MATHEMATICAL APPROACH TO "SPANISH FLU" PANDEMIC

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Abstract

Paper deals with an attempt of description, possible prediction of long-term aftermath and mathematical analysis of famous "Spanish Flu" pandemic in the second decade of 20th century. Authors tried to apply current experience to present situation in the World to, possibly, find the optimal ways of overcoming the continuing epidemic, supplying some helpful analysis of arising situation.

1. Introduction

Being under the huge influence of present situation of global ongoing COVID-19 pandemic covering all over the World, authors decided to carry out some investigations of former happening epidemics making the mathematical approach to them, in the attempt to describe and predict the further long-term aftermath of pandemic using definite mathematical functions for description of the process.

Unfortunately, development of humans' society always been followed by ongoing long-term epidemics of different deceases, periodically arising thru all history of existence of humanity. As one of the most awful, huge and widespread epidemic historians consider the Spanish flu, also known as the 1918 flu pandemic, was an unusually deadly influenza pandemic caused by the H1N1 influenza A virus. Lasting from February 1918 to April 1920, it infected 500 million people – about a third of the world's population at the time – in four successive waves. The death toll is typically estimated to have been somewhere between 17 million and 50 million, and possibly as high as 100 million, making it one of the deadliest pandemics in human history **[1]**.

The first observations of illness and mortality were documented in the US (in Kansas and NYC, and months before, in December 1917, at Camp Greene, North Carolina) **[1]**, France, Germany and UK **[2]**. To maintain morale, World War I censors minimized these early reports.

Newspapers reported the epidemic effects in neutral Spain, such as the grave illness of King Alfonso XIII, and these stories created a false impression of Spain as especially hard hit. This gave rise to the name "Spanish" flu (**Figure 1**). Historical and epidemiological data are inadequate to identify with certainty the geographic origin of pandemic, with varying views as to its location.

Figure 1. From 1918 to 1920, Spanish flu infected third of world's population.

Most influenza outbreaks disproportionately kill the very young and the very old with a higher survival rate for those in between, but the Spanish flu pandemic resulted in a higher-than-expected mortality rate for young adults **[3]**. Scientists offer several possible explanations for the high mortality rate of the 1918 influenza pandemic (**Figure 2**), including a severe 6-year climate anomaly that affected the migration of disease vectors and increased the likelihood of the spread of the disease through bodies of water **[3]**. Some analyses have shown the virus to be particularly deadly because it triggers a cytokine storm, ravaging the stronger immune system of young adults **[4]**.

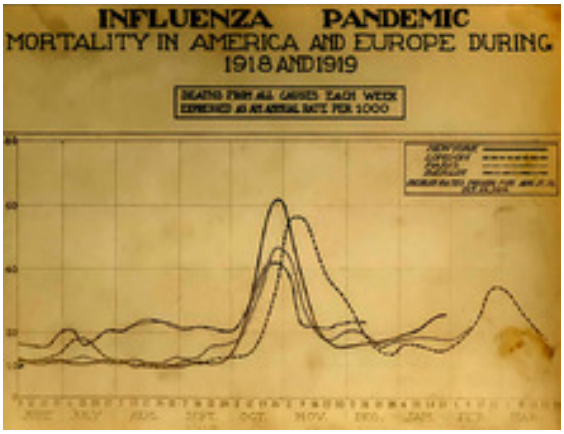

Figure 2. Mortality in America and Europe during 1918 and 1919 pandemic.

In contrast, a 2007 analysis of medical journals from the period of the pandemic found that the viral infection was no more aggressive than previous influenza strains **[4]**. Instead, lack of food, overcrowded medical camps and hospitals together with poor hygiene, all exacerbated by the recent war, and had promoted bacterial super-infection. This super-infection killed most of the victims, typically after a somewhat prolonged death-bed **[3, 4]**.

The 1918 Spanish flu was the first of two pandemics caused by H1N1 influenza A virus; the second was the 2009 swine flu pandemic **[4]**.

It should be noted as well that the World War I greatly influenced on fast expansion of pandemic thru Europe, occupying involved countries one by one.

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2. Move of investigations

Development of Spanish flu pandemic had undergone thru four waves of its expansion.

2.1. First wave of early 1918

The pandemic is conventionally marked as having begun on 4 March 1918 with the recording at Camp Funston in Kansas, US, despite there likely was having been cases before this [5]. The disease had been observed in Haskell County in January 1918. By 11 March 1918, the virus had reached Queens, NY. Failure to take preventive measures in March / April was later criticized.

As the US had entered World War I, the disease quickly spread from Camp Funston, a major training ground for troops of the American Expeditionary Forces, to other US camps and Europe. It became an epidemic in the Midwest, East Coast and French ports by April 1918, and reached the Western Front by the middle of the month. It then quickly spread to the rest of France, Great Britain, Italy, and Spain and in May reached even Odessa [3].

After the signing (March 1918) of the Treaty of Brest–Litovsk , Germany started releasing Russian prisoners of war, who then brought the disease to their country. It reached then North Africa, India, and Japan in May, and soon after had likely gone around the World as there had been recorded cases in Southeast Asia in April. In June, an outbreak was reported in China, while after reaching Australia in July, the wave started to recede [2].

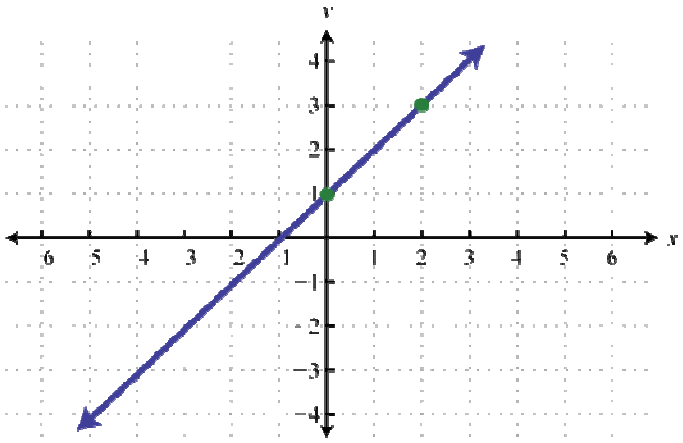

Figure 3. Estimated rate of expansion of epidemic during first wave described by linear function.

Estimating the rate of expansion of epidemic during the first wave of the flu lasted from the first quarter of 1918 and being relatively mild, we concluded that the process may preferably be described by the linear function of the type

$$y = ax + b$$

(**Figure 3**), considering here x as the time given in months or may be in weeks, while y – announcing the total number of infected citizens and mortality corresponding to given time interval; a and b here we assume like numerical coefficients, but not permanently constant, but different for different continents, countries, regions, etc.

Mortality rates were not appreciably above normal in the United States ~ 75000 flu-related deaths were reported in the first six months of 1918, compared to ~ 63000 deaths during the same time period in 1915.

In Madrid, Spain, fewer than 1000 people died from influenza between May and June 1918. There were no reported quarantines during the first quarter of 1918. However, the first wave caused a significant disruption in the military operations of World War I, with three-quarters of French troops, half the British forces, and over 900000 German soldiers' sick [3].

2.2. Deadly second wave of late 1918

The second wave began in the second half of August, probably spreading to Boston and Freetown, Sierra Leone by ships from Brest, where it had likely arrived with American troops or French recruits for naval training [3]. Helped by troop movements, it spread over the next two months to all of North America, and then to Central and South America, reaching Brazil and the Caribbean. In July 1918, the Ottoman Empire saw its first cases in some soldiers. From Freetown, the pandemic continued to spread through West Africa along the coast, rivers, and the colonial railways, and from railheads to more remote communities, while South Africa received it in September on ships bringing back soldiers returning from France.

From Europe, the second wave swept through Russia in a South-West–North-East diagonal front, as well as being covering all its European area. Then it spread throughout Asia following the Russian Civil War and Trans-Siberian railway. Later pandemic reached India in September, as well as China and Japan in October [4]. In December, however, the wave was mostly over.

The second wave of the 1918 pandemic was much more deadly than the first. The first wave had resembled typical flu epidemics; those most at risk were the sick and elderly, while younger, healthier people recovered easily. October 1918 was the month with the highest fatality rate of the whole pandemic. In the US, ~ 292000 deaths were reported between September–December 1918, compared to ~ 26,000 during the same time period in 1915. The Netherlands reported 40000 plus deaths from influenza and acute respiratory disease. The pandemic in India was especially deadly, with an estimated 12.5 – 20 million deaths in the last quarter of 1918 alone [2].

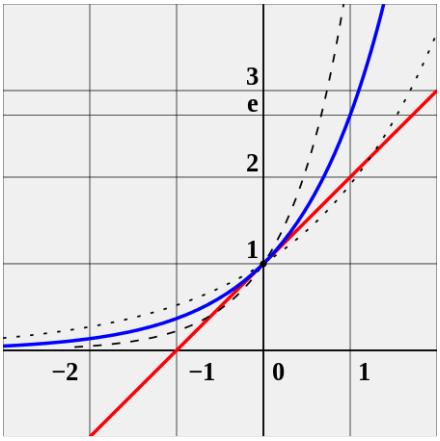

Figure 4. Estimated rate of expansion of epidemic during second wave described by exponential function.

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That is why it became clear that such fast and deadly expansion of epidemic cannot be considered by the linear function any more, as to the process was evidently undergoing the exponential increment of cases, and we used the exponential function, thus

$$y = ke^x + l$$

(**Figure 4**). In given conditions consider x and y to be the same quantities like it was in previous case (of linear relation) and k and l coefficients again may be either constant or different depending on what data used investigators estimating the level of expansion. For the second wave of epidemic, exponential function much better reveals the current conditions because the way of expansion of the epidemic exactly follows the rules of exponents.

2.3. Third (of 1919) and fourth (of 1920) waves

In January 1919, a third wave of the Spanish flu hit Australia, where it killed 12000 following the lifting of a maritime quarantine, and then spread quickly through Europe and the United States, where it lingered through the spring and until June 1919 **[4, 5]**. It affected Spain, Serbia, Mexico, Great Britain, resulting in hundreds of thousands of deaths. It was less severe than the second wave but still much more deadly than the initial first wave. In the US, isolated outbreaks occurred in some cities including Los Angeles, NYC, Frisco, and St. Louis. The overall American mortality rates were in the tens of thousands during the first six months of 1919 **[5]**.

In spring 1920, a fourth wave occurred in isolated areas including NYC, Switzerland, Scandinavia and some South American islands. NYC alone reported 6374 deaths between December 1919 and April 1920, almost twice the number of the first wave in spring 1918. Other US cities were hit particularly hard with death rates higher than all of 1918. Peru experienced a late wave in early 1920, and Japan had one from late 1919 to 1920 with the last cases in March. In Europe, five countries (Spain, Denmark, Finland, Germany and Switzerland) recorded a late peak between January–April 1920.

Analyzing presented data we arrive to the conclusion that both as linear as exponential functions should be involved in description of these years of expansion – the linear function describing the initial period of epidemic, while the exponential one we then apply to show wide expansion of pandemic reaching its peak.

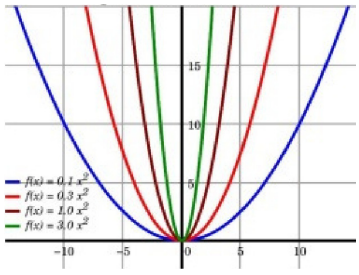

Figure 5. Quadric functions.

We also analyze the possibility of application of quadratic function

$$y = ax^2$$

(**Figure 5**). But then we decided not to use it due to extremely high rate of its increment and necessity of presence of negative values of x, itself being false by definition – all data for x are either time periods (months, weeks, even days), or countries, cities, regions, etc.

3. Conclusions

Due to lack of information concerning the present pandemic and taking into account definite similarities in expansion of epidemics we suppose approximately the same periods of developing present COVID-19 pandemic, but due to much better development of modern treatment and general level of medicines we predict more optimistic results, following soon recede of pandemic.

Authors choose the linear and exponential functions, describing expansion of the pandemic, but also showed the failure of the quadratic function there.

Representing the development of epidemic with as linear as exponential functions appear to be rather precise and completely display the ongoing process. Representation of pandemic in mathematical way using as equations, as graphs greatly clarifies the proper estimation of expansion of the pandemic.

We hope that our studies may be rather useful in searching the proper ways of exit of given situation all over the World as soon as possible.

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