Modeling and Preventive Measures of Ebola: An Analysis of an Epidemic in Libya

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Abstract*—*Ebola is a rare virus, which can cause severe acute hemorrhagic fever and high mortality for humans and non-human primates. In 2014, Ebola virus out breaking in West Africa triggered a grave disaster to the people of the world, finally, it has been inhibited successfully under the vaccine and effective drug. In this article, data from patients and deaths due to Ebola were collected, which were reported by WHO. These data were analyzed and researched the spread of Ebola by SEIR model. In this model, basic reproduction number obtained was 15, which was based on the number of dead and patients from June to September in Libya. And according to the sensitivity analysis for basic reproduction number, it was proved that improving vaccination rate and recovery rate of infectious are two effective ways to suppress the spread of the Ebola epidemic. This article gives a detailed and direct scientific theory basis for the control of Ebola virus in the end.

Keywords*— *Ebola, Differential Dynamic Equations, Basic Reproduction Number.

I. INTRODUCTION

Ebola is a zoonotic fulminating infectious disease which caused by Ebola virus. And the specific symptoms of it are high fever, fatigue, nausea, headache, vomiting, diarrhea, extreme sleepiness and shock,[1] which result in a very high mortality rate for people and apes, chimpanzee, gorillas and other non-human primate animal.[2]

Ebola virus is very rare, that also known as Ebola hemorrhagic fever.[2] According to Waterman (1999), Ebola virus firstly appeared in Sultan and Zaire (who is known as the Democratic Republic of Congo today) in 1976. From then, it has aroused widespread concern and attention in the medical field and was named Ebola River in Zaire.[3] Because the first epidemic situation occurred in Ebola River of Congo of Africa, people call it Ebola from that later. [4] Ebola outbreaks every few years, however, the size of each epidemic is relatively small and confined to the Central African.[1]

In 2014, Ebola epidemic outbreak in Guinea, West Africa, and it quickly spread to Liberia, Sierra Leone, Nigeria, the Democratic Republic of Congo, Uganda, Gabon ,Sultan and many other African countries, which called the most serious case in the history of West Africa.[5] As a result of the fear and economic turmoil in some parts of the region, WHO characterized this epidemic as an international emergency public health event.[4]

Organization of this article is as follows. In the next section, an epidemic model for Ebola is proposed to understand the infectious dynamics. Simulations of the data from WHO and sensitivity analysis of the

basic reproduction number are performed in next Section. This article was concluded with model-based suggestion of intervention improvement to control the Ebola.

II. MODEL FORMULATION

It was assumed that there is no floating population in this research region and only contact transmission for the spread of the Ebola virus was considered. The diseased populations are treated and isolated after onset. Gender, age and other factors that can cause individual differences are not considered in this article.

The population is divided into five epidemiological sub-classes, namely the susceptible (S), vaccinated (V), exposed(E), infectious(I), and recovered(R) individuals. Λ is the number of births in region. The birth flux into the exposed class is given by $\alpha\rho E$, which are infected by their parents. μS, μV, μE and μR are the numbers of naturally died in each compartment.

For the origin of infectious, we only consider infectious individual scan spread Ebola virus and the exposed individuals have no possibility to spread virus. βSI is the number of people, who were infected by I.

Exposed individuals will also get vaccination as they unaware that they have been infected, the number of them is εE. And there is still the possibility of being infected for people who have been vaccinated as their resistance to drugs, the number is $\beta_1\beta VI$.

For recovered, there is still have possibility infected as they do not have permanent antibodies. Flow chart of compartments of Ebola model as shown in Figure 1. The biological meanings of all parameters are listed in Table1.

Figure 1
Flow chart of compartments of Ebola model

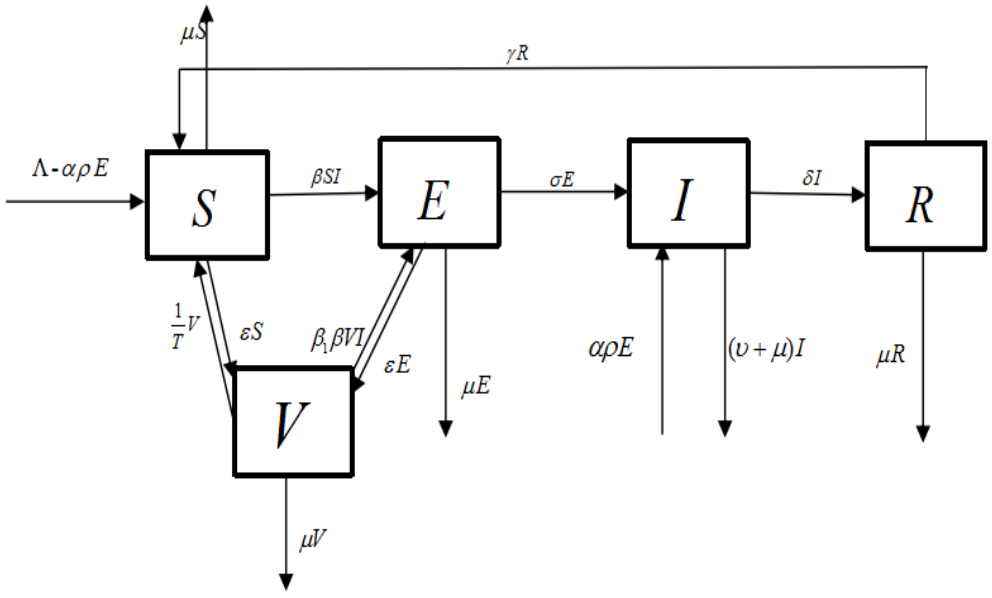


Table 1
Model parameters and definition

Symbol	Definition
Λ	Recruitment rate
α	The natural birth rate
ρ	The offspring from the exposed classes
γ	Remove rate from recovered to susceptible
ε	Vaccination rate of the susceptible and exposed
η	Loss of vaccination rate
μ	Natural death rate
σ	Rate moving from exposed to infectious
δ	Rate moving from infectious to recovered
υ	The diseased mortality rate
β_1	The invalid proportion of the vaccine
β	The transmission rate

According to the flow chart, we get the following differential dynamic equations to describe the Ebola dynamics:

$$\begin{cases} \dot{S} = \Lambda - \alpha\rho E + \gamma R - \beta SI - \varepsilon S + \eta V - \mu S, \\ \dot{V} = \varepsilon S - \eta V - \mu V + \varepsilon E - \beta_1 \beta VI, \\ \dot{E} = \beta SI - \sigma E - \mu E - \varepsilon E + \beta_1 \beta VI, \\ \dot{I} = \sigma E + \alpha\rho E - \delta I - (\upsilon + \mu) I, \\ \dot{R} = \delta I - \gamma R - \mu R. \end{cases} \tag{1}$$

Above the differential dynamic equations, we can conclude disease free equilibrium and basic reproduction number. Disease will persist if the basic reproduction number R_0 is greater than one.[6,7]

So we will be able to get the status of the spread of Ebola through the analysis of the basic reproduction number. By calculating, we get the disease free equilibrium $(S_0, V_0, 0, 0, 0)$. And basic reproduction number expression is as follows:

$$R_0 = \frac{(\sigma + \alpha\rho) \times (\beta S_0 + \beta\beta_1 V_0)}{(\delta + \mu + \upsilon)(\varepsilon + \mu + \rho)}, \tag{2}$$

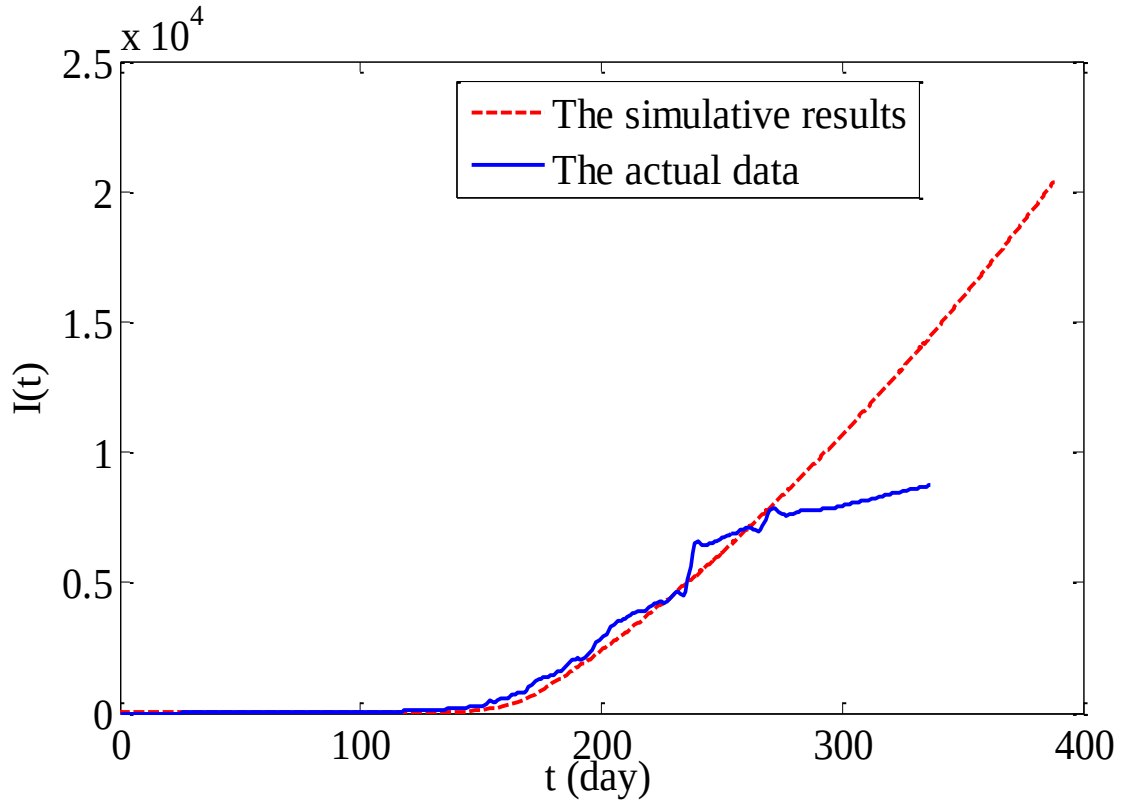
where, $V_0 = \dfrac{\varepsilon\Lambda}{\mu\eta + \mu\varepsilon + \mu^2}$, $S_0 = \dfrac{\eta + \mu}{\varepsilon}$.

III. SIMULATION AND SENSITIVITY ANALYSIS

Through the sensitivity analysis of various controllable parameters for basic reproduction number in the system (1), we can study on the relationship between different parameters with the spread of Ebola virus. And then, we take Libya as the actual object to analysis, where is one of the most serious areas of Ebola in Africa. We get the values of each parameter in equations by fitting data basis on least square,

which is released by WHO. We use system (1) to conduct the data fitting to the number of infectious, as shown in Figure 2. The fitting results of the parameters are shown in Table 3 and from the optimal parameters the basic reproduction number is about 15.

Figure 2
Virtual curve represents the simulative results and the solid curve are the data of days reported by WHO from June to September in Libya in 2014[1]



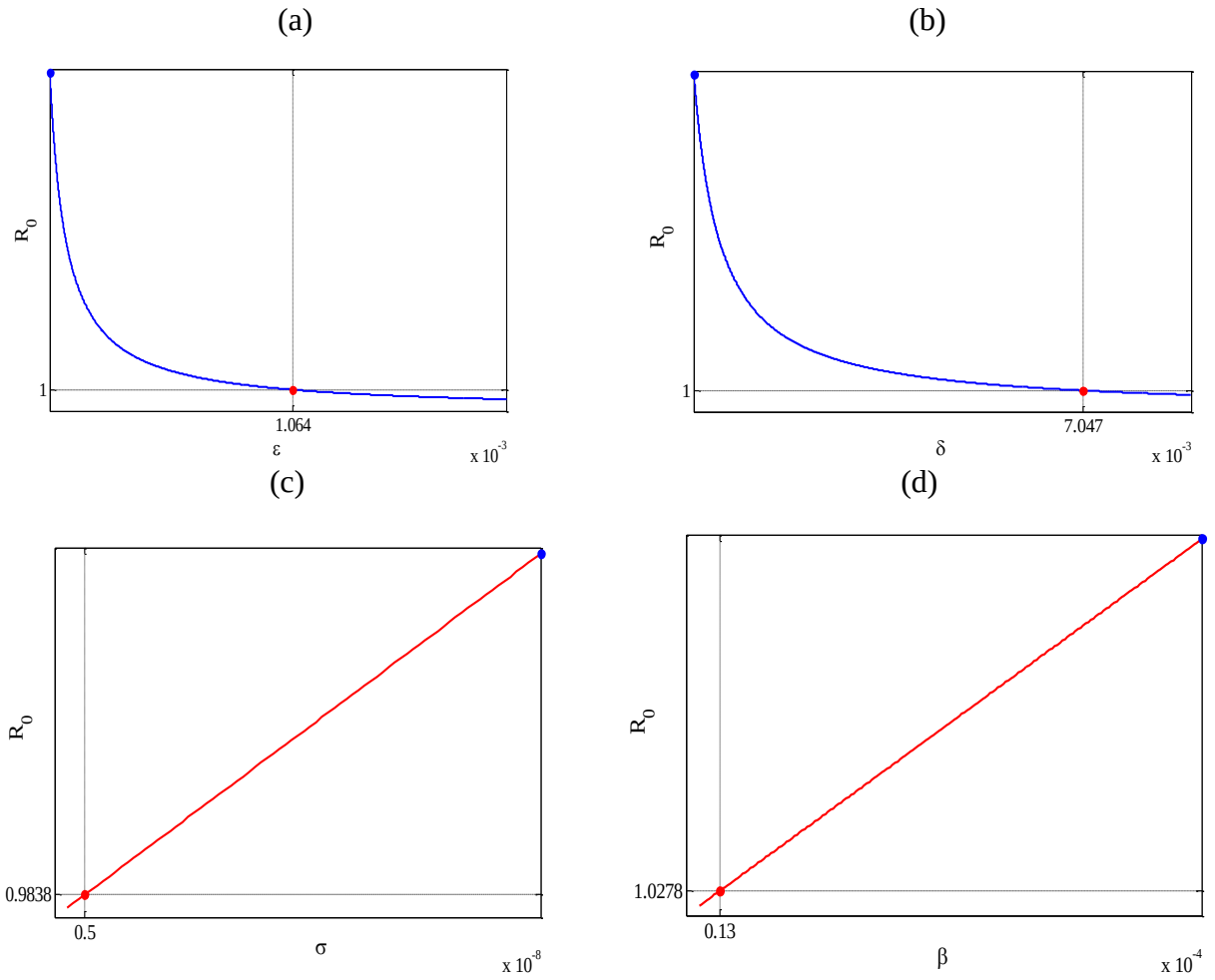
According to the figure 2, our model fit to the actual data very well. The solid line represents the number of patients per day in Libya, the virtual line represents the value fitted by our model. Through the image above we can see that it is relatively gentle at the beginning of the outbreak of disease, and as time goes by, the disease began to erupt behind one hundred and fifty days.

Table 3
Value of the parameters of system (1) (Partly)

β	γ	ε	δ	β_1	ν	σ
2×10^{-4}	2×10^{-9}	3×10^{-7}	4×10^{-6}	2×10^{-8}	4×10^{-4}	8×10^{-8}

Through the parameters in the Table 3,we can obtain the proportion of vaccinated people(ε) and the cure rate (δ) are very close to zero, which is just coincided with reality of the beginning of epidemic. Next, we focus to analyze sensitivity of the two parameters. From it, we get the sensitivity analyses about ε and δ with the basic reproduction number (R_0).

Figure 3.
R_0 in terms of $\beta, \delta, \varepsilon$ and σ



In the figure 3, the horizontal coordinate is the parameter, and the longitudinal coordinate is the basic reproduction number (R_0). Showing in the figure 3 (a) and (b), we can see that the basic reproduction number will decrease strongly when ε and δ increase, which means increasing the rate of vaccination or recovery rate can control the spread of Ebola. And the controllability of these two parameters is convenient, the effect is remarkable, they are the most common and effective methods to control others disease epidemic.

Meanwhile, we carries on the deep analyses to σ and β , which are shown in the figure 3 (c) and (d). We can see that the basic reproduction number will decrease strongly when σ and β decrease, which is consistent with the actual situation that shorten the incubation of the period and reduce the transmission rate are beneficial to control the disease.

IV. CONCLUSION

From this paper, we can improve the vaccination rate to inhibit Ebola completely. In developed region. And by improving the recovery rate of patients is also an important way to suppress the outbreak of the disease. In order to prevent the spread of the Ebola effectively, people should try to avoid staying at the place which has lots of people to reduce the transmission rate. Those who feel indisposed also should go

to hospital to check early. These are some effective patterns to prevent the spread of the Ebola. These methods above all have been proved scientifically in the paper.

CONFLICT

None declared till date.

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