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Modeling The Impact of Rehabilitation Programs on The Propagation of Banditry Crime: A Case Study of Katsina State, Nigeria

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ABSTRACT
Banditry has emerged as a critical socio-economic and security challenge in north western Nigeria, particularly within Katsina State, severely disrupting rural economies and community stability. While conventional approaches heavily rely on kinetic military interventions, there is a growing paradigm shift toward non-kinetic strategies, such as rehabilitation programs. This study develops a deterministic mathematical model to investigate the transmission and control dynamics of banditry crime, explicitly incorporating a rehabilitation compartment for reformed individuals. The population is stratified into distinct epidemiological classes representing vulnerable, susceptible, actively recruited, and rehabilitated individuals. We derive the basic reproduction number R_0 for criminal propagation to evaluate the threshold conditions necessary for banditry eradication or persistence. Stability analysis of the model shows that the banditry-free equilibrium is locally asymptotically stable when $R_0<1$, suggesting that effective rehabilitation and reduced recruitment rates can successfully curb criminal propagation. Numerical simulations are conducted using localized parameters from Katsina State to validate the analytical results. The findings demonstrate that expanding rehabilitation programs significantly reduces the active criminal pool over time, though its long-term success remains highly sensitive to the rate of relapse back into banditry. Ultimately, this model offers a predictive framework for policymakers, demonstrating that integrated rehabilitative strategies provide a more sustainable long-term solution to security challenges than punitive measures alone.

Keywords:
Mathematical Modelling,
Banditry Dynamics,
Rehabilitation Program,
Stability Analysis,
Epidemiological Model,
Katsina State.

INTRODUCTION

Majority of the real – world issues we face, particularly in the physical science, social sciences, and life sciences, may be describe by using differential equation (Sagir, Abdullahi, & Balogun (2023). In recent decades, the intersection of mathematical modeling and social sciences has proven highly effective in understanding, predicting, and controlling complex human behaviors. Among these behaviors, the propagation of criminal activities—ranging from minor infractions to structured organized crime—has increasingly been treated using mathematical epidemiology. The core underlying philosophy rests on the premise that crime, much like an infectious disease, spreads through social contact, environmental peer pressure, and recruitment mechanisms. In northwestern Nigeria, this theoretical challenge matches a pressing humanitarian crisis: the dramatic rise of rural banditry. Characterized by mass abductions, cattle rustling, armed robbery, and fatal assaults on agrarian communities, banditry has transitioned from localized resource conflicts into a sophisticated network of violent crime.

Katsina State has emerged as one of the epicenters of this crisis within the region. The state's vast, porous forested terrains, such as the Rugu Forest, coupled with socio-economic vulnerabilities like youth unemployment, poverty, and weak local governance, have provided an ideal environment for criminal syndicates to thrive and recruit new members. The consequences have been devastating, resulting in the displacement of thousands of citizens, severe disruptions to agricultural supply chains, and a systemic collapse of rural economies.

Historically, state responses to banditry have been overwhelmingly kinetic, relying on military operations, air strikes, and heavily armed policing to neutralize criminal cells.

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While these punitive measures offer temporary relief by disrupting immediate threats, they often fall short of delivering a sustainable, long-term solution. Relying solely on law enforcement can inadvertently trigger a continuous loop of retaliatory violence, overextend state security resources, and fail to address the core socio-economic drivers that make recruitment viable in the first place. Recognizing these limitations, there has been a growing paradigm shift among security analysts and regional policymakers toward non-kinetic interventions. Chief among these alternative strategies are structured amnesty and rehabilitation programs, designed to incentivize voluntary disarmament, offer psychological reorientation, and provide economic reintegration paths for reformed combatants.

To rigorously evaluate the viability of these non-kinetic approaches, researchers have increasingly turned to compartment-based mathematical models. Originally designed for infectious disease dynamics by (Umar, 2013), deterministic systems of ordinary differential equations (ODEs) have been successfully adapted to social contagions. Researchers have modeled phenomena such as riot propagation gang recruitment (Identity-Based Models), and general criminal recidivism. In these frameworks, the transition of an individual from a law-abiding citizen to an active criminal mimic the transition from a susceptible host to an infected individual, driven by a contact-dependent recruitment rate. A few recent studies have begun incorporating intervention compartments, such as incarceration, police deterrence, or judicial sentencing, into these mathematical systems.

Despite these advances, a significant gap remains in the existing literature. While general law enforcement and imprisonment are frequently captured in criminal models, the explicit mathematical formulation of structured, multi-stage rehabilitation programs—specifically within the context of rural banditry in Sub-Saharan Africa—remains underdeveloped. Most existing mathematical studies on crime treat recovery as a permanent exit or a simple transition to a generic "removed" class, neglecting the real-world complexities of systemic relapse, societal stigmatization, and the fragile nature of amnesty in volatile socio-political environments.

This study directly addresses this gap by developing a novel deterministic mathematical model that explicitly captures the transmission and control dynamics of banditry crime with an integrated rehabilitation framework tailored to Katsina State. The total population is stratified into four distinct epidemiological classes: vulnerable, susceptible, actively recruited, and rehabilitated individuals. Moving beyond generic models, our framework accounts for the nuanced pathways of recruitment into banditry cells and the subsequent transition into state-sponsored rehabilitation pipelines. In recent years, researchers have increasingly turned to compartment-based mathematical models to unpack the complex transmission dynamics of armed banditry and alike across Northwest Nigeria (Bashir, Abdullahi, & Garba, 2023). Instead of treating crime merely as a sociopolitical issue, contemporary studies view criminal behavior through an epidemiological lens—analyzing how it spreads through social contact and recruitment pipelines. Their simulations underscore a critical point: interventions that target the economic roots of banditry, effectively making it unprofitable, are among the most powerful ways to shut down recruitment pipelines. Their model breaks down criminal networks by hierarchical roles—separating everyday foot soldiers and high-level leaders from the informers who blend into local communities. Crucially, they integrated a dedicated rehabilitation compartment (R) into their system. By calculating the effective reproduction number for crimes like kidnapping and banditry, their work mathematically demonstrates how structured, accessible rehabilitation pathways can drastically reduce both the initial progression into gangs and the rate of criminal relapse.

To truly understand how rehabilitation programs disrupt criminal networks, recent literature often models criminal habits like a transmissible social disease. A strong example of this is the work by (Nuno, Angel, & Mario, 2011) who developed a comprehensive model looking at the intersecting dynamics of crime and substance abuse. By establishing a control reproduction number, they proved mathematically that expanding both inpatient and outpatient rehabilitation programs creates a stable, crime-free equilibrium over time. Their findings reinforce the idea that rehabilitation isn't just a moral or social good; it is a mathematical necessity to break the "entrenched threshold" where criminal behavior becomes a permanent, self-sustaining fixture in a community (Adamu, Bashir, Ayuba, & Abubakar (2018))

At the same time, researchers stress that rehabilitation cannot work in a vacuum; it must be balanced with law enforcement, tackling this by creating an age-structured optimal control model tailored for criminal gangs in resource-limited environments (Bashir, 2017). Their framework introduces time-dependent controls that represent youth empowerment schemes, community enlightenment campaigns, and modern correctional facilities. Their ultimate conclusion is that minimizing the number of youth falling into delinquency requires a delicate, concurrent balance: continuous, targeted policing to deter active criminals, running alongside highly accessible social re-integration programs. For any mathematical model of Katsina State to be accurate, its parameters must reflect the actual, on-the-ground dynamics of the region. From a structural and policing standpoint, the way banditry spreads across Katsina and its neighboring states relies heavily on vast, remote forest hideouts and localized supply chains (Bashir, Garba, Abdullahi, & Aminu, 2026). Scholars keeps exploring these plural policing models, showing how anti-banditry operations in Katsina frequently focus on cutting off peripheral logistics, such as the networks supplying fuel and food to forest camps. For a mathematical modeler, these empirical insights are invaluable; they provide the real-world context needed to assign realistic values to variables like recruitment rates, transmission vectors, and the overall efficacy of state-sponsored rehabilitation programs (Bonabeau, 2002).

MATERIALS AND METHODS

MODEL FORMULATION

The population is divided into seven (7) compartments: the Susceptible educated S_E , the Susceptible uneducated S_U , the Exposed class E, the Banditry are crime class B_C, the Jail class J, the Rehabilitated class R_1, and the recovered class R_2 and the total population is equal to the sum of all the compartments. The susceptible educated class is the class of people who can be exposed to Banditry crime due to illicit acts by the Bandit individual(s). That is, when the Banditry gang attacks one of the relatives of the susceptible class such that the victim or a relative may go for revenge, in the process of doing so, he may join the gang. The susceptible uneducated class is the class where people are capable of being exposed to Banditry crime due to contact with the Banditry crime individuals; these include people who have closed relationships with the Banditry crime and those who live in the same area with Banditry crime individuals; the exposed class contains individuals that exposed to Banditry crime but do not encourage people to practice; Banditry crime class consists of those who practice Banditry crime and capable of influencing other people to join the Banditry crime either willingly or otherwise; jailed course consists of those who practice Banditry crime and convicted; rehabilitated class consists of those who have been engaged into rehabilitation programmed and the recovered course consists of those that have been fully recovered from the Banditry activities.

Assumption of the model

The following presumptions form the basis of the model:

1. All susceptible individuals are equally likely to join Banditry crime individuals when they come in contact.
2. Those in the uneducated class are more vulnerable to being infected.
3. Rehabilitated individuals are moved into recovered classes for a particular period.
4. We assume recovered individuals can join either the susceptible educated class or the susceptible uneducated class after recovery.

Table 1: Variables and parameters of the model

VAR/PAR	DESCRIPTION	Value	Source
S_E	Number of susceptible educated individuals at time t		
S_U	Number of susceptible uneducated individuals at time t		
E	Number of Exposed individuals at time t		
B_C	Number of Banditry crime individuals at time t		
J	Number of Jail individuals at time t		
R_1	Number of Rehabilitated individuals at time t		
R_2	Number of Recovered individuals at time t		
π	Recruitment rate of susceptible	1000	Sanda et al. 2019
ρ	Proportion of youth that have been enrolled in school	0.70	‘ ’
β_1	Rate of moving from educated class into the exposed class	0.9	‘ ’
β_2	Rate of moving from susceptible uneducated class into the exposed class	0.9	‘ ’
α	Rate of moving from exposed class into the Banditry class	0.30	‘ ’
μ	Natural death rate in all the classes	0.019	‘ ’
δ_1	Death induced by been exposed to kalare crime	0.1	‘ ’
δ_2	Death induced by kalare crime	0.1	‘ ’
ω_1	Rate of moving from recovered class into the susceptible educated class	0.66	Assumed
ω_2	Rate of moving from recovered class into the susceptible uneducated class	0.35	‘ ’
ξ	Rate of moving from exposed class into the rehabilitated class	0.02	‘ ’
σ	Rate of moving from kalare crime class into the rehabilitated class	0.73	‘ ’

η	Rate of moving from exposed class into the jail class	0.15	(Sanda *et al.* 2019)
γ	Rate of moving from jail class into the rehabilitated class	0.67	Assumed
τ	Rate of moving from kalare crime class into Recovered class	0.37	‘ ’
Ψ	Rate of moving from rehabilitated class into the recovered class	0.82	‘ ’
Φ	Rate of moving from jail class into the recovered class	0.15	(Sanda *et al.* 2019)
Y	Rate of moving from jail class into the kalare crime class	0.34	Assumed
θ	Rate of moving from Kalare Crime class into the Jail crime class	0.15	(Sanda *et al.* 2019)

Model equations

$$\left.\begin{aligned}
\frac{dS_E}{dt} &= \pi\rho+\omega_1R_2-(\beta_1B_C+\mu)S_E\\
\frac{dS_U}{dt} &= \pi(1-\rho)+\omega_2R_2-(\beta_2B_C+\mu)S_U\\
\frac{dE}{dt} &= \beta_1B_CS_E+\beta_2B_CS_U-(\xi+\alpha+\eta+\delta_1+\mu)E\\
\frac{dB_C}{dt} &= \alpha E+\upsilon J-(\theta+\tau+\sigma+\delta_2+\mu)B_C\\
\frac{dJ}{dt} &= \theta B_C+\eta E-(\upsilon+\phi+\gamma+\mu)J\\
\frac{dR_1}{dt} &= \xi E+\sigma B_C+\gamma J-(\psi+\mu)R_1\\
\frac{dR_2}{dt} &= \tau B_C+\psi R_1+\phi J-(\omega_1+\omega_2+\mu)R_2
\end{aligned}\right\} \quad \textbf{(1)}$$

MODEL ANALYSIS

The fundamental components of the system (1) are examined in this section. It was possible to achieve the equilibrium's existence and stability. The basic reproduction number was also obtained.

Positivity of the solution

By expressing and demonstrating the following theorem, we demonstrated the positivity of the solutions to model (1).

Theorem 1:

Let the initial solution set

$$\left\{\begin{matrix} S_E(0)>0, S_U(0)>0, E(0)>0, \\ B_C(0)>0, J(0)>0, R_1(0)>0, R_2(0)>0\end{matrix}\right\}\in\Re_+^7, \quad (2)$$

If t>0, the solution set is then positive forever.

Proof:

From $\frac{dS_E}{dt}=\pi\rho+\omega_1R_2-(\beta_1K_C+\mu)S_E$

$$\frac{dS_E}{dt}\geq-(\beta_1B_C+\mu)S_E \quad (3)$$

By separating the variables in problem (3), we have

$$\frac{dS_E}{S_E}\geq-(\beta_1B_C+\mu)dt \quad (4)$$

Integrating (4) we have

$$\int\frac{1}{S_E}dS_E\geq\int-(\beta_1B_C+\mu)dt$$

$$\ln S_E\geq\int-(\beta_1B_C+\mu)dt \quad (5)$$

Taking exponential of both side of (5)

$$S_E(t)\geq e^{\int-(\beta_1B_C+\mu)dt}\geq0$$

Similarly, for $\frac{dS_u}{dt}\frac{dE}{dt},\frac{dB_C}{dt},\frac{dJ}{dt},\frac{dR_1}{dt}$ and $\frac{dR_2}{dt}$. The solution to equation (1) is therefore positive for all times t>0 according to the second theorem.

Existence of invariant region

From the model equation, the population estimate is provided by

$$N=S_E+S_U+E+B_C+J+R_1+R_2$$

That is

$$\frac{dN}{dt}=\frac{dS_e}{dt}+\frac{dS_u}{dt}+\frac{dE}{dt}+\frac{dB_C}{dt}+\frac{dJ}{dt}+\frac{dR_H}{dt}+\frac{dR}{dt}$$

Consequently, when the differential equations are included, we have

$$\frac{dN}{dt}=\pi-\mu(S_E+S_U+E+B_C+J+R_H+R)-\delta_1E-\delta_2B_C$$

$$\frac{dN}{dt}=\pi-\mu N-\delta_1E-\delta_2B_C$$

$$\frac{dN}{dt}\leq\pi-\mu N$$

Integrating this, we obtain $N(t)\leq\frac{\pi}{\mu}$ as $t\to\infty$

Consequently, the area where the model makes biological sense is indicated by

$$\Omega = \begin{Bmatrix} S_E, S_U, E, B_C, J, R_1, R_2 \in \mathbb{R}^7{}_+ : \\ S_E + S_U + E + B_C + J + R_1 + R_2 \leq \dfrac{\pi}{\mu} \end{Bmatrix} \quad (11)$$

Accordingly, every solution with initial condition(s) in Ω continues to be in Ω. Our model is thus mathematically sound, positively invariant, and physiologically plausible in region Ω.

Banditry Crime Free Equilibrium Point (BCFE)

In the absence of Banditry crime, we obtain the following BCFE, denoted by E_O

$$E_0 = \left(\frac{\pi\rho}{\mu}, \frac{\pi(1-\rho)}{\mu} 0,0,0,0,0 \right) \quad (12)$$

Endemic Equilibrium Point

Lemma 1. The Banditry Crime model has a unique endemic equilibrium if and only if $R_0 > 1$.

Proof. When we compute the endemic equilibrium point, we get,

$$\left.\begin{aligned} S_E^* &= \frac{A_4\pi\rho\alpha^2 + \pi\rho\eta\upsilon\alpha + B_c^*\omega_1 G_1}{\alpha\left(A_4\alpha + \eta\upsilon\right)\left(\beta_1 B_c^* + \mu\right)}, \\ S_U^* &= \frac{A_1 A_4 A_6\alpha^2 + A_1 A_2\eta\upsilon\alpha + B_c^*\omega_2 G_2}{\alpha A_6\left(A_4\alpha + \eta\upsilon\right)\left(\beta_1 B_c^* + \mu\right)}, \\ E^* &= \frac{B_c^* G_3}{A_6\left(A_4\alpha + \eta\upsilon\right)} \\ B_c^* &= B_c^*, J^* = \frac{B_c^*\left(\theta\alpha + A_3\eta\right)}{\left(\alpha A_4 + \eta\upsilon\right)}, \\ R_1^* &= \frac{B_c^* G_1}{\alpha\left(\alpha A_4 + \eta\upsilon\right)}, R_2^* = \frac{B_c^* G_2}{A_6\alpha\left(\alpha A_4 + \eta\upsilon\right)} \end{aligned}\right\} \quad (13)$$

Where

$$G_1 = A_3 A_4\xi\alpha + A_3\xi\eta\upsilon + \sigma\alpha^2 A_4 + \sigma\alpha\eta\upsilon$$
$$+\gamma\theta\alpha^2 + \gamma\eta\alpha A_3 - \upsilon\theta\alpha\xi - A_3\upsilon\eta\xi$$
$$G_2 = A_4\tau\alpha^2 + \tau\alpha\eta\upsilon + \psi G_1 + \phi\alpha^2\theta + \phi\alpha\eta A_3$$
$$G_3 = A_3 A_4\alpha + A_3\eta\upsilon - \upsilon\left(\theta\alpha + A_3\eta\right)$$

Basic Reproduction Number of the Model

The basic reproduction number is an important non – dimensional quantity in as it set the threshold in the study (Bashir, Garba, Abdullahi, & Aminu, 2026). Given the disease-free equilibrium, if F_i represents the rate at which new infections emerge in the compartment and V_i represents the rate at which people move from i, , then R_0 is the spectral radius (biggest Eigen value) of the subsequent generation matrix represented by $G = \rho F V^{-1}$.

In order to determine F and V, which are their respective Jacobian matrices at a disease-free equilibrium E_0, Therefore, the basic reproduction number is given below

$$R_0 = \frac{\pi\left(\beta_1\rho + \beta_2(1-\rho)\right)\left(\eta\upsilon + \alpha\left(\upsilon + \phi + \gamma + \mu\right)\right)}{\mu\left(\xi + \alpha + \eta + \delta_1 + \mu\right) \left(\left(\theta + \tau + \sigma + \delta_2 + \mu\right)\left(\upsilon + \phi + \gamma + \mu\right) - \theta\upsilon\right)} \quad (14)$$

Local Stability Analysis of the Banditry Crime Free Equilibrium (BCFE)

$$\begin{vmatrix} -\mu & 0 & 0 & 0 & 0 & \omega_1 & 0 \\ 0 & -\mu & 0 & 0 & 0 & 0 & \omega_2 \\ 0 & 0 & -a_1-\lambda & a_2 & 0 & 0 & 0 \\ 0 & 0 & \alpha & -a_3-\lambda & \upsilon & 0 & 0 \\ 0 & 0 & \eta & \theta & -a_4-\lambda & 0 & 0 \\ 0 & 0 & \xi & \sigma & \gamma & -a_5-\lambda & 0 \\ 0 & 0 & 0 & \tau & \phi & \psi & -a_6-\lambda \end{vmatrix} = 0$$

Where

$$a_1 = (\xi + \alpha + \eta + \delta_1 + \mu),$$
$$a_2 = \frac{\beta_1\pi\rho + \beta_2\left(1-\rho\right)\pi}{\mu},$$
$$a_3 = \left(\theta + \tau + \sigma + \delta_2 + \mu\right),$$
$$a_4 = \left(\upsilon + \phi + \gamma + \mu\right),$$
$$a_5 = \left(\psi + \mu\right), a_6 = \left(\omega_1 + \omega_2 + \mu\right)$$

The four eigenvalues of above are $\lambda_1 = -\mu, \lambda_2 = -\mu, \lambda_3 = -a_6$ and $\lambda_4 = -a_5$ while the remaining three eigenvalues are obtained from 3 by 3 matrix below.

$$G = \begin{vmatrix} -a_1 & a_2 & 0 \\ \alpha & -a_3 & \upsilon \\ \eta & \theta & -a_4 \end{vmatrix}$$

Thus, the eigenvalues of B are real and negative if the Routh-Hurwitz condition is satisfied. Applying the Routh-Hurwitz condition: (i) $Tr(\mathrm{G}) < 0$ (ii) $Det(\mathrm{G}) > 0$.

Thus,

$Tr(\mathrm{K}) = -a_1 - a_3 - a_4 = -(a_1 + a_3 + a_4) < 0$ and

$$Det(K) = \theta\upsilon a_1 + \upsilon\eta a_2 + \theta a_2 a_4 - a_1 a_3 a_4$$
$$= \theta\upsilon a_1 + \upsilon\eta a_2 + \theta a_2 a_4 - a_1 a_3 a_4$$

$$=(\xi+\alpha+\eta+\delta_1+\mu)\left(\frac{\theta\upsilon-(\theta+\tau+\sigma+\delta_2+\mu)}{(\upsilon+\phi+\gamma+\mu)}\right)(1-R_0)$$

Following theorem 2, We conclude that DFE point is locally asymptotically stable.

Global stability Analysis of the Banditry Crime Free Equilibrium (BCFE)

We employ the theorem by Castillo-Chavez et al. (2002) to prove the global stability of the Banditry Crime free equilibrium of the model (1). Achieving the requirements is necessary.

$H_1 : \frac{dX}{dt} = H(X,0), X^0$ is globally asymptotically stable.

$H_2 : G(X,Z) = PZ - \hat{G}(X,Z), \hat{G}(X,Z) \geq 0$ for $(X,Z) \in \Omega$, where $P = \Delta_z G(X^0,0)$ is an $M-matrix$ (the off diagonal elements of P are non-negative) and is also Jacobian of $G(X,Z)$

We write the model equation given by (1) as

$$\frac{dX}{dt} = H(X,Z)$$

$$\frac{dZ}{dt} = G(X,Z), G(X,0) = 0$$

$$E_0(X^0,0) = \left(\frac{\pi\rho}{\mu}, \frac{\pi(1-\rho)}{\mu}, 0\right)$$

Where $X = (S_E, S_U, R_2) \in R^3$ denotes the number of un-infected individuals and $Z = (E, K_C, J, R_1) \in R^4$ denotes the number of infected individuals.

$E_0 = (X^0, 0)$ denotes the DFE of the system.

Take (E, K_C, J, R_1) and evaluated at $E_0(S_E, S_U, R_2) = \left(\frac{\pi\rho}{\mu}, \frac{\pi(1-\rho)}{\mu}, 0\right)$. If the system satisfies the conditions H_1 and H_2 above, then according to Carlos Castillo-Chavez (2002), the following theorems hold.

Theorem 2: The fixed point $E_0 = (X^0, 0)$ is a globally asymptotic stable (GAS) provided that $R_0 < 1$(L.A.S) and those assumptions H_1 and H_2 are satisfied.

Proof: The two functions $H(X,Z)$ and $G(X,Z)$ are given by

$$H(X,Z) = \begin{bmatrix} \pi\rho + \omega_1 R_2 - (\beta_1 B_C + \mu)S_E \\ \pi(1-\rho) + \omega_2 R_2 - (\beta_2 B_C + \mu)S_U \\ \tau B_C + \psi R_1 + \phi J - (\omega_1 + \omega_2 + \mu)R_2 \end{bmatrix}$$

$$G(X,Z) = \begin{bmatrix} \beta_1 B_C S_E + \beta_2 B_C S_U - (\xi + \alpha + \eta + \delta_1 + \mu)E \\ \alpha E + \upsilon J - (\theta + \tau + \sigma + \delta_2 + \mu)B_C \\ \theta B_C + \eta E - (\upsilon + \phi + \gamma + \mu)J \\ \xi E + \sigma B_C + \gamma J - (\psi + \mu)R_1 \end{bmatrix}$$

We then consider the reduced system $\frac{dX}{dt} = H(X,0)$ from condition (1)

$$H(X,0) = \begin{bmatrix} \pi\rho - \mu S_E \\ \pi(1-\rho) - \mu S_U \\ 0 \end{bmatrix}$$

$$\frac{dS_E}{dt} + \mu S_E = \pi\rho$$

To integrate let use the integrating factor.

$$\Rightarrow S_E.IF = \pi\rho \int IF dt$$

At $t \to \infty$

$$S_E(0) = \frac{\pi\rho}{\mu} + C \tag{16}$$

$$C = S_E(0) - \frac{\pi\rho}{\mu}$$

By putting the value of C into (16) $S_E(t) = \frac{\pi\rho}{\mu} + \left(S_E(0) - \frac{\pi\rho}{\mu}\right)e^{-\mu t}$, As $t \to \infty$ an $S_E(\mathrm{t}) \to \frac{\pi\rho}{\mu}$.

Similar for $S_u(\mathrm{t}) \to \frac{\pi(1-\rho)}{\mu}$ and $\mathrm{R(t)} \to 0.$

Convergence of X^0 is therefore global in Ω. This implies $X^0 = \left(\frac{\pi\rho}{\mu}, \frac{\pi(1-\rho)}{\mu}, 0\right)$ is g.a.s equilibrium of $\frac{dX}{dt} = F(X,0).$

Considering the second equation, we have

$$G(X,Z) = PZ - \hat{G}(X,Z), \hat{G}(X,Z) \geq 0$$

Therefore (3) gives,

$$P=\begin{bmatrix} -(\xi+\alpha+\eta+\delta_1+\mu) & \beta_1 S_E+\beta_2 S_U & 0 & 0 \\ \alpha & -(\theta+\tau+\sigma+\delta_2+\mu) & \upsilon & 0 \\ \eta & \theta & -(\upsilon+\phi+\gamma+\mu) & 0 \\ \xi & \sigma & \gamma & -(\psi+\mu) \end{bmatrix}$$

and

$$Z=\begin{bmatrix} E \\ K_C \\ J \\ R_1 \end{bmatrix}$$

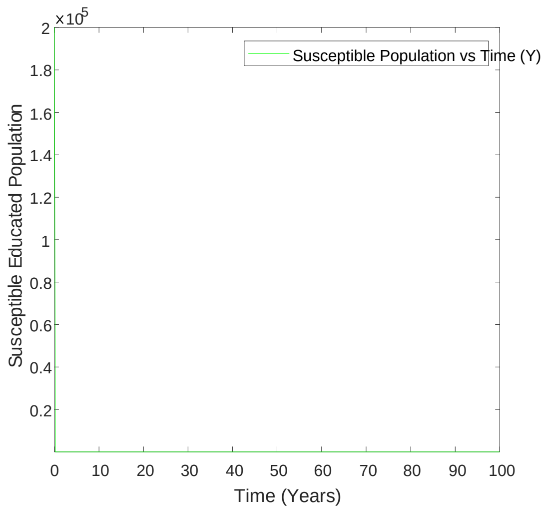
Therefore, $\hat{G}(X,Z)=\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$

But it is clear that $\therefore, \hat{G}(X,Z)=PZ-G(X,Z)\geq 0.$ this implies that $G(X,Z)=0$, hence the Banditry crime free equilibrium of the system is globally asymptotically stable implying that Banditry crime will be eradicated if transmission rate is low in the environment and rehabilitation programmed is effectively employed.

RESULTS AND DISCUSSION

Numerical Simulation

While the math gives us a solid theoretical foundation, we need to see how these equations actually behave in the real world. That is where numerical simulations come in. By translating our abstract formulas into computational models, we can project how banditry dynamics might shift over time under different conditions. For these simulations, we use baseline parameters tailored as closely as possible to the actual security and socio-economic realities of Katsina State.



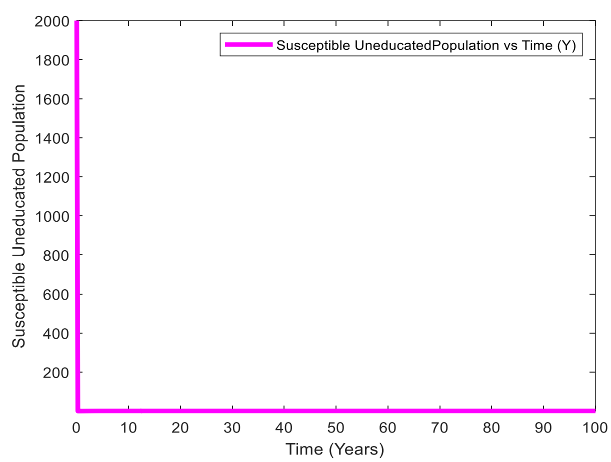
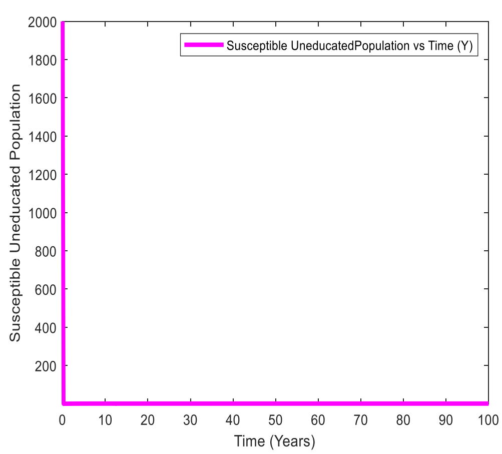


Figure 1. Susceptible uneducated population against time Figure 2. Susceptible uneducated population against time



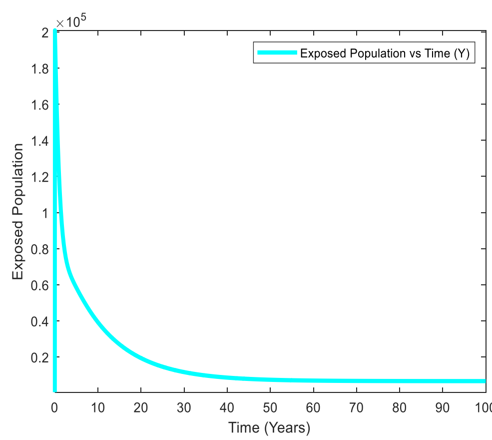


Figure 3.
Susceptible uneducated population against time

Figure 4.
Exposed Population against time

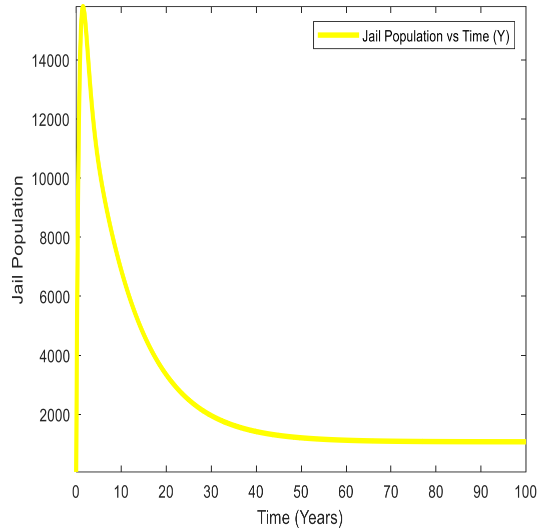


Figure (.5.
Jail population against time

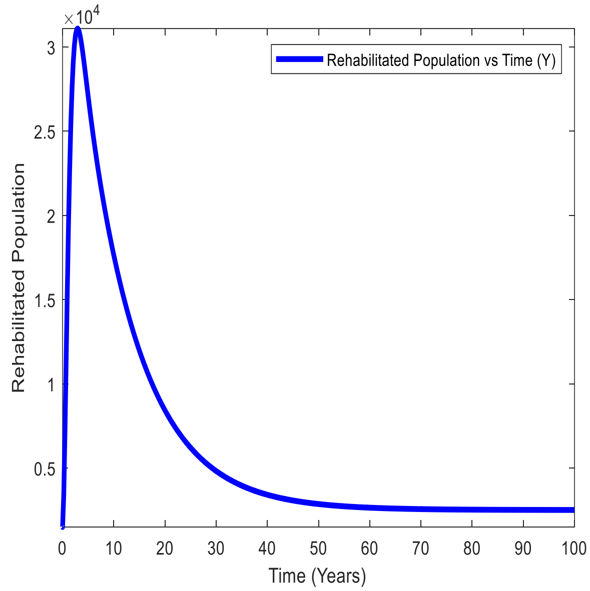


Figure 6.
Rehabilitated Population against time

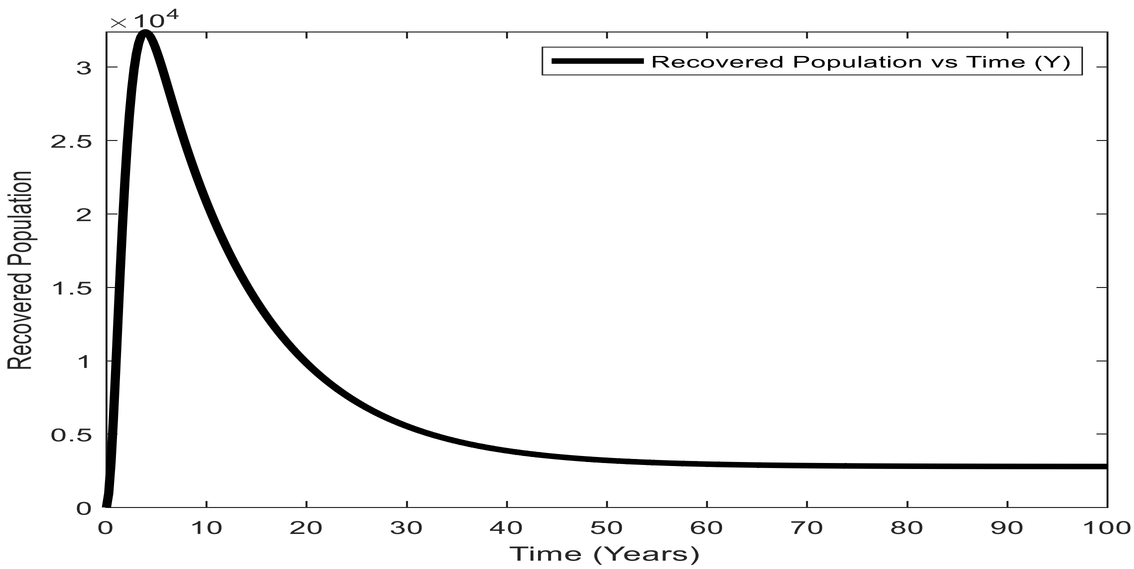


Figure 7. Recovered Population against time

To investigate how Banditry crime spreads, we created a deterministic $S_E, S_U, \mathrm{E}, B_C, J, \mathrm{R}_1, \mathrm{R}_2$ and R model. The findings from our model analysis show that the model is appropriately posed mathematically and epidemiologically, with positive and bounded solutions. We investigated and computed the basic reproduction number and evaluated the stability of the equilibrium point. Based on Lyapunov's theory, our findings show that when $R_0 < 1$ is formed, the equilibrium point where tuberculosis illness is absent is globally asymptotically stable. Figures (1) and (2) revealed that susceptible educated and susceptible uneducated individuals dropped sharply over time. Based on the result, individuals exposed to Banditry and Banditry crime influence the potential ones, thereby reducing the number of susceptible ones. From figures (3) and (4), we observe that the population of primary infectious individuals increased exponentially and dropped drastically to a steady point because of treatment efficacy. From the research, it was observed that the population of drugresistant individuals increased exponentially and later decreased to some certain level because of treatment efficacy. This shows that the people of recovered individuals from figure (7) also increased exponentially over time and later slightly reduced due to proper treatment.

CONCLUSION

This study presents a deterministic, compartmental model of banditry propagation that incorporates a rehabilitation (recovery) pathway, allowing for explicit assessment of non-kinetic interventions. The analysis yields a basic reproduction number for banditry and demonstrates that the banditry-free state is locally asymptotically stable when R0 < 1, indicating that sufficiently strong rehabilitation efforts coupled with reduced recruitment can halt criminal spread. Numerical simulations anchored in Katsina State parameters confirm that expanding rehabilitation programs substantially shrinks the active criminal population over time, though the long-term impact is highly contingent on relapse rates back into banditry. Overall, the findings advocate for integrated rehabilitative strategies as a more sustainable, long-term security solution compared to punitive measures alone, providing policymakers with a predictive framework to guide resource allocation and program design.

Conflict of Interest

The authors of this research have declared that there is no conflict of interest.

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