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Controlling the Spread of Corruption through Social Media: A Mathematical Modelling Approach

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Abstract: *In this paper, corruption is treated as an infection that spreads through social interactions. We developed and analyzed a new mathematical model of corruption in a population with constant recruitment rate, incorporating standard incidence rate, effort rate against corruption andeffect of the embarrassment faced by corrupt individuals due tosocial media freedom, which makes some corrupt individuals temporarily quit corruption. The effective reproduction number and its values are computed using four different control strategies. Results showed that if at least 40% of the corrupt individuals are embarrassed on social media, corruption can be significantly controlled. This may not be a short time effect but will take years to be achieved. A feasible solution to the control of corruption is suggested, i.e a 50% coverage rate of each ofeffort rate against corruption, social media freedom, and embarrassing corrupt individuals on social media. These effects are sizable making them effective tools against corruption.*
Keywords: *Corruption, Effective Reproductive Number, Mathematical Model, Recruitment Rate, Social Media.*

I. Introduction

The term ‘corruption’ overlaps with a wide field of neighbouring concepts such as bribery, campaign finance abuse, cronyism, fraud, embezzlement, extortion, graft, kickbacks, machine politics, misappropriation, misconduct, nepotism, patronage, pork, rent-seeking, scandal, side payments, special interest politics, theft and venality. Indeed, corruption is frequently employed as a generic label for any sort of failure on the part of politics or politicians [1].In a system with corruption, there is no quality of service. To worsen the condition further, those involved in corruption are able to get better promotions and opportunities.

According to [2], corruption is the act of an official or fiduciary person who unlawfully and wrongfully uses his station or character to procure some benefit for himself or for another person, contrary to duty and the rights of others.Political corruption is the abuse of public power, office, or resources by elected government officials for personal gain, by extortion, soliciting or offering bribes. It can also take the form of office holders maintaining themselves in office by purchasing votes and enacting laws which use taxpayers' money. Evidence suggests that corruption can have political consequences – withcitizens being asked for bribes becoming less likely to identify with their country or region [3].

Frequent use of social media has empowered individuals with great tool that enhances their active involvement in political process thereby facilitating communication and mobilization on social issues, and strengthening an emergent civil society [4], [5]. [6]argue that a free press reduces the cost of fighting corruption and show that the countries, where the press enjoys greater freedom, are less corrupt.

[7]carried out a survey on the corruption levels of 90 countries, including Kenya, Cameroon, Angola, Nigeria, Côte-d'Ivoire, Zimbabwe, Ethiopia, Ghana, Senegal, Zambia, India, Venezuela, Moldova, and others. At the end of the ranking, Nigeria was seen as the most corrupt in that ranking because the country occupied the 90th position in terms of transparency. In the year 2015, out of the 168 countries surveyed, Nigeria was seen at the bottom of the table in the category of number 136. This implies that Nigeria was the 32nd most corrupt country in the world in 2015 [8].

Corruption in Nigeria wears many kinds of unattractive and dirty clothes. The situation has made so many people feel a lot of pains as the money which would have been used to reduce poverty in the country are being channeled into the pockets of small group of persons.

In this paper, a new mathematical model of corruption transmission dynamics is developed and analysed to complement and extend the work of [9] by incorporating the effect of social media freedom by creating two additional compartments. The argument here is that social media too act as external control of corruption and help reduce the cost of fighting corruption in several ways.

Firstly, larger internet penetration and the spread of social media would mean a larger audience for the victims of extortive corruption who wish to share the incident of corruption. This will be embarrassing to corrupt individuals. Secondly, the internet and other social media provide cheap and speedy means of sharing information and reaching a larger audience to organize public protests against the corrupt activities of the government officials and politicians. Thirdly, social media can be used to provide electronic-government, or in short, e-government services which eliminate the need of direct interaction between the citizens and public officials, reducing the scope of bribe demand [10], [11].

II. Materials And Methods

2.1 Model Development

In this model, the total population (N) is divided into six (6) classes of Susceptible individuals that are not exposed to social media (S_N), Susceptible individuals that are exposed to social media (S_E), Corrupt individuals (C), Jailed individuals (J), Semi-honest individuals (H_S) and the Honest individuals (H). In the construction of the model, we assumed that:

i. Any act that is not capable of causing an economic damage to the development of a country is not considered corruption.
ii. Social interaction plays a significant role in the spread of corruption.
iii. A susceptible individual has never been engaged in any level of corruption to an extent that it causes an economic damage to the development of his country.
iv. An honest individual will never be corrupt no matter the situation he finds himself.
v. A semi-honest individual will temporarily quit corruption due to the effect of social media.

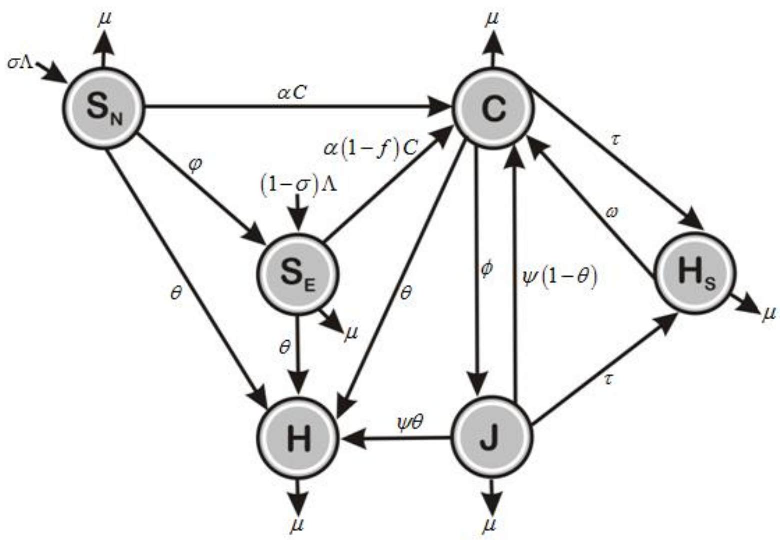

Figure 1: Schematic Diagram of the Model

The S_N class is generated from the daily recruitment of individuals through birth and immigration at the rate Λ where σ is the proportion of susceptible that are not yet exposed to social media.When they become exposed to social media,they leave the class to S_E class at the rate φ. Individuals in S_N and S_E then interact with individuals in class C and acquire infection at the rate $\alpha(1-e)$ and thus become corrupted where $\alpha = \frac{pC}{N}$ and p is the probability of being corrupt.The social media usage rate is defined by f. Individuals in the S_N, S_E, C or J classes become honest due to public enlightenment (through moral and/or religious means) on the danger of corruption on the economy at the rate θ. Corrupt individuals are caught and imprisoned at the rate ϕ. Jailed individuals stay in prison for an average period of $\frac{1}{\psi}$, after which a proportion θ become honest while $1-\theta$ go back to the corrupt class.

Due to the effect of social media (i.e exposing the corrupt individuals, leading to embarrassment), some corrupt or jailed individuals may decide to quit corruption temporarily and become semi-corrupt in the class

H_S at the rate τ due to the embarrassment from social media.Natural death occurs in all the classes at a rate μ .See fig 1.

The model variables and parameters are described below:

$S_N(t)$ Number of susceptible individuals at time (t) that are not exposed to social media

$S_E(t)$ Number of susceptible individuals at time (t) that are exposed to social media

$C(t)$ Number of corrupt individuals at time (t)

$J(t)$ Number of jailed individuals at time (t)

$H_S(t)$ Number of semi-honest individuals at time (t)

$H(t)$ Number of honest individuals at time (t)

p Probability of becoming corrupt when a susceptible individual interact with corrupt individuals

e Effort rate against corruption

φ The rate at which susceptible individuals that are not exposed to social media become exposed to social media

Λ Recruitment number

σ Proportion of recruited individuals that are not exposed to social media

f Social media freedom rate

θ Rate at which individuals in S_N, S_E, C or J compartments become honest

ψ Proportion of jailed individuals that become honest

ϕ Rate at which corrupt individuals are jailed

τ The rate at which corrupt or jailed individuals become embarrassed

ω Waning rate of embarrassment

μ Natural death rate

The corresponding mathematical equations of the schematic diagram can be described by a system of Ordinary Differential Equations (ODEs) given below:

$$\left.\begin{aligned}
\frac{dS_N}{dt} &= \sigma\Lambda - \frac{p\vartheta C S_N}{N} - k_1 S_N \\
\frac{dS_E}{dt} &= \varepsilon_1\Lambda - \frac{p\vartheta\gamma C S_E}{N} + \varphi S_N - k_2 S_E \\
\frac{dC}{dt} &= \frac{p\vartheta C S_N}{N} + \frac{p\vartheta\gamma C S_E}{N} + \psi\varepsilon_2 J + \omega H_S - k_3 C \\
\frac{dJ}{dt} &= \phi C - k_4 J \\
\frac{dH_S}{dt} &= \tau\left(C + J\right) - k_5 H_s \\
\frac{dH}{dt} &= \theta\left(S_N + S_E + C + \psi J\right) - \mu H
\end{aligned}\right\} \quad (1)$$

.

where

$$\left.\begin{aligned}
N &= S_N + S_E + C + J + H_S + H \\
\alpha &= \frac{p\left(1-e\right)}{N}
\end{aligned}\right\} \qquad (2)$$

And

$$\left.\begin{array}{ll} \gamma = 1 - f, & k_1 = \theta + \varphi + \mu \\ \vartheta = 1 - \tau, & k_2 = \theta + \mu \\ \varepsilon_1 = 1 - \sigma, & k_3 = \theta + \phi + \tau + \mu \\ \varepsilon_2 = 1 - \theta, & k_4 = \psi + \tau + \mu \\ & k_5 = \omega + \mu \end{array}\right\} \quad (3)$$

So that

$$\frac{dN}{dt} = \Lambda - \mu N \quad (4)$$

in the biological-feasible region:

$$\Omega = \left. \begin{pmatrix} S_N \\ S_E \\ C \\ J \\ H_S \\ H \end{pmatrix} \in R_+^5 \,\middle|\, \begin{array}{c} S_N \geq 0, \\ S_E \geq 0, \\ C \geq 0, \\ J \geq 0, \\ H_S \geq 0, \\ H \geq 0, \\ S_N + S_E + C + J + H_S + H = N \end{array} \right\} \quad (5)$$

2.2 Effective Reproduction Number $\left(R_{eff}\right)$

One of the highly essential worry about any infectious disease is its ability to invade a population. The effective reproduction number $\left(\mathrm{R}_{eff}\right)$ is 'one of the foremost and most valuable ideas that mathematical thinking has brought to epidemic theory' where control strategies are employed [12]. It represents the total number of new corruption cases recorded when a corrupt individual is introduced into an entirely susceptible population where nobody has immunity for corruption in the presence of interventions to control the corruption.

The next generation operator approach described by [[13] is a better method used in finding R_{eff} and it is widely accepted because it reflects its biological meaning.

The R_{eff} is computed as the spectral radius (ρ) of the next generation matrix, D. Where $D = FV^{-1}$. The matrices of F and V are obtained from the infected classes $\left(i.e\, C, J \text{ and } H_S\right)$ at corruption-free equilibrium $\left(E^0\right)$.

Now, the corruption-free equilibriumstate of the model exist at the point:

$$\begin{pmatrix} S_N{}^0 \\ S_E{}^0 \\ C^0 \\ J^0 \\ H_S{}^0 \\ H^0 \end{pmatrix} = \begin{pmatrix} \dfrac{\Lambda\sigma}{k_1} \\ \dfrac{\Lambda\left(k_1\varepsilon_1 + \sigma\varphi\right)}{k_1 k_2} \\ 0 \\ 0 \\ 0 \\ \dfrac{\Lambda\theta\left(k_2\sigma + k_1\varepsilon_1 + \varphi\sigma\right)}{\mu k_1 k_2} \end{pmatrix} \quad (6)$$

and thus we have:

$$F=\begin{pmatrix} \dfrac{p\vartheta\left(S_N{}^0+\gamma S_E{}^0\right)}{N^0} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \tag{7}$$

and

$$V=\begin{pmatrix} k_3 & -\psi\varepsilon_2 & \omega \\ -\phi & k_4 & 0 \\ -\tau & -\tau & k_5 \end{pmatrix} \tag{8}$$

We have

$$V^{-1}=\frac{1}{Q}\begin{pmatrix} k_4k_5 & k_5\psi\varepsilon_2-\omega\tau & -k_4\omega \\ k_5\phi & k_3k_4+\tau\omega & -\omega\phi \\ \tau\left(k_4+\phi\right) & \tau\left(k_3+\psi\varepsilon_2\right) & k_3k_4-\phi\psi\varepsilon_2 \end{pmatrix} \tag{9}$$

Where

$$Q=k_3k_4k_5+k_4\tau\omega+\phi\omega\tau-k_5\phi\psi\varepsilon_2 \tag{10}$$

Thus, the effective reproductive number is given as:

$$R_{eff}=\frac{k_4k_5p\vartheta\left(S_N{}^0+\gamma S_E{}^0\right)}{\left(k_3k_4k_5+k_4\tau\omega+\phi\omega\tau-k_5\phi\psi\varepsilon_2\right)N^0} \tag{11}$$

III. Results and Discussion

3.1 Numerical Verification

In this section, we presented some numerical simulations to monitor the dynamics of the full system (1) for various values of the effective reproductive number. It is presented in order to confirm the analytical results on the local and global stability of the corruption-free and endemic equilibria.

Table 1: Baseline values for Parameters of system (1)

S/N	Parameter	Value	Source
1	Λ	30,000	Abdulrahman, (2014)
2	μ	$0.011\le\mu\le0.021$	Abdulrahman, (2014)
3	p	0.36	Assumed
4	e	(0,1)	Varied
5	ϕ	0.0001 τ	Abdulrahman, (2014)
6	ψ	0.143	Abdulrahman, (2014)
7	θ	0.000001	Abdulrahman, (2014)
8	σ	(0,1)	Varied
9	φ	0.02	Assumed
10	f	(0,1)	Varied
11	ω	0.001	Assumed
12	τ	(0,1)	Varied

3.2 Effect of Different Control Strategies on the Transmission Dynamics and Control of Corruption

Effort rate against corruption (e), social media usage rate (f), jail term (ϕ) and the rate at which individuals quit corruption temporarily due to embarrassing effect of social media (τ) are the most effective strategies of curtailing the spread of corruption in any population. For the effective reproduction number (R_{eff})

of the model, the control parameters e, f, ϕ and τ are considered at four different control strategies and rates of usage/coverage.
The control strategies are:

(a) Embarrassment rate of social media (τ) only,

(b) Effort rate against corruption (e) and embarrassment rate of social media (τ) only,

(c) Social media usage rate (f) and embarrassment rate of social media (τ) only,

(d) Universal (combined) strategy

Table 2: Effect of FourDifferent Control Strategies on the Effective Reproduction Number (R_{eff}) of the Model

Coverage Rate	a	b	c	D
0.1	2.9962	2.6964	2.6994	2.4293
0.2	1.5838	1.267	1.27	1.0159
0.3	1.0764	0.7534	0.7565	0.5295
0.4	0.8152	0.4891	0.4922	0.2953
0.5	0.656	0.328	0.3311	0.1655
0.6	0.5489	0.2195	0.2226	0.089
0.7	0.4718	0.1415	0.1446	0.0434
0.8	0.4137	0.0827	0.0858	0.0172
0.9	0.3683	0.0368	0.0399	0.004
1	0.3319	0	0.0031	0

The simulation of the results in Table 2 above is shown in **Figure 2:**

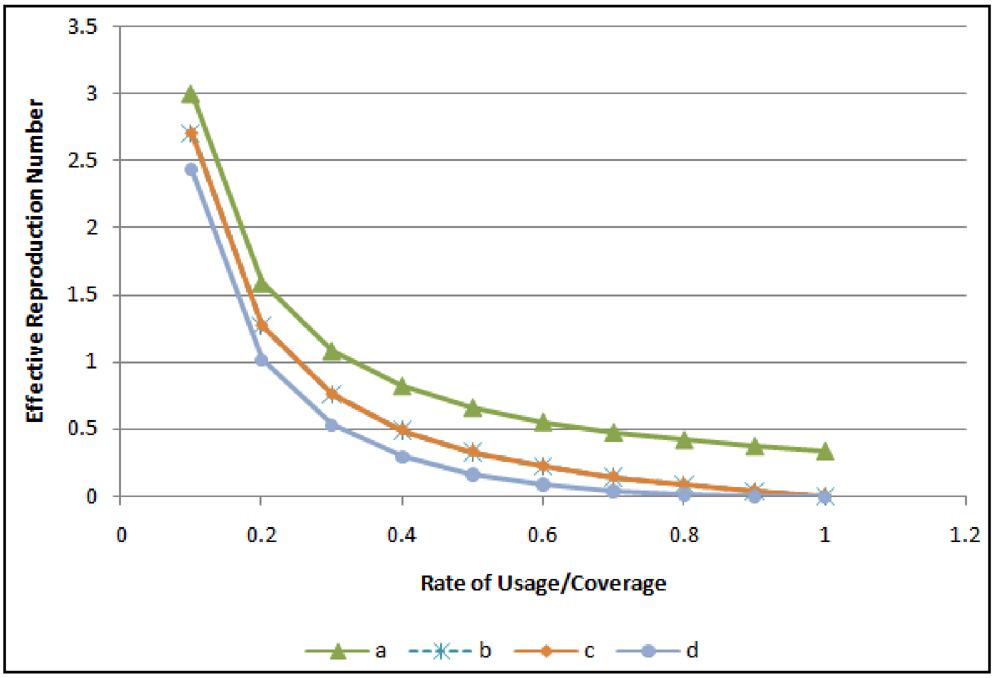

Figure 2: Comparison of the Effective Reproduction Number (R_{eff}) of FourDifferent Control Strategy Levels. Parameter values used are as in Table 1

Figure 2 reveals that any of the four (4) control strategies have positive effect in controlling corruption but not all can lead to stable corruption-free state ($R_{eff} \leq 1$). It revealed that if at least 40% of corrupt individuals are embarrassed due to social media coverage, most of them will become semi-corrupt which can bring about the control of corruption, although, it may not be a short time effect but will take several years before being achieved. It is observed that a 50% coverage rate of the universal strategy can bring corruption under control tending to corruption-free state.

IV. Conclusion

A new mathematical model is developed and analyzed with constant recruitment rate and standard incidence for the transmission dynamics of corruption. The effective reproduction number $\left(R_{eff}\right)$ was obtained and its values computed using different control strategies. The control parameters are embarrassment rate of social media (τ), effort rates against corruption (e) and social media usage rate (f). The analysis reveals that if 40% of corrupt individuals are embarrassed due to social media coverage, most of them will become semi-corrupt which can bring about the control of corruption, although, it may not be a short time effect but will take several years before being achieved. A feasible solution of a 50% coverage rate of the universal strategy (i.e combing all the control strategies) is recommended, which brings corruption under control tending to corruption-free state.

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