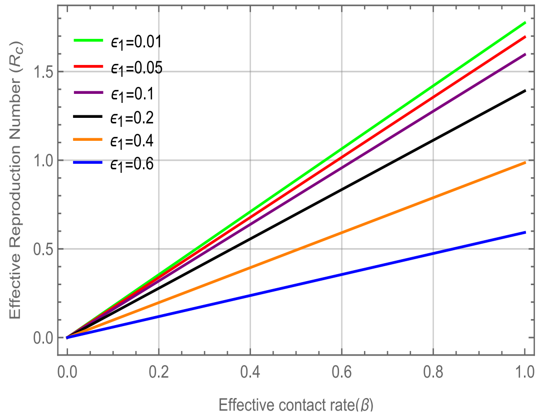

Figure 2: The effect of contact rate and government effort on the behavior of the effective reproduction number with different values.

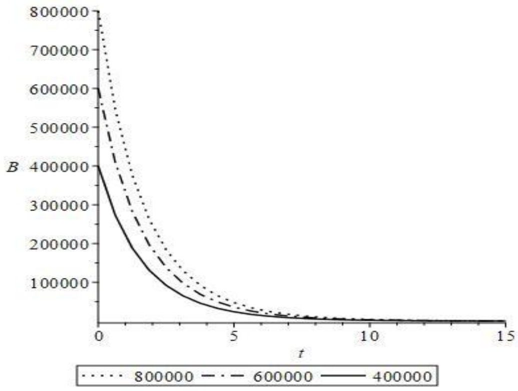

Figure 3: Time series simulation for the bandit compartments with the initial conditions: $B = 800{,}000;$ $600{,}0000; 400{,}000$ and with $\varepsilon = \alpha = \delta_3 = 0.20, \mu = 0.017$ which gives $R_C = 1.835$

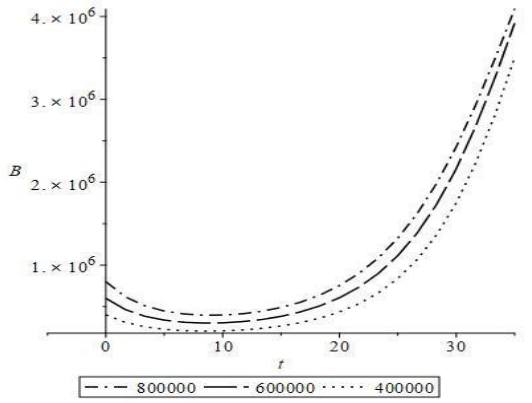

Figure 4: Time series simulation for the bandit compartments with initial condition: $B = 800{,}000;$ $600{,}0000; 400{,}000$ and, $\varepsilon = \alpha = \delta 3 = 0.45, \mu = 0.017$ which gives $R_C = 0.650$

The numerical simulations were done using the parameter values:

$$\Lambda = 2\times 10^5,\ \beta = (0-1),\ \mu = 0.017,$$
$$\kappa = (0-1),\ \delta_1 = 0.1,\ \delta_2 = 0.01,\ \varepsilon_1,$$
$$\varepsilon_2 = (0-1),\ \tau_1, \tau_2, \tau_3 = (0-1)$$
$$\alpha, \delta_3, \delta_4 = (0-1).$$

The behavior of the effective reproduction number $(\mathcal{R}_c)$ is illustrated in Figure (2) where the key parameters that tend to have the most effect in either increasing or decreasing this threshold is presented.

It can be observed that when the effective contact rate (β) is increased past 0.6, then

$(\mathcal{R}_c)$ becomes persistence of course with a corresponding decline in the effect of government aid. Figures (3 & 4) illustrates the time series graph for the bandit's population, with respect to when $(\mathcal{R}_c < 1)$ and also when $(\mathcal{R}_c > 1)$, which are the criteria for either the eratidcating or persistence of the bandits respectively. From Figure (3) it is seen that irrespective of the initial condition of the bandit population, so long as the effective reproduction number is less than unity $(\mathcal{R}_c < 1)$, the bandits will be eradicated. However, there will be persistence in the said population when $(\mathcal{R}_c > 1)$ as depicted in Figure (4). This is a clear sign that with the appropriate control methods, there is a high chance of mitigating to the barest minimum if not total eradication of this menace.

Conclusion and Recommendation.

This study has successfully developed and analyzed a mathematical model for curbing the menace of banditry in Niger State. The results demonstrate that banditry dynamics can be effectively studied using mathematical modeling techniques. The analysis shows that the effective reproduction number R_C plays a crucial role in determining the long-term behavior of banditry in the population. When $R_C < 1$, banditry is eliminated over time, while $R_C > 1$ leads to its persistence. The inclusion of government effort and repentant bandits in the model provides deeper insight into the dynamic mechanisms of banditry.

In particular, increasing government intervention, improving rehabilitation programs, and reducing recruitment into banditry significantly contribute to mitigating banditry. The findings suggest that banditry can be controlled and eventually eradicated if effective strategies are implemented to reduce recruitment, increase detention and rehabilitation of bandits, and strengthen government efforts.

Based on the findings of this study, it is recommended that government should intensify efforts in preventing recruitment into banditry through education and job creation. Also, rehabilitation programs for repentant bandits should be strengthened to reduce recidivism. Consequently, there is need to further investigate the global stability and bifurcation analysis of this study to better improve understand every bit of the banditry model. Incorporating more compartments into the present model can extend the study and help establish a realistic insight on the banditry activities.

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