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HEALTH BROKEN WOVEN POISSON SPHERES TO MANAGE DEADLY EBOLA INCIDENCES

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ABSTRACT

The deadly infectious Ebola incidences scare not only to the residents of western Africa but also to the travelers and medical professionals who treat the patients, as they became victims. Since 27 July until 13 August 2014 alone, about 2,127 Ebola cases occurred in just four Western African countries: *Guinea*, *Liberia*, *Nigeria* and *Sierra Leone* and more than 50% of them died. The mortality is extremely higher. No known medication exists. Though the virus is not airborne spreading, a contact with the patient's fluids, tissues, or bodies is known to transmit Ebola virus. There had been three categories: *Suspected*, *probable*, or *confirmed* in the collection of Ebola incidences and deaths. Their data are quite informative if they are properly processed and it is exactly the aim of this article. For this purpose, the stochastic nature of the data is probed rationally. The Ebola incidences and deaths in each category exhibit a separate Poisson chance environment and yet, they are connected. Therefore, suitable Poisson models are developed for each category and are then woven together to analyse the entire pertinent data on Ebola incidences and deaths in those four countries. Pictures are worth the thousand words to comprehend non-trivial findings. Hence, innovatively the data analytic concepts for three-dimensional sphere for each country is developed and applied. By superimposing the four spheres (one for each country), this article points out the relative performance of the four countries with respect to the Ebola incidences and deaths together in each category. One country does better than others in one category but poorly in other two categories. A better performance by a country is a reflection of effective prevention and successful medical treatment of Ebola cases.

Keywords: Maximum Likelihood Estimator, Concentric Spheres, Multinomial Model

1. MOTIVATION

Ebola is a deadly infectious disease and it is a nightmare even to the medical professionals, as some of them treating the patients became its victims. Lashley and Durham (2007; Magill *et al*., 2012) for a full list of infectious diseases. This epidemic was named *Ebola* because its first case, a school headmaster, was discovered near the African river called Ebola on 26 August 1976 in a village *Yambuku*, in Mongala district in northern democratic republic of Congo and he died on 8th September 1976. BWHO (1978) report provides details. Pattyn (1978; Pourrut *et al*., 2005) illustrates the chronology of Ebola virus. Researchers believe that the Ebola virus originated in monkeys, pigs, or fruit bats but is never air borne. Leroy *et al*. (2005; BBC, 2005; Weingartl *et al*., 2012; Olival *et al*., 2013; BBC, 2014; Nossiter, 2014; Pollack, 2014; GCS, 2014) for details on the sources of Ebola virus.

Medical workers without wearing appropriate protective gloves and masks contract the virus from the Ebola patients. Other preventive action includes a quick disposal of the fluids, tissues and even bodies of the Ebola patients. Morvan *et al*. (1999) have catalogued both DNA and RNA of Ebola virus. In some countries, quarantine of the Ebola patients is allowed to prevent the disease from spreading. No effective vaccine is now available for humans. Johnson *et al*. (1995; Hoenen *et al*., 2012) for details on much needed vaccine for Ebola. No effective treatment now exists.

Weingartl *et al*. (2013) contains an excellent review of Ebola virus.The disease has a high mortality. Given this nature of the disease, many fear that this Ebola virus could be abused as a bioterror weapon. On 31th July 2014, an experimental drug named *ZMapp* has been successfully tested on humans. The long-term complications in surviving patients include inflammation of the testicles, joint pains, skin peeling, blindness, hair loss among others. See CDC (2014; Cham, 2014; Roy-Macaulay, 2014) for further details about the recent Ebola incidences. A hope is created by the announcements CNN (2014a; 2014b)

The recent outbreak of occurred in Guinea on 6th December 2013 and it was a 3-year-old boy in the village of Mellandou, Gueckedou Perfecture, Guinea. However, it was detected only March 2014. Just for the seriousness of the Ebola's infectivity, note that his mother, 3-year-old sister and grandmother also died soon with symptoms. The Ebola's symptoms are fever, sore throat, headache, muscle pain, vomiting, nausea, diarrhoea, decreased functioning of kidney, bleeding within the body and outwardly through nose and other organs. These symptoms could start as early as two days. The Ebola virus could be contracted in contact with blood or bodily fluids.

However, the epidemic has already spread to the neighbouring countries: *Liberia*, *Nigeria and Sierra Leone*. Simpson (1977) for ways to prevent Ebola virus. The total cases exceeded 2,127 cases in these four countries alone and it is known to spread to other parts of the world. It is so sad to notice that more than half of them (about 1145 patients to be specific) died. It has become a great concern to the governing agencies of the countries and the World Health Organization (WHO). Both the infection goes through three identification stages: *Suspect, probable and confirmed*, according to the medical experts.

At any stage, death can happen to the patient. See **Table 1** for the patterns of the Ebola incidences and deaths in the four countries: *Guinea, Liberia, Nigeria and Sierra Leone*. About 194 countries have signed up to apply preventive measures against Ebola virus. See Choi and Croyle (2013) for details on Ebola virus.

The number of Ebola cases and the number of Ebola deaths in **Table 2** during the period starting 27 July 2014 till 13 August 2014 in just four countries alone reveal a lot more non-trivial insights into the healthcare management of Ebola incidences versus deaths. To be specific, let Y denote the number of Ebola cases in a defined geographic region during a selected period. With the sample space $y = 0,1,2,...,\infty$ for the random variable Y and the parameter $\theta > 0$ to denote the *Ebola incidence rate*, it is reasonable to assume that Y follows a *Poisson probability distribution* Equation 1:

$$Poi(y|\theta) = e^{-\theta}\theta^{y} / y!; y = 0,1,2,...,\infty; \theta > 0 \quad (1)$$

It is well known that based on a random sample $y_1, y_2, ..., y_n$, the Maximum Likelihood Estimate (MLE) of the incidence rate is $\hat{\theta} = \bar{y}$ where $\bar{y}$ is the sample average. The MLE is preferred because of its invariance property. That is the MLE of a function of parameters is the function of the MLE. Let I_c = 1 or zero with probability ϕ and 1-ϕ respectively, depending on whether the c^{th} case died or survived. With this classification, let $Z = I_1 + I_2 + ... + I_y$ be the number of Ebola deaths in a region during a period. It is well known that the number of Ebola deaths in a region during a period conditionally follows a binomial distribution in Equation 2:

$$Bin(z|\phi, y) = \frac{y!}{z!(y-z)!}\phi^{z}(1-\phi)^{y-z}; \quad z = 0,1,2,...,y; 0 < \phi < 1 \quad (2)$$

where, ϕ is interpreted as the Ebola mortality rate. Unconditionally speaking (that is, without knowing how many Ebola cases occurred in the region in a period of time), what is the Ebola's mortality rate? To answer this question, we need the unconditional (that is, marginal) probability distribution of the random numbers, z. To find it, we first find the joint bivariate probability distribution of the number of Ebola cases, y and the number of Ebola deaths, z. That is Equation 3:

$$f(y,z|\theta,\phi) = \frac{e^{-\theta}[\theta(1-\phi)]^{y}[\phi/(1-\phi)]^{z}}{z!(y-z)!}; \quad y = 0,1,2,..; z = 0,1,2,..,y; \quad \theta > 0; 0 < \phi < 1 \quad (3)$$

From the joint probability distribution (3), the marginal probability distribution of the number of *Ebola deaths* in a region during a period is obtained and it is parameters compounded Poisson distribution:

$$PCPoi(z|\theta,\phi) = \sum_{y=z}^{\infty} f(y,z|\theta,\phi) = e^{-\theta\phi}(\theta\phi)^{z} / z!; \quad z = 0,1,2,...,\infty; \theta > 0; 0 < \phi < 1 \quad (4)$$

Table 1. Ebola incidences and deaths (until 13 August 2014 since 6 December 2013)

Country	Confirmed	Probable	Suspect	Totals (by country)
Guinea				
Cases	376	133	10	519
Deaths	245	133	2	380
Liberia				
Cases	190	423	173	786
Deaths	154	190	69	413
Nigeria				
Cases	11	0	1	12
Deaths	4	0	0	4
Sierra Leone				
Cases	733	38	39	810
Deaths	309	34	5	348
Totals				
Cases	1310	594	223	2127
Deaths	712	357	76	1145

Table 2. Source: http://en.wikipedia.org/wiki/2014_West_Africa_Ebola_outbreak

	Cumulative		Guinea		Liberia		Sierra Leone		Nigeria	
Date of report	Cases	Deaths	Cases	Deaths	Cases	Deaths	Cases	Deaths	Cases	Deaths
13-Aug-14	2,127	1,145	519	380	786	413	810	348	12	4
11-Aug-14	1,975	1,069	510	377	670	355	783	334	12	3
9-Aug-14	1,848	1,013	506	373	599	323	730	315	13	2
6-Aug-14	1,779	961	495	367	554	294	717	298	13	2
4-Aug-14	1,711	932	495	363	516	282	691	286	9	1
1-Aug-14	1,603	887	485	358	468	255	646	273	4	1
30-Jul-14	1,440	826	472	346	391	227	574	252	3	1
27-Jul-14	1,323	729	460	339	329	156	533	233	1	1

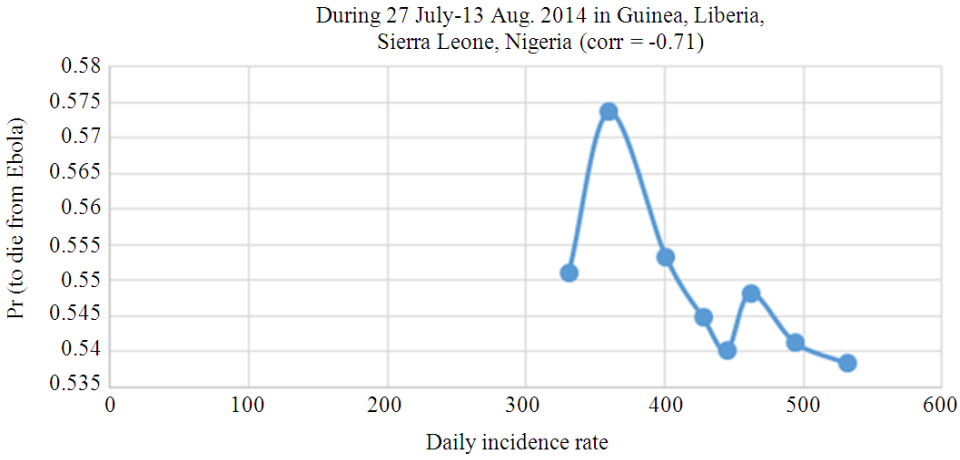

Fig. 1. Pr (to die of Ebola) in terms of incidence rate over 27 July-13 August 2014

It is easy to see the MLE of the Ebola mortality rate is $\hat{\phi}=\frac{\overline{z}}{\overline{y}}$, where $\overline{z}$ is the average number of Ebola deaths. For the data in **Table 2** (note that the sample size is n = 4 based on four countries), the daily Ebola incidence and Ebola mortality rates are estimated and graphed in **Fig. 1**. The Ebola mortality rate ranged between about 53 and 57% from 27 July 2014 until 13

August 2014, which is quite alarming. Let us compare this trend with those of periods: 5 June through 23 July (**Fig. 2**), 2 April through 23 May (**Fig. 3**) and 25 March through 27 March (**Fig. 4**) of 2014. The mortality rate was larger than 60% in earlier periods. Interestingly, the correlation the Ebola incidences and deaths is -0.61, 0.56, 0.36 and -0.71 in the chronological order of time.

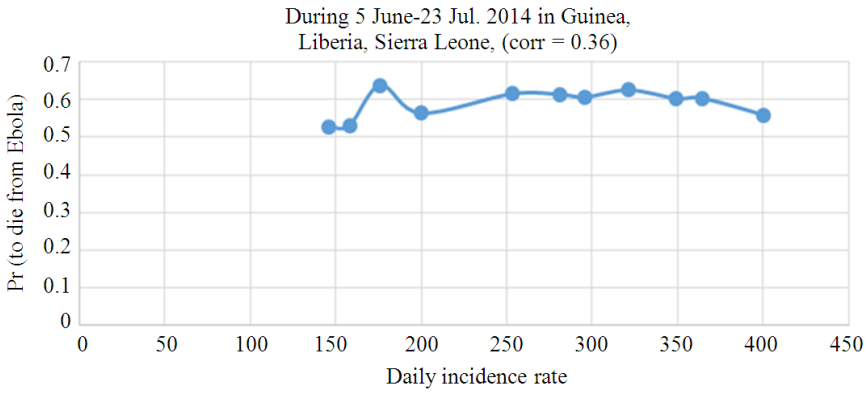

Fig. 2. Pr (to die of Ebola) in terms of incidence rate over 5 June-23 July 2014

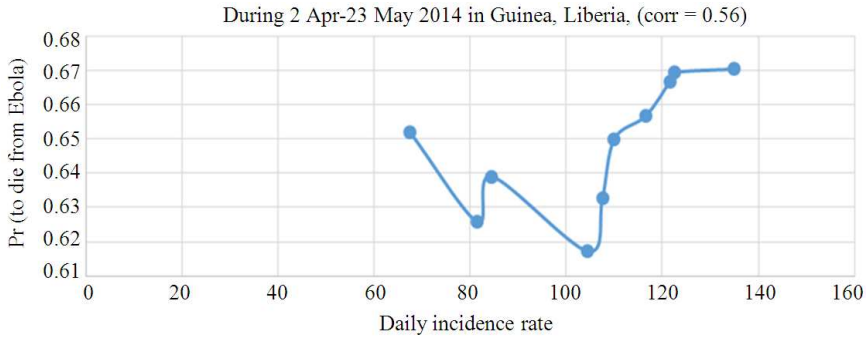

Fig. 3. Pr (to die of Ebola) in terms of incidence rate over 2 April-23 May 2014

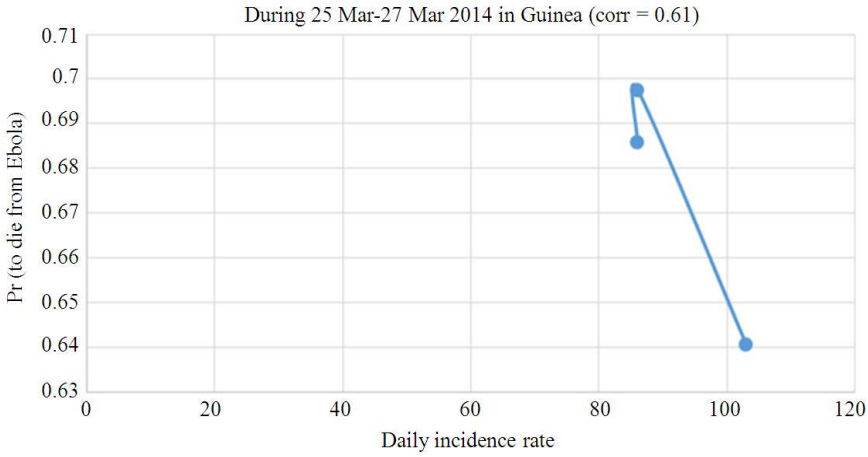

Fig. 4. Pr (to die of Ebola) in terms of incidence rate over 25-27 March 2014

Notice the correlation was negative to begin with, became positive and eventually negative. The negative correlation means that when the Ebola incidence rate is upward, its mortality rate is downward. The positive correlation means that the Ebola incidence and mortality rates were either upward or downward together. The correlations of the data analysis reveal that the healthcare management of Ebola is lately same as before but it must have been out of control in the interim periods. This clue motivates to conduct facts-finding operations by probing through the Ebola data for the four countries in **Table 1** and it is the research aim of this article.

2. MAIN RESULTS: WOVEN POISSONS FOR EBOLA FACTS FINDING

A resident in the region with Ebola epidemic incidence rate θ might encounter the virus and becomes one of three orderly possibilities: *Suspect*, *probable*, or *confirmed* Ebola cases depending on his/her vulnerability and/or intensity of the virus. The virus is in an embryonic stage for the victim to be labelled suspect. The chance for falling in the suspect category is an unknown probability $0<\pi_s<1$. When the person shows symptoms as described in the motivation section, s/he becomes an Ebola probable with a finite chance $0<\pi_p<1$. With the positive outcome (s) in lab test (s) and/or after the physician's medical checking, the person is classified as confirmed with a probability $0<1-\pi_s-\pi_p<1$. Let Y_s, Y_p and Y_c be respectively the number of Ebola suspect, probable and confirmed cases. Note that the number, Y_c of Ebola cases is the sum of all three numbers: Y_s, Y_p and Y_c. That is, $Y=Y_s+Y_p+Y_c$ and it follows a Poisson distribution (1). Because of the damaging process of the Poisson distribution (that is, a Poisson random variable decomposes into only several independent Poisson random variables in the same manner as its incidence parameter decomposes accordingly), the three counts Y_s, Y_p and Y_c follow independently a Poisson distribution with different parameters. That is Equation 5 to 7:

$$Poi(y_s|\theta,\pi_s)=e^{-\theta\pi_s}(\theta\pi_s)^{y_s}/y_s!;\quad y_s=0,1,2,...,\infty;\theta>0;0<\pi_s<1 \tag{5}$$

$$Poi(y_p|\theta,\pi_p)=e^{-\theta\pi_p}(\theta\pi_p)^{y_s}/y_p!;\quad y_p=0,1,2,...,\infty;\theta>0;0<\pi_p<1 \tag{6}$$

and:

$$Poi(y_c|\theta,\pi_c)=e^{-\theta\pi_c}(\theta\pi_c)^{y_c}/y_c!;\quad y_c=0,1,2,...,\infty;\theta>0;0<\pi_c<1 \tag{7}$$

As discussed earlier, the MLE of the compounded Poisson parameters $(\theta\pi_s),(\theta\pi_p)$ and $(\theta\pi_c)$ are $\bar{y}_s, \bar{y}_p$ and $\bar{y}_c$. Nevertheless, the MLE of the Ebola incidence rate, θ is $\hat{\theta}=\bar{y}$. Hence, the MLE of the chances $\pi_s, \pi_p,$ and π_c for an Ebola victim to be a suspect, probable and confirmed are respectively $\hat{\pi}_s=\frac{\bar{y}_s}{\bar{y}}, \hat{\pi}_p=\frac{\bar{y}_p}{\bar{y}}$ and $\hat{\pi}_c=1-\frac{(\bar{y}_s+\bar{y}_p)}{\bar{y}}$.

Analogous to early discussions, each case in suspected, probable and confirmed category could turn out to be dead respectively with a chance ϕ_s, ϕ_p and ϕ_c. In which framework, the number of deaths in suspected, probable and confirmed category are Z_s, Z_p and Z_c. They follow independently a parameter compounded Poisson distribution Equation 8 to 10:

$$PCPoi(z_s|\theta,\pi_s,\phi_s)=e^{-\theta\pi_s\phi_s}(\theta\pi_s\phi_s)^{z}/z_s!;\quad z_s=0,1,2,...,\infty;\theta>0;0<\pi_s<1;0<\phi_s<1 \tag{8}$$

$$PCPoi(z_p|\theta,\pi_p,\phi_p)=e^{-\theta\pi_p\phi_p}(\theta\pi_p\phi_p)^{z}/z_p!;\quad z_p=0,1,2,...,\infty;\theta>0;0<\pi_p<1;0<\phi_p<1 \tag{9}$$

and:

$$PCPoi(z_c|\theta,\pi_c,\phi_c)=e^{-\theta\pi_c\phi_c}(\theta\pi_c\phi_c)^{z}/z_c!;\quad z_c=0,1,2,...,\infty;\theta>0;0<\pi_c<1;0<\phi_c<1 \tag{10}$$

Consequently, the MLE of the Ebola mortality rate in the suspected, probable and confirmed category are respectively $\hat{\phi}_s=\frac{\bar{z}_s}{\bar{y}_s}$, $\hat{\phi}_p=\frac{\bar{z}_p}{\bar{y}_p}$ and $\hat{\phi}_c=\frac{\bar{z}_c}{\bar{y}_c}$, where $\bar{z}_s$ $\bar{z}_s$ and $\bar{z}_s$ are respective average number of Ebola deaths in the suspected, probable and confirmed category.

The epidemic of Ebola has a strangeness unlike other epidemics such as cholera, smallpox etc. See Smith (2005) for reasons to worry about the Ebola incidences as a serious epidemic. The symptoms of Ebola are deceptive for a while for the family members and other community co-residents. After a lag period, a suspect with partial symptoms goes to a medical facility for counseling. The medical facilities may not be fully

equipped to treat Ebola victims. Several announcements appear in online that the foundations and charities are forthcoming with donations to be used for Ebola patients. Such facilitations do probably help the medical professionals to confirm the Ebola cases much better now than before. There is no known medication to cure Ebola patients. With these limitations and blind spots in the data collection process, the number of Ebola cases is under-reported. A probabilistic estimate of the number of Ebola cases is there a necessity, practically viewing. For this purpose, we need to first identify an underlying probability pattern of the number of Ebola cases based on the number of Ebola deaths. This amounts to finding, from (3) and (4), the conditional probability distribution of *Y* given *Z* and it happens to be a *shifted Poisson distribution* Equation 11:

$$SPoi(y|\theta,\phi,z)=\frac{e^{-\theta(1-\phi)}[\theta(1-\phi)]^{y-z}}{(y-z)!};\quad y=z,z+1,z+2,..;z=0,1,2,..,\infty;\quad \theta>0;0<\phi<1. \tag{11}$$

The result (11) indicates that its conditional expected value is Equation 12:

$$E(y|\theta,\phi,z)=\sum_{y=z}^{\infty} ySPoi(y|\theta,\phi,z)=z+\theta(1-\phi)=z+(1-\phi)E(y|\theta) \tag{12}$$

With a variance Equation 13:

$$Var(y|\theta,\phi,z)=\sum_{y=z}^{\infty}\{y-z-\theta(1-\phi)\}^2 SPoi(y|\theta,\phi,z)=\theta(1-\phi)=(1-\phi)Var(y|\theta,\phi) \tag{13}$$

The result (12) implies that the conditional projection of the number of Ebola incidences based on the number of Ebola deaths starts at *z* with an increment (1-ϕ), which is the *survival chance* from Ebola. It is well known that lesser the variance refers more efficiency of projection. The result (13) confirms that the conditional variance $Var(y|\theta,\phi,z)$ is less than the unconditional variance $Var(y|\theta,\phi)$ meaning that the conditional projection is more efficient. The conditional projection efficiency happens to be survival chance (1-ϕ).

Just for a contrast, if we have to project the number *z* of Ebola deaths without a knowledge of how many Ebola cases occurred, it will be $E(z|\theta,\phi)=\theta\phi$ with a variance $Var(z|\theta,\phi)=\theta\phi$ from (4). It means that the heterogeneity increases along with increased Ebola deaths in the absence of knowing how many Ebola cases have occurred. With a knowledge about the number, *y* of Ebola cases, the projection of the number, *z* of Ebola deaths is Equation 14:

$$E(z|\theta,\phi,y)=\{\frac{y}{E(y|\theta)}\}E(z|\theta,\phi) \tag{14}$$

With a variance Equation 15:

$$Var(z|\theta,\phi,y)=\{\frac{y}{E(y|\theta)}\}\{1-\frac{Var(z|\theta,\phi)}{Var(y|\theta)}\}Var(z|\theta,\phi) \tag{15}$$

according to (2), the result (14) implies that the conditional projection, $E(z|\theta,\phi,y)$ of Ebola deaths based on knowing *y* number of Ebola cases have occurred is more, equal, or lesser than the unconditional projection, $E(z|\theta,\phi)$ without knowing the number of Ebola cases depending on whether the *proportionality factor*, $\left\{\frac{y}{E(y|\theta)}\right\}$ more, equal, or lesser than one. Realize that the proportionality factor is a ratio of actual over expected number of Ebola cases. Often, healthcare administrators would prefer to have the actual number of Ebola cases lesser than its expected number. Now, let us examine the efficiency of the conditional projection of the number of Ebola deaths based on a knowledge of the number *y* of Ebola cases and it is a bit more complex amount $\left\{\frac{y}{E(y|\theta)}\right\}\left\{1-\frac{Var(z|\theta,\phi)}{Var(y|\theta)}\right\}$. The first factor $\left\{\frac{y}{E(y|\theta)}\right\}$ has been interpreted already. The second factor $\left\{1-\frac{Var(z|\theta,\phi)}{Var(y|\theta)}\right\}$ refers the variance reduction relative to

the unconditional variance but it is due to the knowledge on the number of Ebola cases. The variance reduction (equivalently, it is the increase in projection efficiency) happens to be the survival chance (1-ϕ).

Several Poisson distributions are oven to describe the chance mechanism in which the Ebola incidences and deaths occur. Yet, there is a symmetry in the Poisson chance environment. The conditional projection of the number of Ebola cases based on knowing the number of Ebola deaths or vice versa has an efficiency level (1-ϕ), which happens to be the survival chance from Ebola epidemic.

Consequently, the number of Ebola cases, *y* and deaths, *z* must be correlated. The value of the correlation explains the latent healthcare management of Ebola epidemic. From (3), the correlation between *y* and *z* is obtained and it is $Corr(Y,Z|\theta,\phi)=\pm\sqrt{\phi}$.

Analogous results and interpretations exist in suspected, probable and confirmed category. The conditional probability distribution of Y_s given Z_s is a *shifted Poisson distribution* $SPoi(y_s|\theta\pi_s,\phi_s,z_s)$. The conditional probability distribution of Y_p given Z_p is a *shifted Poisson distribution* $SPoi(y_p|\theta\pi_p,\phi_p,z_p)$. The conditional probability distribution of Y_c given Z_c is a *shifted Poisson distribution* $SPoi(y_c|\theta\pi_c,\phi_c,z_c)$. The survival chance from Ebola epidemic is $(1-\phi_s)$, $(1-\phi_p)$ and $(1-\phi_c)$ in suspected, probable and confirmed category which are the efficiency of the conditional projection of the number of Ebola incidences based on the number of Ebola deaths and vice versa in the category. The correlation between the number of Ebola cases and the number of Ebola deaths is $\pm\sqrt{\phi_s}$, $\pm\sqrt{\phi_p}$ and $\pm\sqrt{\phi_c}$ in suspected, probable and confirmed category respectively.

3. ILLUSTRATIONS OF EBOLA CASES AND DEATHS IN GUINEA, LIBERIA, NIGERIA AND SIERRA LEONE

The recent outbreak of the Ebola cases and deaths cover a period from 6th December 2013 until 13th August 2014, as occurred in Guinea, Liberia, Nigeria and Sierra Leone in African continent. The summarized data are displayed in **Table 1**. A synapsis of daily occurrence is given in **Table 2**. The derived expression of Section 2 are applied and the results are summarized in **Table 3**.

It is mysterious that the MLE of the daily Ebola incidence rates (with minimum of 21 and a maximum of 531) and the chance of dying due to Ebola (with minimum of 0.52 and maximum of 0.69) are negatively correlated (that is, -0.75) meaning the chance for death is lesser when the Ebola incidence rate is higher. A simple regression fit is performed (**Fig. 5**). The projected daily chance of dying due to Ebola is $0.65-0.0002\,\hat{\theta}$, where $\hat{\theta}$ is the MLE of the Ebola incidence. The regression fir is statistically significant with a multiple correlation coefficient $R^2=0.57$. The residual plot (**Fig. 6**) confirms the significance of the fit. The estimated chance of dying due to Ebola decreases by two for every estimated increase of 10,000 Ebola cases. This change is nominal. The data do not lie. The decrease is not intuitive. Is it a clue that medical facilitations of Ebola cases are quickly taken to a high alert level? The *odds* of surviving from Ebola epidemic across the four countries are dramatically different (**Fig. 7**). Only in Nigeria, the odds are significantly higher. The odds in Guinea, Liberia and Sierra Leone are not good.

Why not probe further in each category among *suspected, probable and confirmed Ebola cases?* **Figure 8** for the comparative estimates of the Ebola incidences and **Fig. 9** for a comparison of the estimated chance of dying due to Ebola across countries: Guinea, Liberia, Nigeria and Sierra Leone. The suspected and probable Ebola cases are estimated to be more in Liberia than in other two countries. The confirmed Ebola cases are estimated to be more in Guinea than in other two countries. The suspected and probable Ebola cases most likely to die in Liberia than in other two countries, according to their MLEs. The confirmed Ebola cases are most likely to die in Nigeria than in other two countries, according to their MLEs. These numerical estimates are summarized in **Table 3**.

3.1. Ebola Geometric Proximities

Unfortunately, the collected data do not exhibit explicitly information how effective were the administrative practices to prevent or about how successful the medical treatment of Ebola cases. Yet, an insight into them needs to be developed for future operations. The data of the four countries with respect to the suspected, probable and confirmed Ebola incidences and deaths should be molded with an appropriate innovative three-dimensional graphical concept because pictures are worth thousand words.

Table 3. Comparison of estimate of suspected, probable and confirmed Ebola cases

Country	Survival odds	Pi(c)	Pi(p)	Pi(s)	All	Estimate
Guinea						
Cases		0.72	0.26	0.02	173.00	Incidence
Deaths	7.54552E-21	0.64	0.35	0.01	0.73	Death
Liberia						
Cases		0.24	0.54	0.22	262.00	Incidence
Deaths	1.00628E-54	0.37	0.46	0.17	0.53	Death
Nigeria						
Cases		0.92	0.00	0.08	4.00	Incidence
Deaths	0.074671913	1.00	0.00	0.00	0.33	Death
Sierra Leone						
Cases		0.90	0.05	0.05	270.00	Incidence
Deaths	1.31416E-67	0.89	0.10	0.01	0.43	Death
Totals						
Cases		0.62	0.28	0.10	709.00	Incidence
Deaths	6.9333E-143	0.62	0.31	0.07	0.54	Death

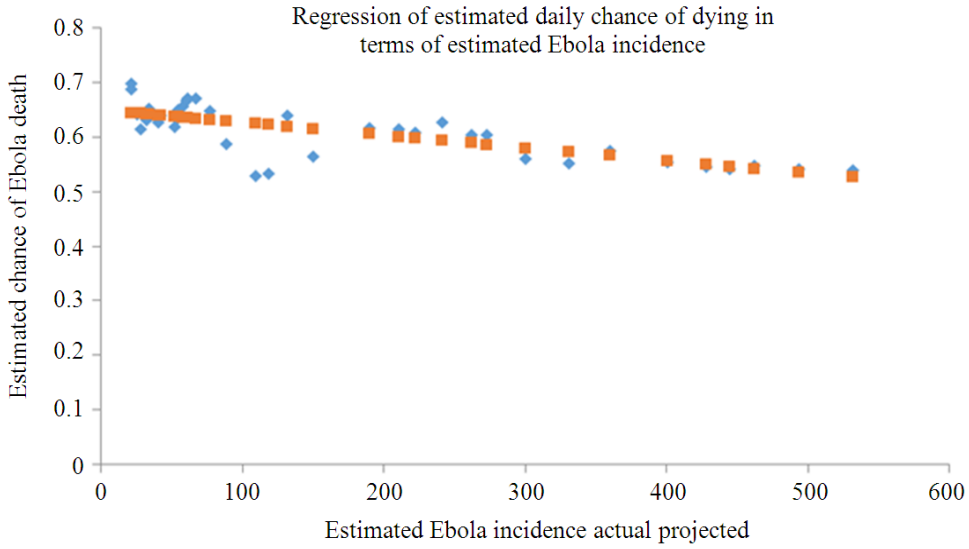

Fig. 5. The chance of dying from Ebola in terms of its incidence rate

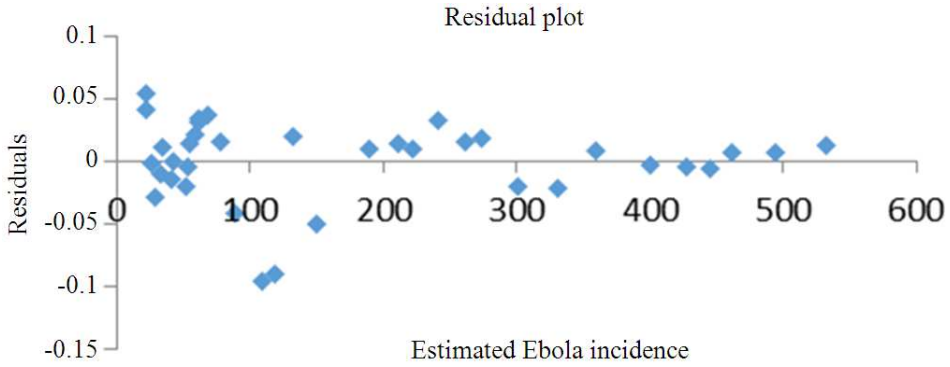

Fig. 6. Residual plot revealing no pattern

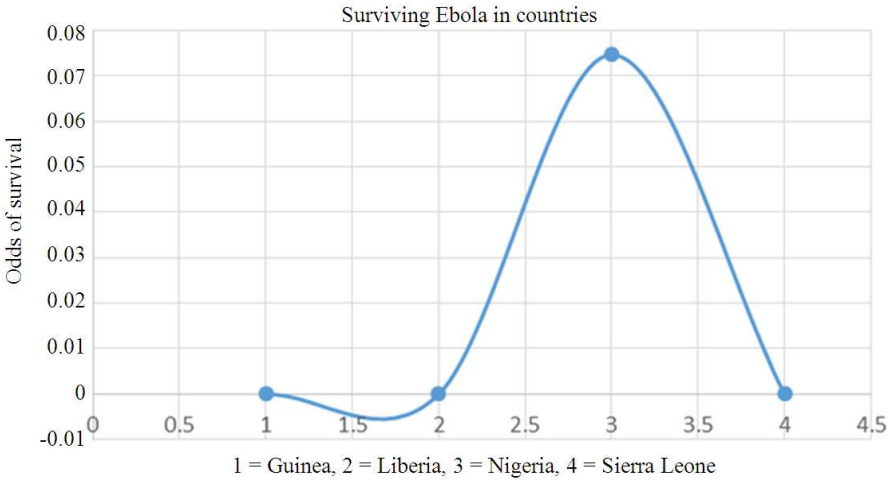

Fig. 7. Comparison of estimated odds of surviving Ebola epidemic across four countries

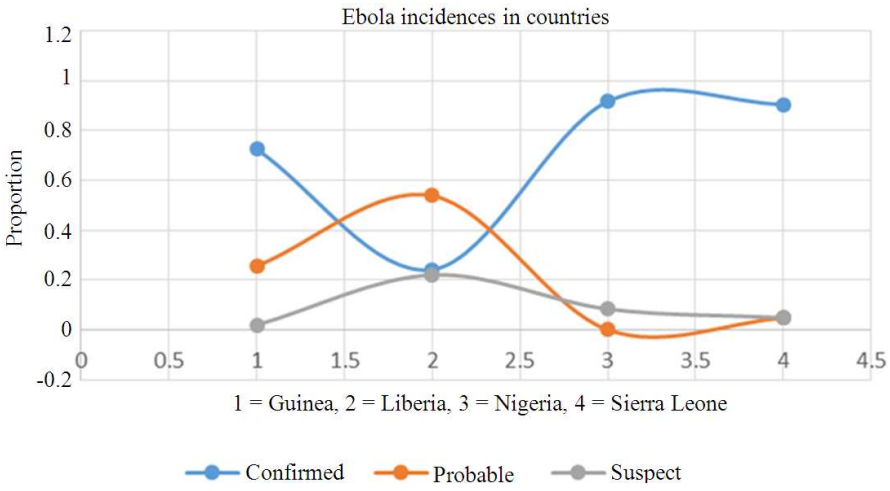

Fig. 8. Comparison of estimated suspected, probable and confirmed incidences

For this purpose, let a vector (θ,π_i,ϕ_i) denote respectively the expected aggregate number of Ebola cases, the probability for an Ebola case is in the i^{th} category (i = 1 for suspected), (i = 2 for probable) and (i = 3 for confirmed), the probability for an Ebola case in the i^{th} category to die. The MLE of the vector is $(\hat{\theta},\hat{\pi}_i,\hat{\phi}_i)$ and it varies among the four countries. Note that $d=\sqrt{\hat{\theta}^2+\hat{\pi}_i^{\,2}+\hat{\phi}_i^{\,2}}$ is the radial length of a country's sphere in a three-dimensional illustration.

Let $(\hat{\theta}_{\min},\hat{\pi}_{i,\min},\hat{\phi}_{i,\min})$ and $(\hat{\theta}_{\max},\hat{\pi}_{i,\max},\hat{\phi}_{i,\max})$ be their minimum and maximum respectively. Note that the Equation 16 is the *Poisson sphere* for a country in the i^{th} category:

$$\frac{(\hat{\theta}-\hat{\theta}_{\min})^2}{\hat{\theta}_{\max}}+\frac{(\hat{\pi}_i-\hat{\pi}_{i,\min})^2}{\hat{\pi}_{i,\max}}+\frac{(\hat{\phi}_i-\hat{\phi}_{i,\max})^2}{\hat{\phi}_{i,\max}}=d \tag{16}$$

Sphere with a larger volume signifies more volatility with respect to the Ebola incidences and deaths. In each category, there are four concentric spheres at different locations and sizes depending their radius and the estimates $(\hat{\theta},\hat{\pi}_i,\hat{\phi}_i)$. See **Figure 10** through 11 for concentric spheres for the *confirmed, probable and suspected* categories.

In the confirmed category (**Fig. 10**), the countries (the spheres) rank from smallest to largest in an order: Liberia,

Guinea, Nigeria and Sierra Leone. The country Sierra Leone is the most volatile in the confirmed category.

In the probable category (**Fig 11**), the countries (the spheres) rank from smallest to largest in an order: Nigeria, Sierra Leone, Guinea and Liberia. The country Liberia is the most volatile in the probable category. In the suspected category (**Fig. 12**), the countries (the spheres) rank from smallest to largest in an order: Nigeria, Guinea, Sierra Leone, and Liberia. The country Liberia is again the most volatile in the suspected category.

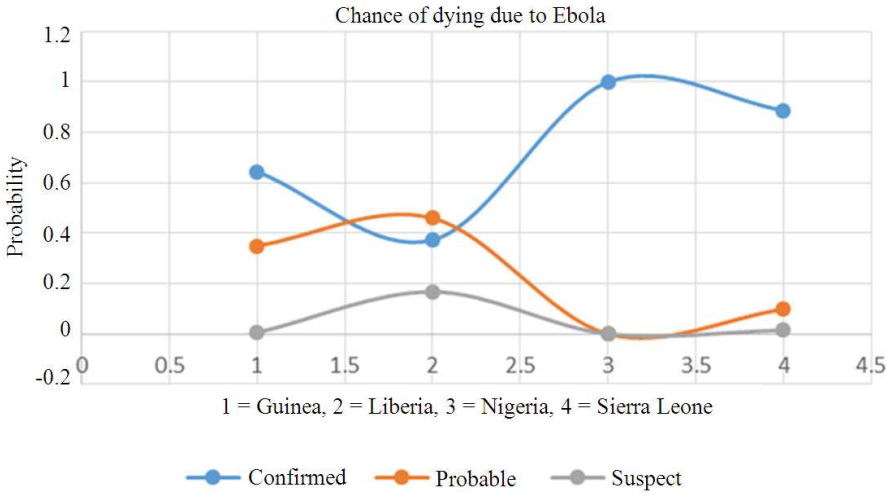

Fig. 9. Comparison of estimated chance of dying due to Ebola across countries

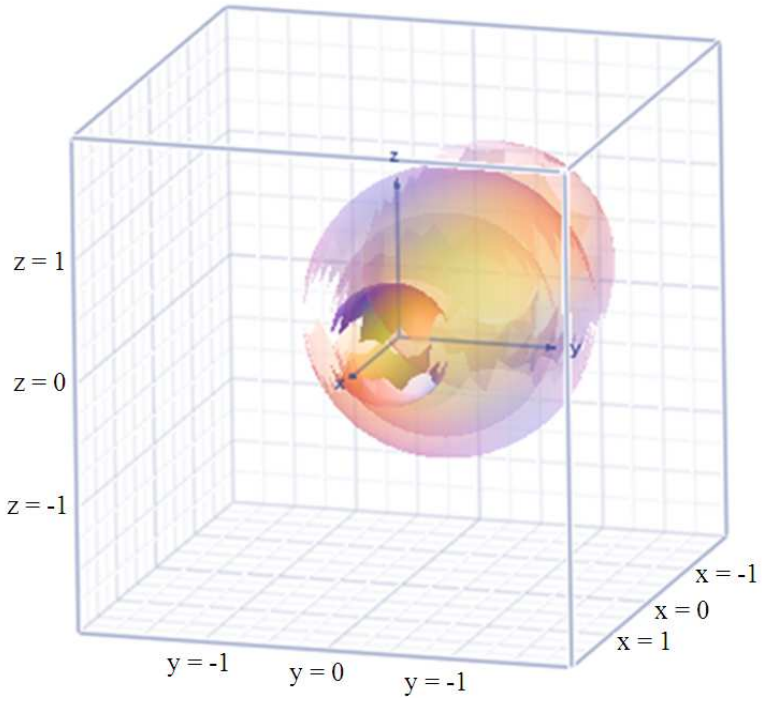

Fig. 10. Health broken spheres of Ebola incidence, proportion of confirmed, chance of dying after confirmed (1st sphere = Liberia, 2nd sphere = Guinea, 3rd sphere = Nigeria, 4th sphere = Sierra Leone)

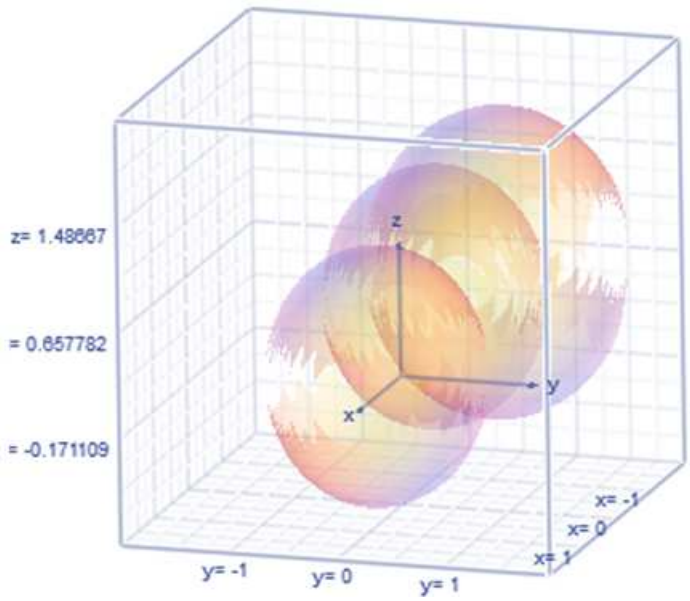

Fig. 11. Health broken *spheres* of Ebola incidence, proportion of probable, chance of dying after probable (1st sphere = Nigeria (a single point), 2nd sphere = Sierra Leone, 3rd sphere = Guinea, 4th sphere = Liberia)

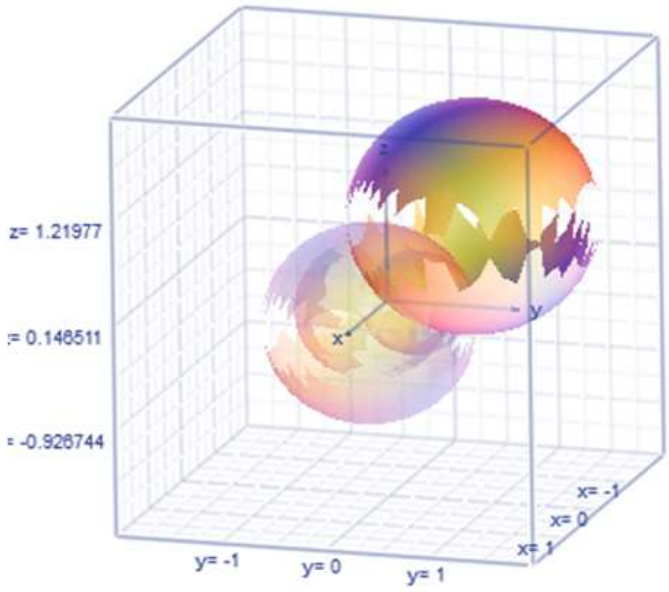

Fig. 12. Health broken spheres of Ebola incidence, proportion of suspected, chance of dying after suspected (1st sphere = Nigeria, 2nd sphere = Guinea, 3rd sphere = Sierra Leone, 4th sphere = Liberia)

4. CONCLUSION

Having learned that one country is more volatile than others in one category are but is better in other category. This transition is due to administrative, medical and other several infrastructures within the country. International travelers stop visiting such a volatile country. The ships or other commercial

transportations cease to arrive or leave from such volatile country causing the economy of the volatile country suffers. To find out, how destructive the Ebola incidences and deaths of these four countries on their economies requires an expansion of pertinent database but it is worthwhile.

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