

# EVD Outbreak-2014: Burden of the Disease and Comprehensive Steps in Preventing the Epidemic

Saddam Hossain<sup>1</sup>, Sumaiya Akter<sup>2</sup>, Mhamud Hasan<sup>1</sup>

<sup>1</sup>BRAC University, Dhaka, Bangladesh

<sup>2</sup>University of Dhaka, Dhaka, Bangladesh

Email: [saddam8089@gmail.com](mailto:saddam8089@gmail.com), [Urmi\\_dhabi@yahoo.com](mailto:Urmi_dhabi@yahoo.com), [mahmudmathju@gmail.com](mailto:mahmudmathju@gmail.com)

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## Abstract

As of December 2<sup>nd</sup> 2015, a total of 28,601 cases have been reported with 11,300 reported deaths (not including cases where the outcome is unknown) during the current outbreak of ebola virus disease (EVD). In this paper, we mainly focus on the transmission of ebola virus disease, estimate the burden of the disease and the persistent nature by finding the basic reproduction number, and analyze the comprehensive steps to control the virulent disease. We have considered three mostly affected countries, Guinea, Liberia, and Sierra Leone respectively and collected data from various sources are used to surmise the present and future nature of the disease. Being the poorest country in the world like Guinea, Liberia, and Sierra Leone, they do not have efficient policies to fight against such kind of endemic and they have been unable to control the spread of the disease. We have found some real facts that increase the chances to be infected by this virulent disease. Since the reproduction number  $R_0$  is still above unity and if we do not take precautionary steps and work accordingly then the disease will definitely exist in the community and the burden of the disease would increase continuously.

## Keywords

EVD, SIR, Basic Reproduction Number, Mathematical Modeling, GDP, Epidemic

## 1. Introduction

According to the World Health Organization (WHO), as of 25 January 2015 the current outbreak of the disease had almost 22,000 cases and 9000 deaths. The outbreak began in March 2014, with Liberia, Sierra Leone and Guinea being the

nations worst affected. The Ebola virus disease is a severe illness in humans, with a fatality rate of around 50% [1] [2] [3]. The initial symptoms can include fever, weakness, muscle pain and a sore throat while subsequent stages are vomiting, diarrhea and possible internal and external bleeding. There are currently no licensed Ebola vaccines.

The first Ebola virus disease cases were reported in 2 outbreaks in Sudan and Democratic Republic of Congo in 1976. The latter occurred in a village near the Ebola River, from which the disease takes its name. The 2014 outbreak in West Africa is the largest and deadliest Ebola outbreak since the virus was first discovered. The virus is transmitted to humans through contact with fluids from infected animals in the wild, including fruit bats and monkeys, either dead or alive. It spreads in the human population through human-to-human transmission by direct contact with the bodily fluids of infected people. It can also be indirectly transmitted by contacting with surfaces including clothing and bedding, which are contaminated with these fluids.

Transmission interruption is the key to preventing the spread of any infectious disease, for Ebola this is achieved by preventing contact with bodily fluids of those infected. This involves three key approaches, according to the WHO safe burials of the infected that are deceased, immediate isolation of patients before they can infect others and monitoring of people who have been in contact with an infected patient. The current Ebola outbreak has claimed the lives of doctors and nurses in the region, including international volunteer health workers, putting further strain on the already limited health services of these West African countries. Wearing protective clothing and equipment when exposed to patients as well as standard hand-hygiene is hoped to limit the spread to health workers

Knowing the propensity for Ebola to spread is essential for effective control measures. Mathematical theory of epidemiology has introduced the basic reproduction number,  $R_0$ , of an infection as the number of cases one case of the disease generates over the course of its infectious period. Essentially, Ebola's  $R_0$  value is the number of people who will likely become infected from one person with the virus. If this value exceeds unity—that is if  $R_0 > 1$ —the theory predicts that the disease will be able to spread through a population of uninfected people, whereas if  $R_0 < 1$ , the infection will die out.

The calculated  $R_0$  values ranged from 2.6 to 8.6 for the Yambuku, Zaire outbreak in 1976; meanwhile the range for  $R_0$  for the 1995 epidemic in Kikwit, Zaire was slightly lower 1.57 to 5.03. Recent research published in PLoS Current Outbreaks by Christian Althaus estimated the basic reproduction number for the 2014 outbreak of Ebola as 1.51 (95% confidence interval: 1.50 - 1.52) for Guinea, 2.53 (2.41 - 2.67) for Sierra Leone and 1.59 (1.57 - 1.60) for Liberia. These estimates were obtained using an SEIR (susceptible-exposed-infectious-recovered) epidemiological model of Ebola spread and statistically fitting the model output to the reported infected cases and deaths in Guinea, Sierra Leone and Liberia

from the WHO for March-June 2014. In order for these estimates to be as accurate as possible, it is crucial that the epidemiological data input into the mathematical model is as rich and reliable as possible. This involves having reasonable knowledge of the number of cases of Ebola infection and the number of Ebola-related fatalities. However, at this stage, the WHO admits that figures are only estimates, as some disease cases and Ebola-related deaths are only probable or suspected.

With an accurate estimate of the basic reproduction number of the disease, potential transmission interrupting strategies can be effectively evaluated and compared, within the mathematical framework, as has been done for other infectious diseases. With the help of the real-time analysis and evaluation of Ebola cases and deaths within the theoretical model, useful transmission interrupting strategies can then be implemented on the ground, with the hope to prevent future infection and spread of the disease. Ebola is characterized by initial unlike symptoms including sudden onset of fever, fatigue, muscle pain, headache and sore throat. This then rapidly progresses to vomiting, rash, symptoms of impaired kidney and liver function, and in some cases, both internal and external bleeding. Most infected persons die within 10 days after their initial infection (80% - 90% mortality). Using a simple SIR (susceptible-infectious-removed) epidemic model and data from Ebola outbreaks in Sierra Leone, Liberia, and Guinea 2014, we have calculated the tendency of the present and its future situation.

## **2. A Brief Background of These Three Nation and Steps Involves in Prevention of the Disease (EVD)**

The Republic of Sierra Leone is located in Western Africa region; bordering the Atlantic Ocean, between Guinea and Liberia. About a third of the populations (2 million) displaced from Serra Leone due to the civil war during 1991 to 2002 and over the past year about 850 peacekeepers have deployed in the African Union Mission in Somalia. As of 2014, the situation has changed because Serra Leone also fielded 122 staff for five UN peacekeeping mission. It is the 111<sup>th</sup> largest country in the world by its populations and also the 119<sup>th</sup> largest country in the world by its area (71,740 square kilometers). The population of Sierra Leone was estimated to be 6,391,064 people (1 January 2015). Population growth rate is 2.25 percent compare to the previous year 6,250,552. External Migration affects the population growth rate substantially by 0.43 percent. The sex ratio of the total population was 0.956 (956 males per 1000 females) which is lower than global sex ratio. The Gross Domestic Product (GDP) in Sierra Leone was worth about 4.89 billion US dollars in 2014 which was about 4.93 billion in 2013.

It was 1847, when the freed slaves from U.S were able to establish a republic and now not only it is the 127<sup>th</sup> largest country in the world by population but also the 104<sup>th</sup> largest country by area with 111,369 square kilometers. The population of Liberia was estimated to be 4,602,514 people (1 January 2015). Population growth rate is 3.18 percent compare to the previous year 4,460,838. Migration

affects the population increase rate by 0.51 percent. The sex ratio of the total population was 1.011 which is lower than global sex ratio (In 2014, 1016 males to 1000 females was approximately the sex ratio of the world population). The Gross Domestic Product (GDP) in Liberia was worth about 2.03 billion US dollars in 2014.

The inception of the first National Assembly was in January 2014 and the president Alpha CONDE was elected to a five year term as president in 2010, was also the first free and competitive democratic presidential and legislative election in Guinea. Now Guinea is the 75<sup>th</sup> and 79<sup>th</sup> largest country in the world by population and area (245,857 square kilometers) respectively. The population of Guinea was estimated to be 1,384,178 people (1 January 2015). Population growth rate is 2.65 percent compare to the previous year 12,065,057. Migration does not create any potential affects to the population growth rate of Guinea. The sex ratio of the total population was 1.022 which is higher than global sex ratio and that was the positive thing only happened during the last few month substantially. The Gross Domestic Product (GDP) in Guinea expanded 4.20 percent in 2014 from the previous year. GDP Annual Growth Rate in Guinea averaged 3.53 percent from 1987 until 2014, reaching an all time high of 6.31 percent in 1988 and a record low of  $-0.30$  percent in 2009. GDP Annual Growth Rate in Guinea is reported by the Central Bank of Republic of Guinea.

Now if we look into the outbreak of this virulent disease, we see that the mortality rate is very high and there are several aspects that are directly related with this epidemic. Guinea, Liberia and Serra Leone are known to be some of the poorest countries in the world, with extremely high unemployment rate. The three countries economies depend largely on the exploitation of mineral resources, such as iron, gold, uranium, diamonds, rubber and petroleum in various regions. They have also become a home base for drug trafficking, especially cocaine, between the African countries that produce the substance and the consumers in Europe and North America. This is largely due to minimal border control in the region which makes crossing frontiers very easy. The Gross National income per capita for Guinea, Liberia, and Sierra Leone are 1020, 340, and 830 respectively and this information is indicative of the background context of these countries before the 2014 Ebola outbreak. The literacy rate is also alarmingly low, indicating that less than 50% of the population in Guinea and Sierra Leone and just over 50% in Liberia are literate. This suggests that access to education and the quality of education are very precarious. There is also a significant rural population which is made up of different tribes and ethnic groups. This complicates this population access to education, health services and basic infrastructure due to language barriers, cultural differences, varied religious beliefs and physical isolation. Even before the Ebola outbreak in 2014, diseases such as Cholera, Dysentery, Malaria, AIDS and many others had been causing death among civilians in the region on a daily basis [2]. Liberia, Guinea and Sierra Leone have been ranked near the bottom of the UN's human development

index [3] [4]. All three countries have in recent times gone through civil wars, dictatorships and other political turmoil that have largely destroyed much of their existing social and economic infrastructure. Economic recoveries, restoration of peace and democracy, as well as improvements in certain social indicators were the main concern of the three nations before the outbreak. According to a UNDP report, the Ebola epidemic has essentially robbed these countries of much of the progress made in the past decade.

The infrastructure in these countries has been very precarious for a long time and not only were they not prepared for an outbreak of such a calamity, but these countries were not ever properly equipped to care for patients of other diseases common to the region before the outbreak, such as malaria, AIDS, Cholera, Dysentery, etc. Even before the Ebola epidemic, their respective health care systems lacked many items that would have been necessary for the containment of the virus: medication, ambulances, facilities, clinics, properly trained human resources, even basic hygienic equipment such as protective gloves, robes and needles, etc. [4]. This complete lack of medical resources greatly contributed to the rapid spread of the disease, not only amongst the general population but also amongst medical workers. 28,598 confirmed, probable, and suspected cases have been reported in Guinea, Liberia, and Sierra Leone, with 11,299 deaths since the onset of the Ebola outbreak [5] [6] [7] [8] [9]. The majority of these cases and deaths were reported between August and December 2014, after which case incidence began to decline as a result of the rapid scale-up of treatment, isolation, and safe burial capacity in the three countries.

The unprecedented scale of the EVD outbreak in Guinea, Liberia, and Sierra Leone means there are estimated to be several thousands of survivors throughout the three countries. Survivors have contributed enormously to many aspects of response, but they face many challenges. In addition to the stigmatization they frequently experience when they return to their own communities, survivors also face myriad health issues, from joint pains and headaches to problems with vision and poor mental health. Although there is a vibrant self-organized survivor-support community, survivors require specialized medical support as well as access to routine health care services such as ante-natal care and vaccinations and screening. With guidance from WHO and other partners, ministries of health in the three most-affected countries have plans in place to deliver a comprehensive package of services to ensure the welfare of survivors and mitigate risks posed by viral persistence [8] [9] [10] [11] [12]. The causes behind this widespread of Ebola are political instability, socio-cultural factors, human rights violation, limited access of social media and high levels of illiteracy. Being the poorest country in the world like Guinea, Liberia, and Sierra Leone, they do not have the efficient policies to fight against such kind of endemic and they have been unable to control the spread. According to the president of Liberia Ellen Johnson Sirleaf criticized the response of her citizens to the epidemic “We have been unable to control the spread due to continued denials, cultural burying

practices, disregard for the advice of health workers and disrespect for the warnings by the government”.



The glow from a crematorium fire lights up the night sky where bodies of people who died from Ebola are cremated on Sept. 14 in Monrovia. The crematorium was built by the Indian Embassy but has been transformed to cremate up to 120 people at a time to deal with the Ebola crisis (Photo by Michel du Cille)

Once a top Red Cross official had said it will take up to six months to get Ebola outbreak under control as the hunt continues for a vaccine to the deadly disease. Even that time frame will only be realistic if medics in West Africa ensure “safe burials”, “good isolation” and “good treatment”, according to Red Cross secretary general Elhadj As Sy (22 October 2014). He warned a press conference many nations’ workers are “coming out and running away and others are very hesitant to send people” (By Dan Bloom and Annabel Grossman).

Indeed his statement was true by and large, cause without ensuring “safe burials”, “good isolation” and “good treatment”; it is quite hard to control the current virulent disease like EVD. We hope to see the WHO and developed countries will come across to solve this conundrum and work for the poorest people of this world. Now we will look into the recent outbreak of EVD Mathematically so that we will be able to make conclusion about the present and its future epidemiological situation:

### 3. Model Formulation

The dynamics of this system happen in two stages, susceptible to infected, and infected to dead. This is a closed system where those that are susceptible could become infected at some point in time. This model assumes that the initial population is equal to the population that will eventually be infected. The parameters are  $\mu$ , the per-capita death rate; and  $\beta$ , the probability that a susceptible host will become infected. The parameter  $\beta$  can vary from a constant function to an exponential function of decay with respect to the number of infected at time  $t$ . Once the parameters are found, the system modeling the data is solved using

MatLab.

The population studied is divided into three Classes:  $S(t)$ , the number of susceptible individuals;  $I(t)$ , the number of individuals infected; and  $R(t)$  the number of dead individuals at time  $t$ . We will assume that the population studied will be a constant population during the outbreak, meaning there are no deaths due to outside factors and the number of births that occurred are so small that we can essentially ignore them. We will denote our total population at time  $t$  by  $N$ , so at any time  $t$ :

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

Following a model proposed by Kermack and MacKendrick (1927) to explain the frequent rapid rise and fall of cases observed frequently in epidemics such as the Great Plague in London (1665-1666), the cholera epidemic in London (1865) and the plague in Bombay (1906), we are able to propose a model that approximates the outbreak reasonably well:

$$\begin{aligned} \frac{dS}{dt} &= \frac{\beta SI}{N}, \\ \frac{dI}{dt} &= \frac{\beta SI}{N} - \mu I, \\ \frac{dR}{dt} &= \mu I. \end{aligned} \quad (1)$$

This model takes into consideration the number of people infected due to direct contact with an infected individual at time  $t$ :  $\frac{\beta SI}{N}$ , Where  $\beta = pc$ ;  $p$  is the probability of successfully getting infected when coming into contact with an infected individual, and  $c$  is the per-capita contact rate.

The death rate is denoted by  $\mu I$ , where  $\mu$ , is the per-capita death rate. Even though recoveries do occur, we will not return these individuals to the susceptible class since there has never been a person who has recovered from Ebola and contracted the disease again in the same epidemic. From our data analysis and mathematical relation we will be able to estimate the parameter  $\beta$  by solving the second differential equation for several values of  $t$ .

Since  $\frac{dI}{dt} = \frac{\beta SI}{N} - \mu I$ , for small value of  $t$ ,  $\frac{dI}{dt} \approx \frac{\beta I}{N} - \mu I$ ; solving this equation,  $I(t) = I(0)\text{Exp}[(\beta - \mu)t]$ , where  $I(0) = 1$ ;

Under these conditions, we can assume that  $I(t) \propto R\left(t + \frac{1}{\mu}\right)$ ; cause  $1/\mu$  is the average time for an infected individual to die. For different geographical region we will have an equation of the form

$$\begin{aligned} (\beta - \mu)t &= \ln(k) + \ln\left[R\left(t + \frac{1}{\mu}\right)\right]; \\ \beta &= q + \mu \end{aligned} \quad (2)$$

Which vary for the values of  $R(t)$ ,  $k$  and  $\mu$ . With this information we will be

able to calculate a range for the basic reproductive number  $R_0$  where  $R_0 = \frac{\beta}{\mu}$ .

#### 4. Discussion

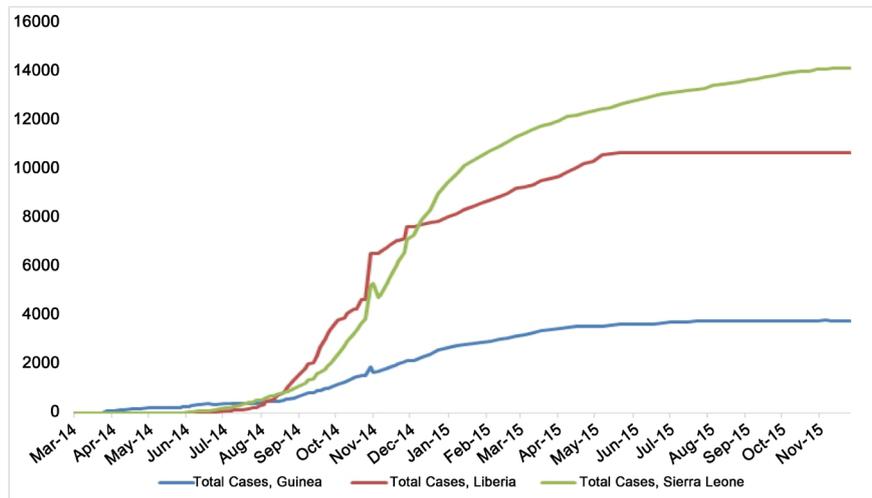
Mathematical models constitute interesting tools for the understanding of diseases. They usually provide insights, improve intuitions, clarify assumptions for formal theory, allow for planning studies, estimating parameters, determining sensitivities, assessing conjectures, simulating simple and complex phenomena and providing future predictions. As our goal to critically look into the present outbreak of EVD-2014 and find some prediction about future conditions of this virulent epidemic. We have a simple Mathematical model proposed by Kermack and MacKendrik (1927) and using this model and existing data, we have found some of the interesting facts of this current epidemic.

The model (1) is simulated, using the parameter values given in **Table 1** and **Figures 1-7** (unless otherwise stated). We have rigorously analyzed the outbreak and the comparative situation among these three countries by using available data from various sources. At the beginning of this current outbreak the overall situation of Guinea was devastating, because about 86 persons were infected and among them 56 were dead. Our calculated value for basic reproduction number  $R_0 = 1.498$  and  $\beta = 0.974$ , which was very high and that indicates the burden of the outbreak was enormous (**Figure 8**). By this time the inception of the disease took part both in Liberia and Sierra Leone, though the rate was very negligible. But by the end of the march, 2014 Sierra Leone and Liberia became infected and our calculated value for  $R_0$  was about 1.29 and 1.25 for Liberia and Sierra Leone respectively [8] [9] [11] [13].

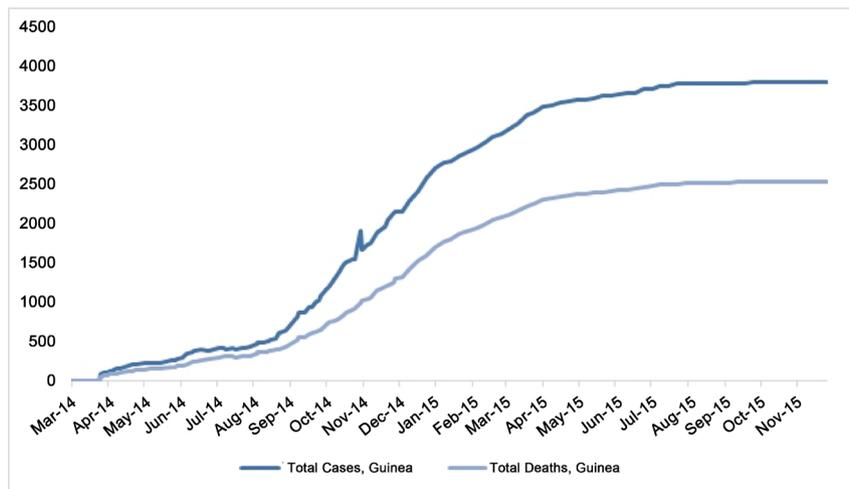
It was immersed severely by the end of the month August and September, 2014. Particularly the fatality rate was very high among the three major infected countries. The whole World come standstill and thinking about the prevention of the deadliest disease of the world. That time infected rate was very high and

**Table 1.** The value of the parameters.

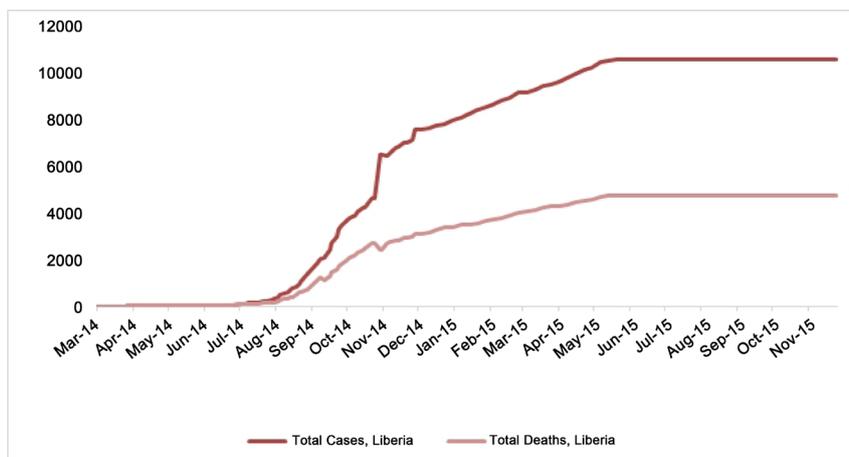
WHO report date	Total Cases, Guinea	Total Deaths, Guinea	Total Cases, Liberia	Total Deaths, Liberia	Total Cases, Sierra Leone	Total Deaths, Sierra Leone
3/25/2014	86	59	0	0	0	0
3/27/2014	103	66	8	6	6	5
6/2/2014	291	193	13	9	50	6
8/28/2014	648	430	1378	694	1026	422
10/29/2014	1906	997	6535	2413	5235	1500
3/25/2015	3429	2263	9602	4301	11,841	3747
9/24/2015	3800	2532	10,672	4808	13,823	3955
10/22/2015	3803	2535	10,672	4808	14,001	3955
11/25/2015	3804	2536	10,675	4808	14,122	3955



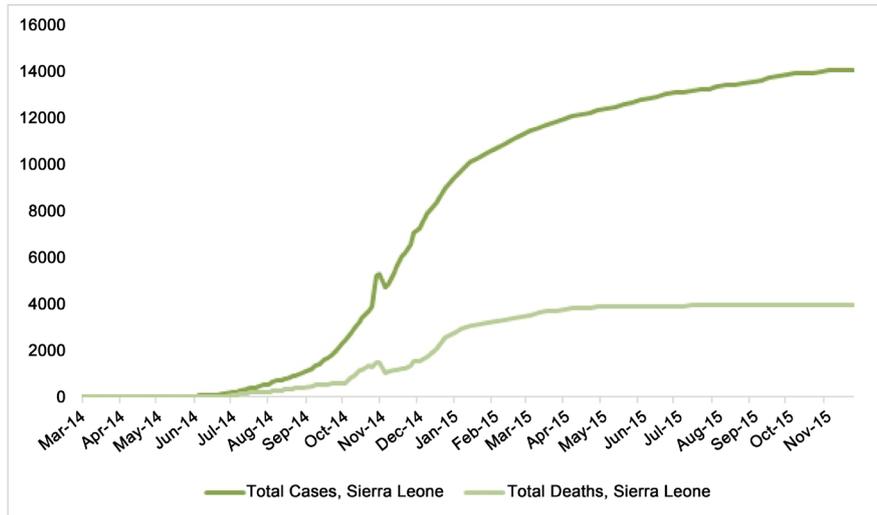
**Figure 1.** Total suspected, probable, and confirmed cases of Ebola virus disease in Guinea, Liberia, and Sierra Leone, March 25, 2014-November 22, 2015, by date of WHO Situation Report, n = 28,601.



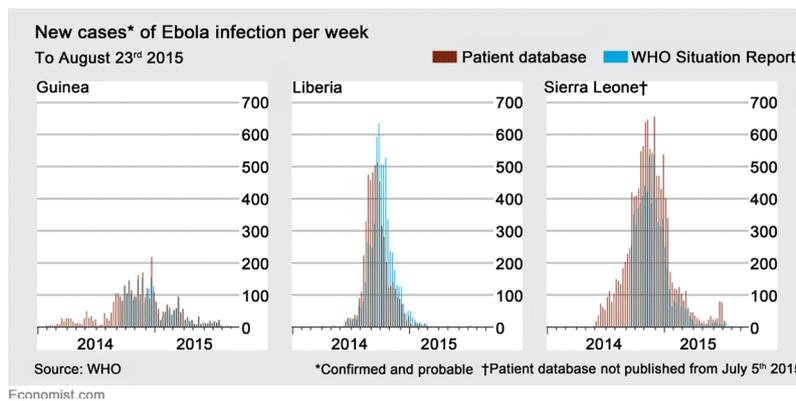
**Figure 2.** Total suspected, probable, and confirmed cases and deaths of Ebola virus disease in Guinea, March 25, 2014-November 22, 2015, by date of WHO Situation Report, n = 3804.



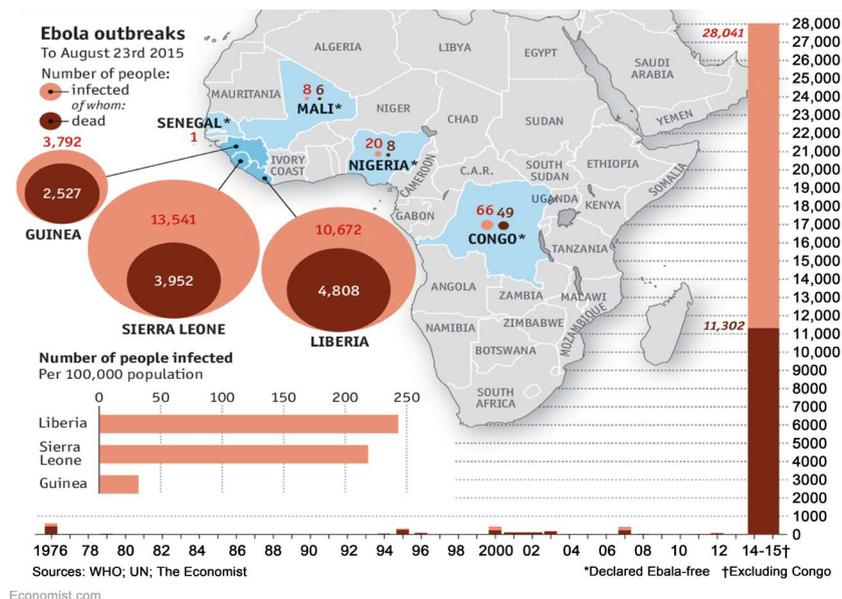
**Figure 3.** Total suspected, probable, and confirmed cases and deaths of Ebola virus disease in Liberia, March 25, 2014-November 22, 2015, by date of WHO Situation Report, n = 10,675.



**Figure 4.** Total suspected, probable, and confirmed cases and deaths of Ebola virus disease in Sierra Leone, March 25, 2014–November 22, 2015, by date of WHO Situation Report, n = 14,122.



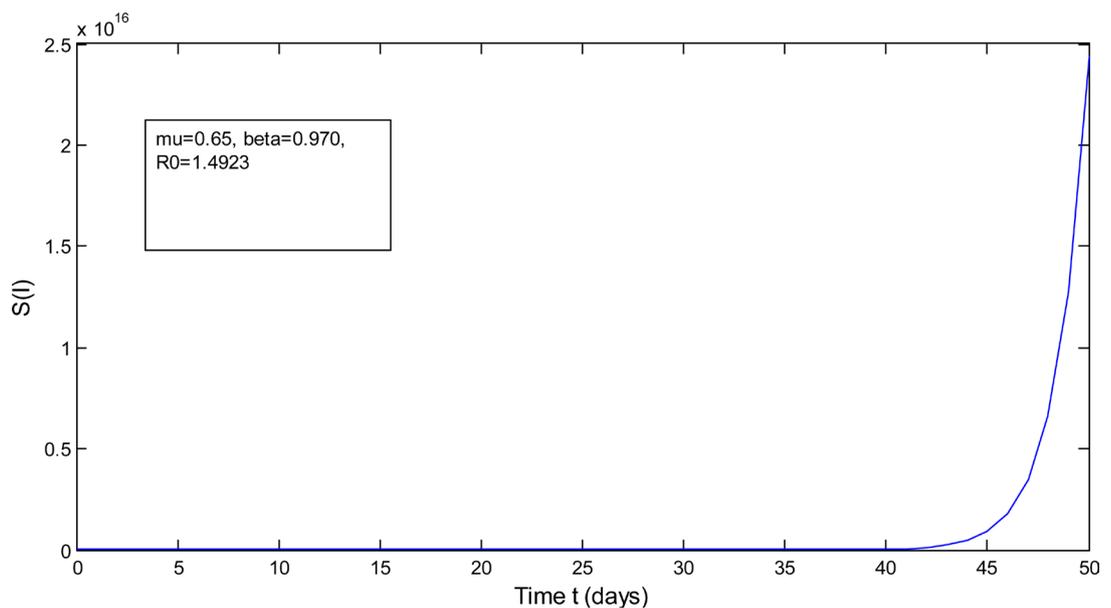
**Figure 5.** New cases of Ebola infection per week in Guinea, Liberia and Serra Leone.



**Figure 6.** Comparative situation among the three Nation during the latest Ebola outbreak.



**Figure 7.** 2014 West African Ebola outbreak distribution map. The current outbreak is located mainly in the West African countries of Guinea, Sierra Leone and Liberia. Image courtesy of the Centers for Disease Control and Prevention, World Health Organization.



**Figure 8.** Simulations of the model showing the total number of susceptible population.

about 997 dead in Guinea, 694 dead in Liberia and about 422 dead in Sierra Leone. The disease continuously persisting in the region and going devastatingly not only throughout the region but also create alarming situation for the whole world. World leaders had no clue about what going on. In the mean while a top Red Cross official had said it will take up to six months to get Ebola outbreak under control as the hunt continues for a vaccine to the deadly disease.

Our Mathematical analysis shows that the disease took a consistent persistent in the community and burden was rising boundlessly. By the end of the year of 2014 and at the beginning of the year 2015 the overall dear toll was mammoth.

Our calculated value for basic reproduction number was approximately 1.10, 1.58 and 1.19 for Guinea, Liberia and Sierra Leone respectively. This indicates that, the disease existed and precautionary measures were not taken properly. Being the poorest countries it was hard for them to control the disease properly. Although some of the world health organization came forward but they actually not sustain there for some other reasons.

However at the middle of the year the disease shows some stability and gradually the rate of infected population was decreasing because the reproduction number getting close to unity. As we know that the disease will no longer persist in the community if the reproduction number becomes less than unity [14].

At the end of the month November our calculated reproduction number was about 1.06, 1.0929 and 1.13 for Guinea, Liberia and Sierra Leone respectively. This result indicating that the EVD getting losses its strength and suddenly the burden of the disease were decreases. Since the reproduction number was above unity, it could be emerged strongly again if something wrong done. For future evaluation about the disease we could only say that a comprehensive measure needs to be implemented throughout the affected region. Since the number  $R_0$  still above unity [8] [9] [11] [13] and if we take our hand close from the precautionary steps and do not work accordingly then it will definitely come again and will come strongly.

## 5. Conclusion

As of December 2<sup>nd</sup> 2015, a total of 28,601 cases have been reported with 11,300 reported deaths (not including cases where the outcome is unknown) [8] [9] [13]. Three thousand eight hundred and four (3804) cases are from Guinea, with 2536 deaths; in Liberia there have been 10,675 cases with 4809 deaths and in Sierra Leone 14,122 cases with 3955 deaths. Our mathematical analysis shows that the basic reproduction number  $R_0$  is still above unity and if we take our hand close from the precautionary steps and do not work accordingly then it will definitely come again and will come strongly. There are some traditional facts that are working as a drawback against the controlling process of the disease. Since the main causes behind this widespread of Ebola are political instability, socio- cultural factors, human's rights violation, limited access of social media and high levels of illiteracy, world leaders would come forward to take some steps for improving this situations.

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