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Mathematical modeling of corruption dynamics with mass education and Yogachara

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Abstract

Corruption hinders development by undermining public trust, wasting resources, and generating social and economic instability. Despite ongoing efforts, it remains a persistent challenge. This study develops and analyzes a compartmental mathematical model to describe the dynamics of corruption and explore strategies for its control. The model identifies two key states: a corruption-free equilibrium (CFE) and a corruption-persistent equilibrium (CPE). Using the next-generation matrix method, the corruption reproduction number, R_e, was derived. Analysis shows that the CFE is stable when $R_e < 1$, whereas the CPE is stable when $R_e > 1$. Sensitivity analysis reveals that corruption driven by greed and poverty has the strongest positive effect on R_e, while mass education and Yogācāra (Aparigraha) teachings exert the strongest negative effect. Numerical simulations indicate that the combined implementation of mass education and Yogācāra instruction reduces corruption more rapidly than either intervention alone. Overall, the findings suggest that integrating mass education with ethical instruction provides an effective and sustainable strategy for controlling corruption.

Keywords: Corruption control; Mass education; Yogāchāra ethics; Corruption-free equilibrium; Corruption-persistent equilibrium; Stability analysis.

1. Introduction

Mathematics provides powerful tools for analyzing dynamic systems across multiple disciplines. Among these, ordinary differential equations (ODEs) models are widely used to describe the time evolution of complex phenomena. In this study, we employ ODE-based modeling to investigate the dynamics of corruption in Nepal, where corruption is pervasive across the government, education, politics, and the judiciary.

Corruption, derived from the Latin word *corruptus* ("to destroy"), refers to the abuse of entrusted authority for private gain. It ranges from petty bribery to large-scale embezzlement, undermining the rule of law, eroding economic growth, and destabilizing governance—particularly in low-income countries of South Asia. Corruption spreads through social interaction much like an infectious disease: individuals exposed to corrupt practices may themselves become corrupt. Although measuring corruption is challenging, mathematical modeling can provide a quantitative framework to estimate its prevalence and assess the impact of preventive strategies. Among such strategies, mass education and Yogachara (the *Aparigraha* ethic of non-possessiveness) offer promising, low-cost approaches to transform public attitudes and reduce the reproduction rates of corruption [1].

Empirical studies link corruption to weak institutions and economic underperformance across Asia, Africa, and Latin America [2]. Inflation has also been shown to have a significant positive association with corruption [3]. In India, long-term analyses reveal persistent large-scale scams [4]. Several mathematical studies have modeled corruption as a transmissible process. For example, [5] introduced a four-compartment framework and derived a basic reproduction number, R_0, demonstrating the existence of a corruption-free equilibrium when $R_0 < 1$. Subsequent studies refined this approach using sensitivity analysis [6] and examined control measures such as mass education and religious teaching [7]. Other research has highlighted service innovation, transparency, and automation as preventive mechanisms [8], while econometric evidence confirms the negative multiplier effect of corruption on human capital development [9]. Collectively, these studies underscore the effectiveness of education and ethical training in reducing corruption. Building on this evidence, the present model incorporates these preventive measures to provide both analytical and numerical insights into corruption control in Nepal.

Mass education is widely recognized as an effective means of reducing corruption by promoting ethical awareness and civic responsibility. However, its influence on corruption dynamics has rarely been examined within a formal mathematical framework. This creates a need for models that capture how education-driven awareness alters behavioural transitions in corrupt environments. Recent scholarship also highlights the role of internal psychological transformation. Yogāchāra philosophy, with its focus on reshaping cognitive patterns and fostering aparigraha (non-grasping), offers a useful lens for understanding how ethical self-cultivation influences decision-making [10]. Incorporating these ideas allows corruption to be modeled as a process shaped not only by social contagion but also by shifts in individual cognition. This

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study combines mass education and Yogāchāra-based ethical transformation within a unified compartmental differential-equations model. By introducing parameters for educational awareness and cognitive–moral resilience, the model provides a new framework for analyzing how external interventions and internal ethical development interact to reduce corruption. To our knowledge, this is the first mathematical model to integrate Yogāchāra theory into corruption dynamics. Through stability analysis and numerical simulations, the study offers new insights and practical implications for designing comprehensive anti-corruption strategies [11, 12].

This study addresses a key gap in the mathematical literature on corruption: most existing models neither define measurable behavioral indicators nor incorporate explicit preventive mechanisms such as mass education and Yogācāra (the Aparigraha ethic). Recognizing greed and poverty as principal drivers, we treat five behaviors—financial dishonesty, unfaithfulness, lack of devotion to duty (including work delays for bribes or gifts), lack of punctuality, and misbehavior—as "mathematical viruses" and integrate them into a Susceptible–Corrupt–Recovered–Immune (SCRI) differential equation framework. Following a standard seven-step modeling cycle—problem identification, formulation, mathematical analysis, interpretation, validation, communication, and revision—the model captures real-world corruption dynamics and evaluates the impact of targeted interventions, as illustrated in Figure 1.

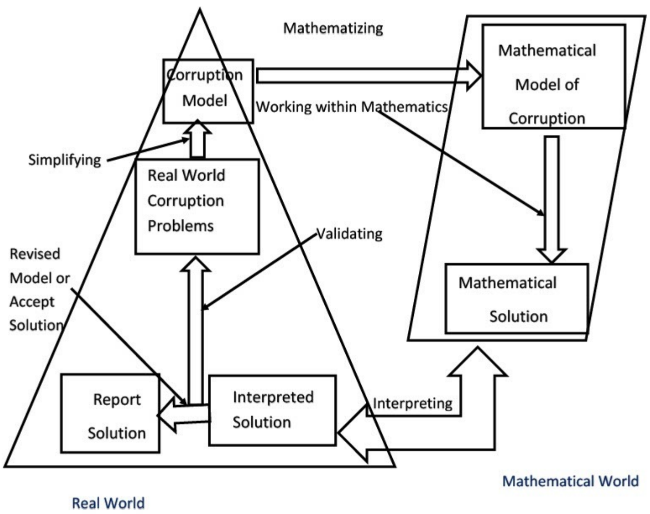


Figure 1: Conceptual framework of corruption dynamics and preventive interventions.

The objectives of this study are to formulate and analyze the SCRI model, derive stability and sensitivity conditions, and validate the findings through numerical simulations. Model parameters are estimated by incorporating five negative behavioral traits that represent corruption "infection," while mass education and Yogācāra serve as preventive measures. The model provides quantitative estimates of corruption levels, identifies key drivers, and highlights the sectors most severely affected. In doing so, it offers policymakers a rigorous and cost-effective tool for designing and evaluating anti-corruption strategies that align with both academic and ethical standards.

An SCRI compartmental model is developed to capture corruption dynamics and evaluate targeted prevention strategies. The population is divided into Susceptible, Corrupt, Recovered, and Immune groups, and mass education and Yogācāra are incorporated as explicit control parameters. Using the next-generation matrix method, the effective reproduction number is derived, local and global stability conditions are established, and sensitivity analysis is performed to identify the most influential drivers of corruption. Through this framework, the impact of preventive interventions is quantified, enabling evidence-based policy design.

2. Methods and methodology

2.1. Assumptions and model formulation

A compartmental model is developed to describe the dynamics of corruption within a population. The total population is subdivided into four groups according to individuals' involvement in corrupt behavior. The model is adapted from [7] and [13], with two key extensions: the inclusion of an immune compartment and the incorporation of two preventive interventions—mass education and Yogācāra (the *Aparigraha* ethic).

Let the total population at time t be denoted by $N(t)$. The population is partitioned into four compartments—Susceptible (S), Corrupt (C), Recovered (R), and Immune (I)—defined as follows:

1. **Susceptible class (S):** Individuals who have not engaged in corruption but remain vulnerable to influence from corrupt members of the community.

2. **Corrupt class (C):** Individuals who are actively involved in corruption and can transmit corrupt practices to susceptible individuals. This class includes those influenced by factors such as greed or poverty, which are treated as underlying "viruses" during parameter estimation.

3. **Recovered class (R):** Individuals who previously participated in corruption but have subsequently adopted ethical behavior. After recovery, they may either revert to the susceptible class or transition to the immune class.

4. **Immune class (I):** Individuals who are resistant to corruption irrespective of external pressures. This category includes those who are inherently honest (i.e., born immune through adherence to *Aparigraha*) as well as those who acquire immunity through mass education or Yogācāra-based ethical practice.

The susceptible compartment consists of individuals recruited through births and immigration who generally possess good conduct but may become corrupt through interactions with corrupt individuals at a rate $(\beta + \theta)$. The immune compartment consists of individuals who are ethically strong from birth (practicing *Aparigraha*) at a rate $\Lambda(1 - \pi)$ and who are assumed never to engage in corruption.

Susceptible individuals increase at the birth rate $\Lambda\pi$, while immune individuals increase at the rate $\Lambda(1 - \pi)$. A susceptible individual becomes corrupt upon contact with corrupt individuals at the rate $(\beta + \theta)$. All individuals in the susceptible, corrupt, recovered, and immune compartments are subject to a natural removal rate μ. Corrupt individuals transition to the recovered class at the combined rate $(\alpha + \phi + \gamma)$. Individuals in the recovered compartment may return to the susceptible class due to behavioral relapse at the rate $(1 - \lambda)$, or they may acquire permanent immunity at the rate λ.

Behavioral estimation of the transmission rate. A key methodological contribution of this study is the formulation of the transmission rate β on the basis of observable behavioral factors associated with corruption. Existing corruption-transmission models commonly treat β as a fixed or abstract parameter. To provide a more empirically grounded representation, it is assumed that the growth of corruption at time t is proportional to the number of corrupt individuals:

$$\frac{dC}{dt} = \beta C, \beta = \frac{1}{t} \ln\left(\frac{C(t)}{C(0)}\right),$$

where β is defined as the *mathematical E-virus constant*. This expression allows β to be estimated directly from the initial corruption level $C(0)$ and the observed corruption level $C(t)$.

To relate this formulation to measurable behavioral characteristics, the corruption level $C(t)$ is expressed as

$$C(t) = \sum_{i=1}^{5} c_i,$$

where each c_i corresponds to a corruption-related behavioral trait:

i. c_1: financial dishonesty,

ii. c_2: unfaithfulness,

iii. c_3: lack of devotion to duty or delays in work for bribes or gifts,

iv. c_4: lack of punctuality,

v. c_5: misbehavior.

These greed-driven tendencies are collectively referred to as *mathematical E-viruses*. This behavioral decomposition of $C(t)$ provides a novel and operational mechanism for estimating the transmission rate β, thereby strengthening the empirical foundation of the corruption-dynamics model.

The model is formulated as a system of ordinary differential equations (ODEs). Figure 2 presents the compartmental flow diagram illustrating the transitions between the four compartments.

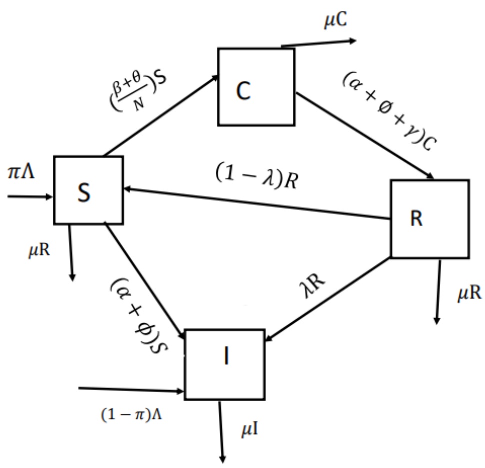


Figure 2: Corruption model flow diagram. Arrows indicate transitions between compartments.

The variables and parameters used in the model are defined in Table 1.

The governing equations of the model are developed as follows

$$\begin{aligned}
\frac{dS}{dt} &= \Lambda\pi + (1-\lambda)R - \frac{(\beta+\theta)}{N}SC - (\alpha+\phi)S - \mu S,\\
\frac{dC}{dt} &= \frac{(\beta+\theta)}{N}SC - \mu C - (\alpha+\phi+\gamma)C,\\
\frac{dR}{dt} &= (\alpha+\phi+\gamma)C - \mu R - (1-\lambda)R - \lambda R,\\
\frac{dI}{dt} &= \Lambda(1-\pi) + (\alpha+\phi)S + \lambda R - \mu I.
\end{aligned} \quad (1)$$

2.2. Estimation of parameters

Parameter values were selected based on a combination of literature estimates, demographic data, and reasonable modeling assumptions. Parameters such as the natural removal rate (μ) and recruitment rate (Λ) were derived from national demographic statistics. Behavioural transition rates (β, θ, γ) were guided by ranges used in related social–behavioural and corruption-transmission models. Parameters representing educational and moral interventions (α, ϕ, λ) have no direct empirical measurements and were therefore assigned plausible values consistent with qualitative observations.

While qualitative and macro-level empirical studies document the prevalence and drivers of corruption in Nepal, no individual-level longitudinal data are currently available to estimate key parameters such as the transmission rate β. To obtain preliminary behavioural insights, a small-scale intervention was conducted in Kailali across three offices using a questionnaire encompassing five greed-driven indicators. Based on these responses, β was estimated, while other parameter values used in the simulations were assumed. These values are intended primarily to explore the qualitative behaviour of the model rather than to provide precise empirical estimates. Future research should focus on systematic data collection to enable rigorous parameter calibration.

3. Results and discussion

3.1. Analysis of model properties

This section presents the derivation of the model's properties, the computation of the corruption reproduction number, the identification and stability analysis of equilibrium states, and the results of sensitivity and numerical simulations.

3.1.1. Positivity of the solution

The positivity and boundedness of the model must be verified to ensure that the system is mathematically and physically meaningful. The model is valid only when all solutions remain positive and bounded for all $t \geq 0$. To establish that system 1 is well-posed, it is shown that $S(t)$, $C(t)$, $R(t)$, and $I(t)$ remain nonnegative for all $t \geq 0$. This is done by isolating, in each equation, the terms involving the corresponding state variable, allowing the positivity of each compartment to be confirmed individually.

$$\begin{aligned}
\frac{dS}{dt} &\geq -\left(\frac{(\beta+\theta)}{N}C + (\alpha+\phi) + \mu\right)S,\\
\int_0^t \frac{dS}{S} &\geq \int_0^t -\left(\frac{(\beta+\theta)}{N}C + (\alpha+\phi) + \mu\right)dt,\\
\ln(S(t)) - \ln(S(0)) &\geq -(\alpha+\phi+\mu)t - \int_0^t \frac{(\beta+\theta)}{N}C\,dt,\\
S(t) &\geq S(0)e^{-(\alpha+\phi+\mu)t - \int_0^t \frac{(\beta+\theta)}{N}C\,dt} \geq 0, \forall t \geq 0
\end{aligned}$$

Similarly, we obtain the following positive solutions for the remaining compartments as

$$\begin{aligned}
C(t) &\geq C(0)e^{-(\alpha+\phi+\mu+\gamma)t} \geq 0, \quad \forall t \geq 0,\\
R(t) &\geq R(0)e^{-(\mu+1)t} \geq 0, \quad \forall t \geq 0,\\
I(t) &\geq I(0)e^{-\mu t} \geq 0, \quad \forall t \geq 0.
\end{aligned}$$

Thus, all state variables remain nonnegative for all $t \geq 0$, confirming the positivity of the solutions.

3.1.2. Boundedness of the solution

To establish boundedness, all equations in system 1 are summed, and upon simplification, the following expression is obtained

$$\frac{dN}{dt} = \Lambda - \mu N,$$

Table 1: Model parameters, baseline numeric values, and supporting literature.

Parameter	Definition	Value	Citation
β	Greed-driven corruption transmission rate	0.2- 0.06 month^{-1}	Estimated
θ	Poverty-driven corruption transmission rate	0.02 0.06 month^{-1}	Assumed according to World Bank (2010); Transparency Int'l (2023) and [14, 15]
γ	Natural behavioral recovery rate	0.08 month^{-1}	Assumed according to [6]
α	Reduction due to mass education	0.02- 0.06 month^{-1}	Assumed
ϕ	Effect of Yogachara(Aparigraha) moral training	0.02 - 0.06 month^{-1}	Assumed
π	Fraction not born immune to corruption	0.02 - 0.80	Estimated based on [14, 15]
Λ	Recruitment rate of individuals	10 -50 month^{-1}	Assumed based on UN Population Division (2022) and [14, 15]
μ	Natural removal rate	0.0012 month^{-1}	Assumed based on WHO Life Expectancy Data (2022) and [14, 15]
λ	Recovered $\to$ immune rate	0.02 -0.050	Assumed based on [14, 15]

which gives

$$\frac{dN}{dt} + \mu N = \Lambda.$$

Integrating, we get

$$N(t) = \frac{\Lambda}{\mu} + \left(N(0) - \frac{\Lambda}{\mu}\right) e^{-\mu t}.$$

This implies that

$$N(t) \leq \max\left\{\frac{\Lambda}{\mu}, N(0)\right\}.$$

Hence, if $N(0) \leq \frac{\Lambda}{\mu}$, then $N(t) \leq \frac{\Lambda}{\mu}$ for all $t \geq 0$. Therefore, the feasible region of the system is given by

$$\Omega = \{(S, C, R, I) \in \mathbb{R}^4_+ : N(t) \leq \frac{\Lambda}{\mu}\}. \tag{2}$$

This shows that system 1 is bounded and possesses solutions that remain within the region Ω. Consequently, the system 1 is mathematically meaningful and suitable for further analysis.

3.2. Corruption-free equilibrium (CFE)

The corruption-free equilibrium (CFE) represents a state in which the population is entirely free of corruption, consisting only of susceptible and immune individuals. To determine this equilibrium, the right-hand side of system 1 is set to zero, following [16]. The resulting algebraic system of equations for the corruption-free equilibrium point(s) are

$$\begin{aligned}
\Lambda\pi + (1-\lambda)R - \left(\frac{\beta+\theta}{N}\right) SC - (\alpha+\phi)S - \mu S &= 0, \\
\left(\frac{\beta+\theta}{N}\right) SC - \mu C - (\alpha+\phi+\gamma)C &= 0, \\
(\alpha+\phi+\gamma)C - \mu R - (1-\lambda)R - \lambda R &= 0, \\
\Lambda(1-\pi) + (\alpha+\phi)S + \lambda R - \mu I &= 0
\end{aligned} \tag{3}$$

Solving 3 gives the corruption-free equilibrium (CFE) $= (S, 0, 0, I)$, expressed as

$$(S, 0, 0, I) = \left(\frac{\Lambda\pi}{\alpha+\phi+\mu},\ 0,\ 0,\ \frac{\Lambda(1-\pi)(\alpha+\phi+\mu) + \Lambda\pi(\alpha+\phi)}{\mu(\alpha+\phi+\mu)}\right).$$

3.3. Corruption reproduction number

The reproduction number measures the average number of individuals who adopt corrupt practices after a single corrupt individual enters a fully susceptible population, without control measures. The corruption reproduction number R_e accounts for interventions (mass education and Yogachara). Corruption persists if $R_e > 1$, is controlled if $R_e < 1$, and $R_e = 1$ marks a critical threshold. Key factors include the probability of corruption, duration of involvement, and interaction frequency. Stochastic fluctuations may allow corruption even when $R_e < 1$ [7, 16, 17] . From system 1, the corrupt class satisfies

$$\frac{dC}{dt} = \left(\frac{\beta+\theta}{N}\right) SC - \mu C - (\alpha+\phi+\gamma)C, \tag{4}$$

with $N = S + C + R + I$.

$$\mathcal{F} = \left(\frac{\beta+\theta}{N}\right) SC,$$
$$\mathcal{V} = (\mu+\alpha+\phi+\gamma)C.$$

The corresponding Jacobian entries are

$$F = \frac{\partial \mathcal{F}}{\partial C} = \frac{\beta+\theta}{S+C+R+I} S - \frac{\beta+\theta}{(S+C+R+I)^2} SC,$$
$$V = \frac{\partial \mathcal{V}}{\partial C} = \mu+\alpha+\phi+\gamma.$$

At the corruption-free equilibrium (CFE), we have $C^* = 0, R^* = 0$, and $S^*, I^* \neq 0$, giving $N^* = S^* + I^*$. Substituting into F gives

$$F = \frac{\beta+\theta}{S^*+I^*} S^*.$$

From the equilibrium conditions, we obtain

$$S^* = \frac{\pi\mu}{\alpha+\phi+\mu}.$$

Therefore,

$$F = \frac{(\beta+\theta)\pi\mu}{\alpha+\phi+\mu},$$
$$V^{-1} = \frac{1}{\mu+\alpha+\phi+\gamma}.$$

Finally, using the next-generation matrix method, the corruption reproduction number is given by

$$R_e = FV^{-1} = \frac{(\beta+\theta)\pi\mu}{(\alpha+\phi+\mu)(\mu+\alpha+\phi+\gamma)}. \tag{5}$$

It can also be expressed as

$$R_e = \frac{(\beta+\theta)S^*}{N(\mu+\alpha+\phi+\gamma)}.$$

$$R_c = \frac{(\beta+\theta)s^*}{\mu+\alpha+\phi+\gamma}, \qquad \text{where } s^* = \frac{S^*}{N}.$$

Equation 5 shows that the effective reproduction number R_e depends on corruption driven by poverty (θ) and greed (β), relative to preventive measures—mass education (α), Yogachara (ϕ), and the natural removal rate (μ). When these forces dominate, $R_e > 1$ and corruption persists; increasing α or ϕ (with other factors constant) reduces R_e below unity, preventing sustained corruption. In summary, $R_e > 1$ implies corruption is self-sustaining, $R_e < 1$ implies corruption declines, and $R_e = 1$ implies corruption persists at a steady level.

3.4. Stability analysis

3.4.1. Local stability analysis at the corruption-free equilibrium

Theorem 1. *The corruption-free equilibrium (CFE) of system 1 is locally asymptotically stable if $R_e < 1$ and unstable if $R_e > 1$.*

Proof. The local stability of the equilibrium is assessed by linearizing system 1 and computing the Jacobian matrix with respect to the state variables S, C, R, and I. The equilibrium is locally stable if all eigenvalues of the Jacobian have negative real parts; otherwise, it is unstable.

Let us denote the model equations as functions

$$\begin{aligned}
A &= \Lambda\pi + (1-\lambda)R - \left(\frac{\beta+\theta}{N}\right)SC - (\alpha+\phi)S - \mu S,\\
B &= \left(\frac{\beta+\theta}{N}\right)SC - \mu C - (\alpha+\phi+\gamma)C,\\
P &= (\alpha+\phi+\gamma)C - \mu R - (1-\lambda)R - \lambda R,\\
Q &= \Lambda(1-\pi) + (\alpha+\phi)S + \lambda R - \mu I,
\end{aligned}$$

where $N(t) = S(t) + C(t) + R(t) + I(t)$.

The Jacobian matrix evaluated at the corruption-free equilibrium (CFE) is

$$\mathbf{J_0} = \begin{bmatrix} \frac{\partial A}{\partial S} & \frac{\partial A}{\partial C} & \frac{\partial A}{\partial R} & \frac{\partial A}{\partial I} \\ \frac{\partial B}{\partial S} & \frac{\partial B}{\partial C} & \frac{\partial B}{\partial R} & \frac{\partial B}{\partial I} \\ \frac{\partial P}{\partial S} & \frac{\partial P}{\partial C} & \frac{\partial P}{\partial R} & \frac{\partial P}{\partial I} \\ \frac{\partial Q}{\partial S} & \frac{\partial Q}{\partial C} & \frac{\partial Q}{\partial R} & \frac{\partial Q}{\partial I} \end{bmatrix}.$$

At the CFE, $N = S + I = \frac{\Lambda}{\mu}$ and $S_0 = \frac{\pi\mu}{\alpha+\phi+\mu}$. Hence, the Jacobian becomes

$$\mathbf{J_0} = \begin{bmatrix} -(\alpha+\phi+\mu) & -\frac{(\beta+\theta)\pi\mu}{\alpha+\phi+\mu} & 1-\lambda & 0 \\ 0 & \frac{(\beta+\theta)\pi\mu}{\alpha+\phi+\mu} - (\mu+\alpha+\phi+\gamma) & 0 & 0 \\ 0 & \alpha+\phi+\gamma & -(1+\mu) & 0 \\ \alpha+\phi & 0 & \lambda & -\mu \end{bmatrix}$$

The characteristic polynomial is a fourth-degree equation with eigenvalues

$$K_1 = -\mu, \quad K_2 = -(\alpha+\phi+\mu), \quad K_3 = -(1+\mu),$$

$$K_4 = \frac{(\beta+\theta)\pi\mu}{\alpha+\phi+\mu} - (\mu+\alpha+\phi+\gamma).$$

Clearly, K_1, K_2, and K_3 are negative. K_4 is negative if and only if

$$\begin{aligned}
&\frac{(\beta+\theta)\pi\mu}{\alpha+\phi+\mu} < \mu+\alpha+\phi+\gamma,\\
\Rightarrow\quad &\frac{(\beta+\theta)\pi\mu}{(\alpha+\phi+\mu)(\mu+\alpha+\phi+\gamma)} < 1,\\
&\Rightarrow\quad R_e < 1.
\end{aligned}$$

Thus, all eigenvalues of $\mathbf{J_0}$ are negative if $R_e < 1$, implying that the CFE is locally asymptotically stable. Conversely, if $R_e > 1$, the CFE is unstable. □

3.5. Global stability analysis at the corruption-free equilibrium

Lyapunov Stability Theorem

The Lyapunov Stability Theorem analyzes equilibrium stability in dynamical systems, particularly nonlinear ones, via a Lyapunov function, which serves as an energy-like measure [18].

Theorem 2. *Consider $\dot{x} = f(x)$, $x \in \mathbb{R}^n$, with $f(0) = 0$. Let $V : \mathbb{R}^n \to \mathbb{R}$ be continuously differentiable, $V(x) > 0$ for $x \neq 0$, $V(0) = 0$, and $\dot{V}(x) = \nabla V \cdot f(x) \leq 0$ near $x = 0$. Then $x = 0$ is Lyapunov stable if $\dot{V}(x) \leq 0$, asymptotically stable if $\dot{V}(x) < 0$ for $x \neq 0$, and globally asymptotically stable if $V(x) \to \infty$ as $\|x\| \to \infty$.*

LaSalle's Invariance Principle

Theorem 3. *Let $V(x)$ be positive definite in a region D with $\dot{V}(x) \leq 0$. Define $C = \{x \in D : \dot{V}(x) = 0\}$ and let M be the largest invariant set in C. Then all trajectories starting in D converge to M.*

□

Theorem 4. *The corruption-free equilibrium (CFE) is globally asymptotically stable if $R_e < 1$ and unstable if $R_e > 1$.*

Proof. Using LaSalle's Invariance Principle, let $V = \frac{1}{2}C^2$. Then

$$\frac{dV}{dt} = C\frac{dC}{dt} = C^2\left[(\beta+\theta)\frac{S}{N} - (\mu+\alpha+\phi+\gamma)\right].$$

Substituting $S = \pi\mu/(\alpha+\phi+\mu)$ and simplifying yields

$$\frac{dV}{dt} = C^2\frac{(\beta+\theta)\pi\mu}{\alpha+\phi+\mu}\left(1 - \frac{1}{R_e}\right).$$

Hence, $\frac{dV}{dt} \leq 0$ for $R_e < 1$, establishing global asymptotic stability of the CFE, and $\frac{dV}{dt} > 0$ for $R_e > 1$, implying instability. □

3.6. Stability analysis at the corruption-persistent equilibrium (CPE)

The corruption-persistent equilibrium (CPE), where corruption persists at a steady level, represents the steady-state solution of the model with all compartments strictly positive. Setting the right-hand sides of system 1 to zero, we solve for S^*, C^*, R^*, and I^* to determine conditions for endemic persistence and assess the impact of interventions.

$$\begin{aligned}
\Lambda\pi + (1-\lambda)R - \frac{\beta+\theta}{N}SC - (\alpha+\phi)S - \mu S &= 0,\\
\frac{\beta+\theta}{N}SC - (\mu+\alpha+\phi+\gamma)C &= 0,\\
(\alpha+\phi+\gamma)C - (1+\mu)R &= 0,\\
\Lambda(1-\pi) + (\alpha+\phi)S + \lambda R - \mu I &= 0,
\end{aligned} \tag{6}$$

where $N = S + C + R + I$.

The corresponding equilibrium values are

$$R^* = \frac{N}{\beta+\theta}\cdot\frac{(\mu+\alpha+\phi+\gamma)(\alpha+\phi+\mu)-(\beta+\theta)\lambda\pi}{(\mu+\alpha+\phi+\gamma)(1+\mu)-(\alpha+\phi+\gamma)(1-\lambda)},$$

$$C^* = \frac{1+\mu}{\alpha+\phi+\gamma}R^*,$$

$$S^* = \frac{\mu+\alpha+\phi+\gamma}{\beta+\theta}N,$$

$$I^* = \frac{1}{\mu}\Big[\Lambda(1-\pi)+(\alpha+\phi)S^*+\lambda R^*\Big].$$

Thus, the equilibrium (S^*, C^*, R^*, I^*) represents a *corruption-persistent equilibrium*, where all compartments remain positive under the given parameter values.

Theorem 5. *Let $E^* = (S^*, C^*, R^*, I^*)$ denote the corruption-persistent equilibrium of system 1. Then E^* is globally asymptotically stable in the feasible region*

$$\Omega = \{(S, C, R, I) \in \mathbb{R}^4_+ \mid S, C, R, I \geq 0\},$$

if the corruption reproduction number satisfies

$$R_e = \frac{(\beta+\theta)S^*}{\mu+\alpha+\phi+\gamma} \geq 1.$$

Proof. We construct the following Lyapunov function

$$U(S, C, R, I) = \sum_{i=1}^{4} a_i\Big(X_i - X_i^* - X_i^*\ln\frac{X_i}{X_i^*}\Big),$$

where $X_1 = S, X_2 = C, X_3 = R, X_4 = I$ and $a_i > 0$ are positive constants.

The derivative along system trajectories is

$$\frac{dU}{dt} = \sum_{i=1}^{4} a_i\left(1-\frac{X_i^*}{X_i}\right)\dot{X}_i.$$

Substituting $\dot{S}, \dot{C}, \dot{R}, \dot{I}$ from 1 and simplifying, we obtain

$$\frac{dU}{dt} = -a_1(\alpha+\phi+\mu)(S-S^*)^2 - a_2(\mu+\alpha+\phi+\gamma)(C-C^*)^2 - a_3(1+\mu)(R-R^*)^2 - a_4\mu(I-I^*)^2 \leq 0.$$

Equality holds if and only if $(S, C, R, I) = (S^*, C^*, R^*, I^*)$. By Theorem 3 , all trajectories in Ω converge to the largest invariant set where $\dot{U} = 0$, i.e., the corruption-persistent equilibrium E^*.

Hence, E^* is globally asymptotically stable if $R_e \geq 1$. □

3.7. Sensitivity analysis

3.7.1. Analytical insights into the corruption reproduction number

Sensitivity analysis quantifies the impact of each model parameter on the corruption reproduction number R_e, helping to identify the most influential parameters for effective intervention. We employ the *normalized forward sensitivity index*, defined as

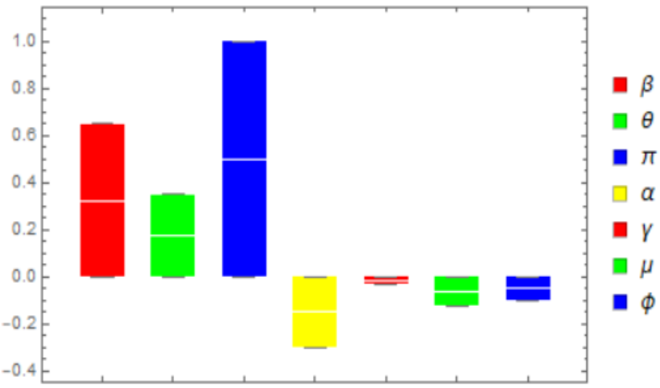
$$T_z^{R_e} = \frac{\partial R_e}{\partial z}\cdot\frac{z}{R_e},$$

where z is a model parameter. The indices are given in Table 2 and they are computed using baseline values listed in Table 1.

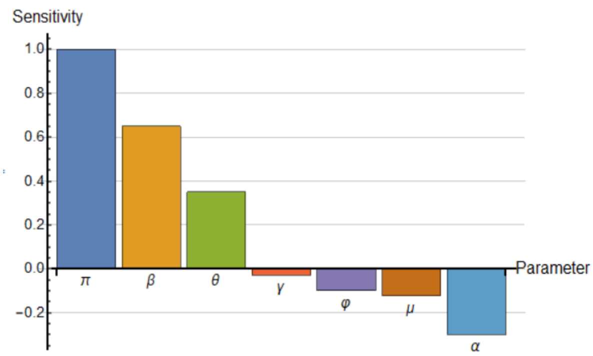
Negative sensitivity indices indicate that increasing the parameter reduces R_e and helps control corruption, while positive indices indicate that increasing the parameter elevates R_e, promoting corruption. The most negatively sensitive parameters are α and ϕ (mass education and ethical interventions), whereas π and β (poverty and greed-driven motives) show the strongest positive influence.

Table 2: Sensitivity indices of R_e with respect to model parameters.

Parameter	Sensitivity index
π	$+1.00$
β	$+0.65$
θ	$+0.35$
α	-0.30
ϕ	-0.10
μ	-0.123
γ	-0.03



(a) Box plot of sensitivity indices.



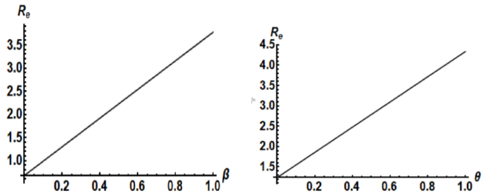
(b) Bar chart of sensitivity indices

Figure 3: Sensitivity analysis of model parameters: (a) box plot and (b) bar chart.

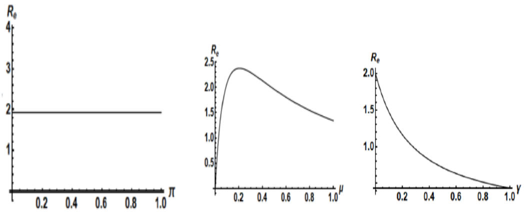
Variation of the corruption reproduction number

Figures 4a, 4b and 4c illustrate how the corruption reproduction number varies with respect to key model parameters. As the corruption transmission parameters increase, the reproduction number rises accordingly, indicating a heightened potential for corruption to spread within the population. In contrast, parameters associated with recovery, education, and ethical interventions reduce the reproduction number, reflecting their stabilizing influence on the system. These trends highlight the relative importance of both preventive and corrective measures in controlling corruption dynamics.

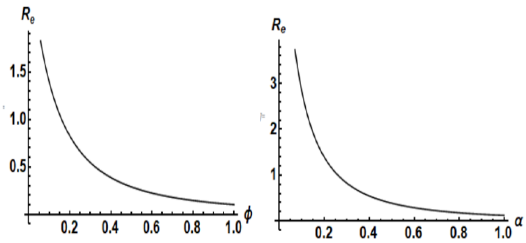
These results highlight that an effective approach to corruption control requires combining social strategies, such as mass education and ethical awareness, with economic interventions like



(a) Sensitivity indices of $R_e(\beta, \theta)$.



(b) Sensitivity indices of $R_e(\pi, \mu, \gamma)$



(c) Sensitivity indices of $R_e(\phi, \alpha)$

Figure 4: Sensitivity analysis of the effective reproduction number R_e with respect to model parameters

poverty alleviation.

3.8. Numerical simulations and results

3.8.1. Dynamics of the model in the absence of control measures

The model was simulated using the parameter values listed in Table 1. Initially, the simulation was performed in the absence of control measures by setting $\alpha = 0$ and $\phi = 0$, while all other parameters were maintained at their baseline values. The outcomes of this simulation are presented in Figure 5.

Figure 5 shows that the susceptible population initially declines due to the combined effects of the high corruption contact rate $(\beta+\theta)$ and the natural removal rate μ. This is followed by a gradual increase in the susceptible population driven by the recovery rate $(1 - \lambda)$. The number of corrupt individuals rises sharply during the early phase, reflecting the influence of heightened greed and poverty on engagement in corrupt activities. After approximately $t = 100$ days, the corrupt population either stabilizes or begins to decline as individuals leave the corrupt class or recover through natural self-correction mechanisms.

In Figure 5, the number of corrupt individuals exceeds that of susceptibles during the early stage of the simulation. This is primarily due to the high corruption contact rate $(\beta + \theta)$, which facilitates rapid conversion of susceptible individuals into the corrupt class. Additionally, the recovery rate $(1 - \lambda)$ is relatively low,

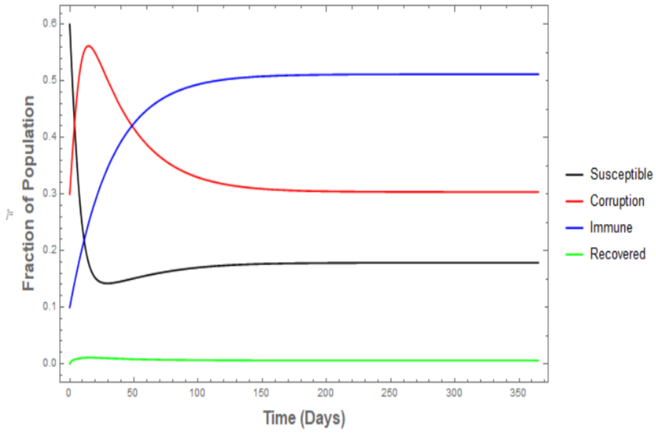


Figure 5: Corruption dynamics in the absence of control strategies.

so individuals leave the corrupt class slowly, allowing the corrupt population to accumulate. The initial conditions, combined with the natural removal rate μ, further contribute to this early dominance of corruption. Such behavior is consistent with epidemic-type models, where the “infection” spreads faster than recovery in the absence of control interventions.

Figure 6 illustrates that the number of immune individuals initially increases due to the birth rate and remains approximately constant after $t = 100$ days. Recovered individuals increase from $t = 0$ to $t = 50$ due to natural recovery but subsequently decline to zero, as some move to the immune class at rate λ and others return to the susceptible class at rate $(1 - \lambda)$, consistent with the assumption of temporary immunity.

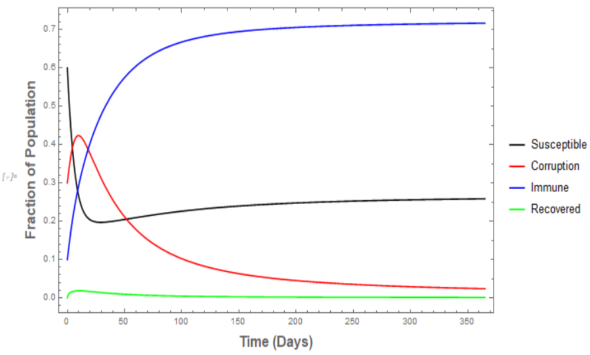
3.8.2. Simulation of the model under control measures

Impacts of mass education against corruption. The impact of mass education was examined using the parameter values presented in Table 1. Figures 6a and 6b demonstrate that increasing the rate of educational interventions aimed at raising awareness of the detrimental effects of corruption leads to a notable reduction in the number of corrupt individuals. These findings indicate that enhanced governmental investment in educational programs can play a critical role in mitigating corruption. Integrating corruption awareness and ethics education across all levels of the academic curriculum may further strengthen societal resilience against corrupt practices.

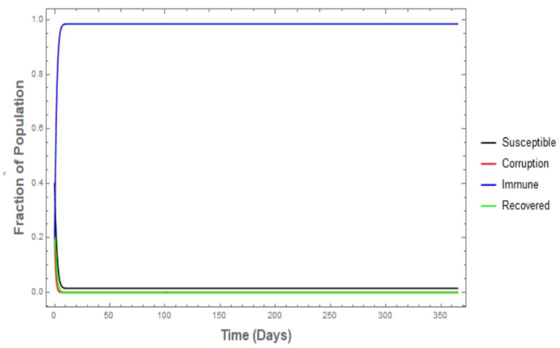
Around $t = 100$ days, the number of corrupt individuals either stabilizes or begins to decline, reflecting the sustained effectiveness of educational interventions. At the same time, the proportion of immune individuals increases, contributing to long-term corruption control. Moreover, Figure 6b shows that the combined implementation of mass education and Yogācāra ethical principles (Aparigraha ethics) yields a more rapid and pronounced reduction in corruption compared to either intervention applied in isolation.

Impacts of Yogachara against corruption. Figure 7a illustrates the impact of mass education on corruption control, showing that increased educational efforts enhance public awareness of corrupt practices and contribute to their reduction. Similarly, Figure 7b demonstrates that higher rates of Aparigraha-based ethical teachings delivered by Yoga Sādhaka leaders lead to a decline in the number of corrupt individuals. The model assumes that most followers place substantial trust in these leaders; therefore, their active engagement in anti-corruption initiatives is strongly recommended.

These results suggest that promoting ethical and value-based education through trusted community figures can serve as an effective strategy for mitigating corruption. Notably, the prevalence of

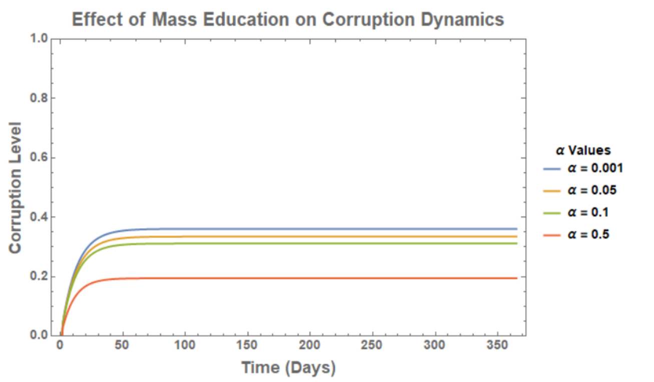


(a) Mass education

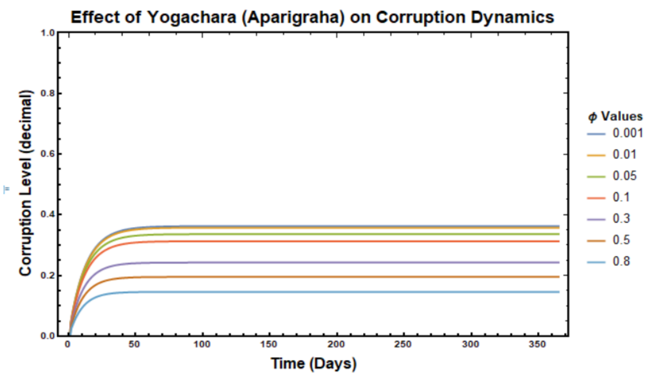


(b) Mass education and Yogācāra ethical principles (Aparigraha ethics)

Figure 6: Corruption dynamics under control measures.



(a) Variation with α



(b) Variation with ϕ

Figure 7: Dynamics of corrupt individuals under varying rates of mass education (α) and Yogachara teaching (ϕ).

corruption begins to decrease at approximately $t = 50$ days, indicating a plausible timeframe for the observable impact of such interventions.

Simulations assessing the combined effect of mass education and Yogācāra teachings show that increased educational interventions reduce the number of corrupt individuals (Figures 4a–6b). By around $t = 100$ days, the corrupt population stabilizes or declines, while the proportion of immune individuals rises, supporting overall community-level control of corruption. These trends are consistently observed in Figures 4a–4c and 7a–7b.

4. Conclusion

This study presents a mathematical framework for understanding corruption dynamics and provides insights that can inform governmental initiatives in Nepal aimed at mitigating corruption. Analytical results based on the corruption reproduction number, R_e, indicate that R_e is directly influenced by the parameters $\alpha, \beta, \theta, \phi$, π, γ, and μ. In particular, β and θ, representing the transmission rate from susceptible to corrupt individuals, positively impact corruption prevalence; higher values result in $R_e > 1$ and the persistence of corruption. Conversely, parameters α and ϕ, corresponding to mass education and Yogācāra teachings, respectively, contribute to reducing R_e. When these parameters are sufficiently increased while others remain constant, $R_e < 1$, leading to effective control of corruption within the community.

These findings underscore the importance of investing in mass education programs and promoting Yogācāra teachings through Yoga Sādhaka leaders, as these interventions can influence followers' behavior and reduce engagement in corrupt practices. The analysis further demonstrates that the corruption-free equilibrium is globally asymptotically stable when $R_e < 1$, whereas it becomes unstable when $R_e > 1$, allowing corruption to persist. Although complete eradication of corruption may be challenging, its prevalence can be reduced to levels that do not significantly impede economic development.

Beyond educational and ethical interventions, broader socio-economic measures—such as poverty reduction and ensuring adequate public sector wages—can further discourage corrupt behavior among citizens and public officials. While the Commission for the Investigation of Abuse of Authority (CIAA) has made significant efforts to combat corruption in Nepal, the results of this study suggest that enhanced focus on education and the strategic engagement of Yoga Sādhaka leaders could further strengthen these efforts, given their strong cultural and religious influence within Nepalese society.

References

[1] Nathan O M & Jackob K O, Stability analysis in a mathematical model of corruption in Kenya, *Asian Research Journal of Mathematics* (2019) 1–15. ISSN 2456-477X. https://doi.org/10.9734/arjom/2019/v15i430164.

[2] Gould D & Amaro-Reyes J. *The effects of corruption on administrative performance: illustrations from developing countries*. No. v. 1 in The Effects of Corruption on Administrative Performance: Illustrations from Developing Countries. World Bank (1983). ISBN 9780821302590. URL https://books.google.com.np/books?id=UArsAAAAMAAJ.

[3] Akça H, Yılmaz A & Karaca C, Inflation and corruption relationship: Evidence from panel data in developed and developing countries, *International Journal of Economics and Financial Issues*, 2. URL https://www.econjournals.com/index.php/ijefi/article/view/234.

[4] Bibek D, Laveesh B, Anklesaria A S S & Ashok G. Economic freedom of the states of India 2013 (2014). URL https://www.cato.org/sites/cato.org/files/economic-freedom-india-2013/economic-freedom-states-of-india-2013.pdf.

[5] Abdulrahman S, Stability analysis of the transmission dynamics and control of corruption, *Pacific Journal of Science and Technology*, 15(1) (2014) 99–113. URL https://api.semanticscholar.org/CorpusID:214589671.

[6] Binuyo A O, Eigenvalue elasticity and sensitivity analyses of the transmission dynamic model of corruption, *Journal of the Nigerian Society of Physical Sciences* (2019) 30–34. ISSN 2714-2817. https://doi.org/10.46481/jnsps.2019.6.

[7] Danford O, Kimathi M & Mirau S, Mathematical modelling and analysis of corruption dynamics with control measures in Tanzania, *Journal of Mathematics and Informatics*, 19 (2020) 57–79. ISSN 2349-0640. https://doi.org/10.22457/jmi.v19a07179.

[8] Ekomwenrenren I & Ekuobase G, Curbing corruption in Nigeria using service innovation, *A Multidisciplinary Journal Publication of the Faculty of Science, Adeleke University*, 2(2) (2015) 103–114. URL https://api.semanticscholar.org/CorpusID:157544463.

[9] Simo-Kengne B D & Bitterhout S, The effect of corruption on economic growth in the BRICS countries: A panel data analysis, *Journal of Economics, Finance and Administrative Science*, 28(56) (2020) 257–272. ISSN 2077-1886. URL https://api.semanticscholar.org/CorpusID:220845101.

[10] Miller B S. *Yoga: Discipline of Freedom: The Yoga Sutra attributed to Patanjali*. University of California Press (1996). ISBN 9780520916753. https://doi.org/10.1525/9780520916753.

[11] Sudha H S, Rani D P J, Jain, Preeti D & Jain R. Aparigraha: The jain philosophy of non-possession and its ethical implications in fostering minimalism and sustainable practices. URL https://api.semanticscholar.org/CorpusID:270098898.

[12] Bali A, Kachwala T & Sivaramakrishnan S, Aparigraha - is it good for organisations, *International Journal of Management Concepts and Philosophy*, 12(3) (2019) 360. ISSN 1741-8135. https://doi.org/10.1504/ijmcp.2019.100688.

[13] Waykar S R, Mathematical modelling: A way of life, *International Journal of Scientific & Engineering Research*, 4(4) (2013) 1336–1352. URL https://api.semanticscholar.org/CorpusID:265991733.

[14] Gupta A K, Adhikari S H & Shrestha G L, Corruption in Nepal: Level, pattern and trend analysis, *Journal of Management and Development Studies*, 28 (2018) 36–52. ISSN 2392-4888. https://doi.org/10.3126/jmds.v28i0.24957.

[15] Parajuli C, Corruption trend analysis and problem in Nepal. https://doi.org/10.5281/ZENODO.8372190.

[16] Athithan S, Ghosh M & Li X Z, Mathematical modeling and optimal control of corruption dynamics, *Asian-European Journal of Mathematics*, 11(06) (2018) 1850090. ISSN 1793-7183. https://doi.org/10.1142/s1793557118500900.

[17] Eguda F, Oguntolu F & Ashezua T, Understanding the dynamics of corruption using mathematical modeling approach, *International Journal of Innovative Science, Engineering & Technology*, 4(8) (2017) 190–197. URL https://api.semanticscholar.org/CorpusID:260340637.

[18] Bitsoris G. *Stability and Lyapunov Theory*. Springer Nature Switzerland (2025). ISBN 9783031762208, pp. 9–37. https://doi.org/10.1007/978-3-031-76220-8_2.