The association of online search interest with polio cases and vaccine coverage: an infodemiological and ecological study

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Research Article

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Abstract

Background: Achievement of universal eradication of paralytic poliomyelitis has remained a challenge. Despite the general decline in cases, multiple outbreaks attributed to poor vaccination still occur. Noncompliance from vaccination can be improved through education on various media platforms. In the internet age, online health-seeking behavior plays a significant role in this regard. Hence, our study investigated the association between global online search interest in polio with the number of polio cases and vaccination coverage.

Methods: This infodemiological and ecological study utilized Google Trends' search volume index (SVI) for "polio" and the World Health Organization data on the number of polio cases (PC) and vaccine coverage rate (VCR) per country between 2006 to 2019. Associations between SVI for "polio" with PC and with VCR were evaluated.

Results: From the years 2006 to 2019, the global inquiry for this term was highest (i.e., SVI at 100) last October 2018. There is a direct correlation between the SVI for "polio" and PC while there is an inverse relationship between SVI and VCR per country per year. Both relationships have weak- to moderate strength of associations. Based on our models, a one-unit increase in the SVI leads to a 3.8% increase in the number of polio cases. On the other hand, a one-unit increase in the SVI leads to a 0.01% decrease in the VCR.

Conclusions: Dynamic changes in global SVIs for polio may reflect fluctuations in the number of polio cases and rates of vaccine coverage. Our study brings into light the largely untapped and potential use of online search behavior for polio to anticipate changes in PC and VCR in real-time.

Summary

What is Known:

- Parental vaccine hesitancy is a strong hindrance to the eradication of vaccine-preventable diseases.
- The internet is a major source of information that modifies this attitude.

What is New:

- Internet health-seeking behavior can be measured using Google Trends' search volume index and can be used to correlate to certain aspects of public health determinants of a certain disease.
- Google Trends' search volume index correlates with the number of polio cases/ immunization rates and this provides a basis for considering public health measures online.

1. Introduction

Paralytic poliomyelitis is a global problem of the old world. In the advent of an inexpensive vaccine and the thrust of multiple eradication programs all over the world, the Global Polio Eradication Initiative intended to eliminate this problem universally by the year 2000 [1]. Two decades have passed since the targeted year of complete eradication of polio. However, the virus has remained endemic in two countries – Pakistan and Afghanistan and multiple outbreaks have been reported in the Western Pacific (China, Malaysia, Philippines), Southeast Asia (Myanmar), Eastern Mediterranean (Somalia, Sudan, Yemen) and Africa (Angola, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Côte d'Ivoire, Democratic Republic of Congo, Ethiopia, Ghana, Guinea, Mali, Niger, Nigeria, Togo, Zambia) [2]. Despite these reported isolated outbreaks, the incidence of paralytic polio has been largely reduced and two of the three wild-type strains of polioviruses have been completely eliminated [3,4].

Obstacles in achieving complete eradication include difficult access to child care in endemic areas due to insecurity, inadequacies in program performance and the surfacing of circulating oral poliovirus vaccine-derived polioviruses (VDPVs) [2,3]. Moreover, there is varying reception of parents or guardians to vaccination despite government efforts. Parental attitudes toward immunization have been described and those on the spectrum that may lead to non-compliance are the cautious, the relaxed and the unconvinced parents [5].

The media has been a major factor that influences these parental attitudes towards vaccination [6]. In addition to the traditional media, the internet has offered a huge amount of information that spans both reliable and unregulated data. On the good end, the efforts of the different health care sectors to disseminate information particularly on preventive immunization are easily delivered and accessed by the target recipients. On the other side, this has also been utilized by vocal anti-vaccination activists to send their message further influencing those with negative parental attitudes [7-9].

With more than four billion internet users globally [10], the significant impact of the internet on public health is apparent. Since a major factor for complete eradication of the poliovirus is conformity to mass immunizations, population behavior may be evaluated in order to detect areas of poor compliance and address where there is a necessity. One good measure of population behavior is determining trends and variations of online interest on a particular topic. Being the most frequently used online search platform, traffic of data from Google has been shown to be useful in analyzing human behavior toward health topics and in predicting disease occurrences and outbreaks [11]. Through its platform, *Google Trends*, a free and publicly available online portal, analyzing a portion of Google's daily search is plausible and has been increasingly used in the past decade. This offers data on geospatial and temporal patterns in search volumes for specific online queries [12].

Since the internet is a huge source of information for people seeking health advice, we hypothesized that there is an association between online health-seeking behaviors with the number of polio cases and the coverage rate for vaccination per country. Therefore, the purpose of this study was to investigate the online search behavior for polio as measured by Google Trend's search volume index (SVI) and to determine its relationship with regional polio cases (PC) and vaccine coverage rates (VCR) for polio. Furthermore, we aimed to determine if polio's SVI is a significant factor for PC and VCR. In this study, we considered both the paralytic poliomyelitis occurring due to the wild-type strains and the ones occurring due to the circulating oral polio vaccine-derived polioviruses.

2. Methods

Global online search interest was measured using Google Trends database which provide reports on search trends in the unit of SVI [13]. This index reflects an estimate of the search activity relative to the topmost volume of searches documented within an indicated time period and location [13]. These are normalized to the time period and geographic region in which the term was most commonly searched (i.e., the topmost period and area in which a term is searched is assigned with an SVI value of 100 and other online search behavior from other time and locations are relative to this value) [13]. The use of the SVI as an index of health-seeking behavior has been largely used in the past decade in health care research.

We evaluated the search query "polio" in Google Trends last October 2020 and retrieved the SVIs of this term from 2006 to 2019 from 250 countries. Likewise, the data about the number of polio cases (PC) and the vaccine coverage rates (VCR) per country per year from 2006 to 2019 were retrieved from the World Health Organization (WHO) [14]. VCR is based on the computed coverage for the annual national target population [14].

We used IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA)

Median and interquartile ranges (IQR) were utilized to summarize continuous variables while frequencies and percentages were employed for categorical variables. The non-parametric Spearman's rho correlation test was employed to determine associations of SVI to PC and VCR. A table heatmap was also generated to illustrate varying strength of correlations. A generalized linear mixed model (GLMM, fixed effects) was also used to estimate the effect of the SVI on PC and VCR. A GLMM with a negative binomial (log function) was used since PC and VCR are counts in nature. Akaike and Bayesian Information Criterion (AIC, BIC) were also reported to determine the prediction error. The p-value for all analyses was set at 0.05.

3. Results

The global incidence of paralytic poliomyelitis from 2006 to 2019

Out of 250 countries, 190 reported on the annual number of PC and the VCR allowing inclusion in the analysis. In the data retrieved from the WHO, a total of 10,409 cases of paralytic poliomyelitis were documented between 2006 to 2019 [14]. During these years, Nigeria (n=3334, 32%), India (n=2910, 28%) and Pakistan (n=1262, 12%) were the top three countries with the most number of reported cases (see **Fig 1**) [14]. Despite multiple records of outbreaks from different countries during these years, there was a marked general decrease in the trend of the cases of paralytic poliomyelitis all over the world (see **Fig 2**).

Google Trends' SVI for Polio from 2006 to 2019

Using Google Trends, the search term "polio" was evaluated. From the years 2006 to 2019, the global inquiry for this term was highest (i.e., SVI at 100) last October 2018. This was twice the mean SVI per month for the past 14 years (see **Fig 3**). It was concomitantly concentrated in Papua New Guinea (SVI – 100), where an outbreak of polio occurred.

We also noted that the people searching for the term "polio" also searched for polio-related topics. **Table 1** lists the most popular search queries normalized in frequencies and reported in SVI scoring. Top on the list of related search terms for "polio" are the terms "vaccine" and "polio vaccine". It was also noteworthy that almost half of the top related queries were related to immunization. The remaining half were Google inquiries for the virus and the disease it brings.

Correlation between SVI, PC and VCR

Two sets of analyses were done for this ecological study. Those with non-zero SVI only and those with zero SVI. When analysis included those with non-zero SVIs only, there were notable positive, weak- to moderate correlations between PC and SVI over the years (see **Table 2**). The correlation was strongest in the data from the years 2009 and 2010. There was insufficient data during the year 2017 which precluded appropriate statistical analysis

For VCR, all correlations were significant where there was a notable inverse relationship (see **Table 2**). This means that an increase in the SVI is associated with a decrease in the VCR. Most of the relationships were also of moderate strength. The strongest correlations were found in the years 2006 to 2013. However, in the later years, the relationship between SVI and VCR weakened.

Estimating the effect of SVI on PC and VCR

For this analysis, the researchers utilized the panel data. This meant that the modeling considered the repeated measures per country over the years. Note that the standard linear regression cannot be used in this situation since the values in the dataset are not independent of each other (i.e., the 2006 Afghanistan data point is related to the 2007 Afghanistan value). Hence, this analysis considered such autocorrelation.

As the model pooled the data for all the countries, it supported the previous result of the correlation between the SVI to PC and VCR. With this model, across the years and regardless of the country, the effect of SVI on the number of PC and the VCR was minimal. Based on our model (see **Table 3**), one unit increase in the SVI leads to a 3.8% increase in the number of polio cases. On the other hand, a one-unit increase in the SVI will lead to a 0.01% decrease in the VCR. The small effect size was brought by the predominant invariability of the data available (i.e., mostly zero cases of polio, high vaccination rates of most countries and a prevalent zero SVI in a normalized data set). Large values of the AIC and BIC show a high prediction error of this generated model.

4. Discussion

Our results showed that the search term “polio” may implicate various aspects of this paralytic disease. It may be part of other search terms (e.g., outcomes of polio, the pathophysiology of polio, immunization of polio). Top search terms associated with polio also provided us a glimpse of online searchers’ interest on the topic. There seemed to be a remarkable inclination to explore polio vaccine-related topics by the online searchers especially during an increased polio incidence/ outbreak according to this 14-year trend study.

We hypothesized prior to the conduct of this study that an increased SVI is associated with a lowered PC. The rationale for this theory is that an increase in the online interest for the term “polio” may be more associated with more informed individuals who are more compliant to immunization and sanitation practices. However, our evidence showed that an increase in SVI on polio was correlated to an increase in PC. A logical explanation for this result is likely the necessity of certain populations in a specific location and period to search for greater knowledge on polio especially during an outbreak. Such is evident with the clustering of the search queries for “polio” that was evidenced by a higher SVI in regions where there were outbreaks and where the virus has remained endemic. Then, polio outbreaks may be reported in news headlines on several media platforms which may result in an increased queries on polio by interested online searchers. This event was evident when the polio outbreaks in Namibia (2006), Pakistan (2014), Papua New Guinea (2018) and the Philippines (2019) were accompanied by recording the highest SVI during the same years in these mentioned countries. Likewise, the endemicity of polio in Pakistan has made it a top country searching for “polio” from the years 2015 to 2017 and making it consistently on the list through the years [13].

Another phenomenon that explains the relationship between SVI and PC seen in our data is the importation of the wild poliovirus in countries where poliomyelitis had not occurred in years which subsequently cause an epidemic transmission. This mechanism of spread was demonstrated via the annual Muslim pilgrimage where travelers from some Middle Eastern countries and Indonesia may have carried the virus back to their countries [19]. The sudden surges of polio cases seemed to be related to the fluctuation of the polio SVIs in those countries during those years.

We also hypothesized *a priori* that an increase in the SVI is probably correlated with high VCR on the basis that a well-informed population will probably have good compliance to vaccination programs. Interestingly, our data showed that this correlation was inverse. Such a relationship may occur when a region with low VCR expectedly causes polio outbreaks that subsequently leads to emergence of outbreak news delivered in media platforms. The information is further assimilated by the public through online search strategies which could likely generate peaks in SVI for the term “polio”. A remarkable instance showing this correlation between SVI and VCR were shown by the outbreaks of polio in Papua New Guinea (2018) which was not considered due to virus importation. After 18 years of being polio-free, Papua New Guinea reported a case of VDPV Type 1 [20,21]. This occurred after it only achieved a low five-year mean polio VCR of 59% [14]. The outbreak received a massive online search response during this time and it was also accompanied by the country’s hosting and funding of the Asia-Pacific Economic Cooperation Summit [21]. This was the first time that SVI for “polio” peaked to twice the usual in the past 14 years [13].

Another instance which may elucidate such an inverse relationship between SVI and the VCR was during the Philippine polio outbreak of 2019. Due to the anxieties following the removal of the dengue vaccine (*dengvaxia*) in 2017 due to its alleged health risks, there was a sharp decline in the proportion of Filipinos who believe that *“vaccines are important, safe and effective”* from 100% in 2015 to 60 to 80% in 2018 [22,23]. This vaccine mistrust led to a general diminished compliance of the parents to immunization, particularly the vaccine coverage rate for OPV (66%) and IPV (44%) in 2018 [14]. Additionally, the fraction of the people who have been vaccinated may excrete the weakened virus which is passed in the community and may mutate over time infecting the unvaccinated population leading to vaccine-derived poliovirus outbreaks [24]. The health department’s reflex will likely be an educational reinforcement via several forms of media about the importance of immunization. The interested parent and other stakeholders will likely search the internet about the disease and its vaccine that may induce a surge of queries or peaks in SVI.

Indeed, other relevant factors such as hygiene practices/ sanitation and other socioeconomic factors in every country may likely confound the effects of SVI on PC and on VCR. Furthermore, it is pertinent nowadays to consider the possible effects of misinformation during this era (e.g., anti-vaccine advocates are looming in social media and other platforms.). This epidemic of misinformation or *infodemics* may be related to SVI, PC, and VCR and may be difficult to account in our current data and analysis. These potential confounding factors are extremely difficult to evaluate and to eliminate due to the unavailability of reliable information on these variables. In addition, minimizing the effects of these probable confounders in an ecological study, in which the unit of observation are populations or groups of people, is significantly more complex than an individual-level analysis. Adjustment for these factors may not eliminate the ecological bias inherent in this study design.

Our study has some inherent limitations. The SVI from Google Trends, a reflection of online health-seeking behavior, requires access to the internet, the use of the search engine Google and its associated sites. Therefore, people with no internet connection or who utilize a different search engine are not taken into consideration. Another restriction is the inaccessibility to the demographic data of Google searchers. Different age groups may have different reasons for doing the query, i.e., children may research for a school assignment while adults may inquire out of curiosity on recent news about a polio outbreak or about the information dissemination programs made available by health sectors. In addition, potential confounding factors and ecological bias are implausible to eliminate as mentioned. Furthermore, the SVIs are non-absolute values that restrict a more extensive and detailed data analysis. Nonetheless, analysis of information normalized to time and region like SVI allows for a study of the dynamics of online health-seeking behavior.

In summary, we found a weak- to moderate correlation between Google's SVI for the term "polio" and the number of PC in a region at a particular time. We also found a predominantly moderate, inverse correlation between the SVI and polio VCR. Such relationship brings into light the largely untapped and potential use of online search behavior to anticipate changes in PC and VCR in real-time; however, these associations does not provide an evidence of direct causation due to the nature of the employed study design and intrinsic limitations of our study. Performing a research with rigorous, prospectively conducted study design is still fundamental to determine with considerable certainty the utility of polio SVI in predicting PC and VCR. Nonetheless, understanding these dynamic trends of online health seeking-behavior may aid in the creation of public health measures particularly in the aspect of information dissemination that is primal in promoting any form of preventive public health measures.

Abbreviations

AIC – Akaike Information Criterion

BIC – Bayesian Information Criterion

GLMM – Generalized linear mixed model

IQR – interquartile range

PC – polio cases

SVI – search volume index

VAPP – vaccine-associated paralytic poliomyelitis

VCR – vaccine coverage rates

VDPVs – Vaccine derived polioviruses

WHO – World Health Organization

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Code availability: N/A

Author contribution:

EJVL: Conceptualization, data curation, formal analysis, interpretation of data, writing-original draft, writing-review, and editing. AIE: Conceptualization, data curation, formal analysis, interpretation of data, writing-original draft, writing-review, and editing. LVCC: Conceptualization, data curation, formal analysis, interpretation of data, writing-original draft, writing-review, and editing. RDGJ: Conceptualization, data curation, formal analysis, interpretation of data, writing-original draft, writing-review, and editing.

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Tables

Table 1. Top associated search terms also used by people searching for “polio” (2006 to 2019).

Search query	Search volume index
“Vaccine”	100
“Polio vaccine”	99
“Virus polio”	27
“Virus”	26
“What is polio”	26
“Post Polio”	18
“Polio disease”	17
“WHO polio”	17
“Polio Symptoms”	15
“La polio” *(Spanish)*	15
“Vaccination”	14
“Polio vaccination”	14
“Pulse polio”	14
“Polio India”	13
“Vaccine for polio”	13
“Polio drops”	13
“Polio syndrome”	12
“Tetanus”	12
“Polio impfung” *(German)*	11
“Vaccin Polio” (*French)*	11
“Post polio Syndrome”	10
“DT Polio”	10
“Vaccines”	10
“Polio Vaccines”	9
“Polio in India”	8

Table 2. Spearman’s correlation for search volume index with incidence of polio cases and vaccine coverage rate per year.

	Number of polio cases per year				Vaccine coverage rate per year			
Year	N	Spearman's rho	p-value	Strength of correlation	N	Spearman's rho	p-value	Strength of correlation
2006	47	0.453	0.001	Moderate	47	-0.481	0.001	Moderate
2007	45	0.351	0.018	Weak	46	-0.403	0.005	Moderate
2008	47	0.35	0.016	Weak	46	-0.595	< 0.001	Moderate
2009	45	0.504	< 0.001	Moderate	43	-0.587	< 0.001	Moderate
2010	47	0.503	< 0.001	Moderate	47	-0.584	< 0.001	Moderate
2011	49	0.317	0.026	Weak	50	-0.588	< 0.001	Moderate
2012	55	0.249	0.067	Weak	55	-0.522	< 0.001	Moderate
2013	56	0.392	0.003	Weak	56	-0.488	< 0.001	Moderate
2014	58	0.375	0.004	Weak	57	-0.389	0.003	Weak
2015	57	0.314	0.018	Weak	58	-0.463	< 0.001	Moderate
2016	57	0.308	0.02	Weak	57	-0.294	0.027	Weak
2017	55	-	-	-	56	-0.291	0.03	Weak
2018	52	0.308	0.026	Weak	54	-0.316	0.02	Weak
2019	54	0.492	< 0.001	Moderate	48	-0.333	0.021	Weak

Table 3. Effect of search volume index on polio cases and vaccine coverage rates using a generalized linear mixed model.

Model	Rate Ratio	95% CI	P-value	AIC	BIC
PC	1.038	1.003 - 1.074	0.035	4733.574	4728.998
VCR	0.999	0.998 - 1.000	< 0.001	-1487.129	-1482.558
AIC, Akaike information criterion; BIC, Bayesian information criterion; VCR, Vaccine coverage rate; PC, Polio cases					

Figures

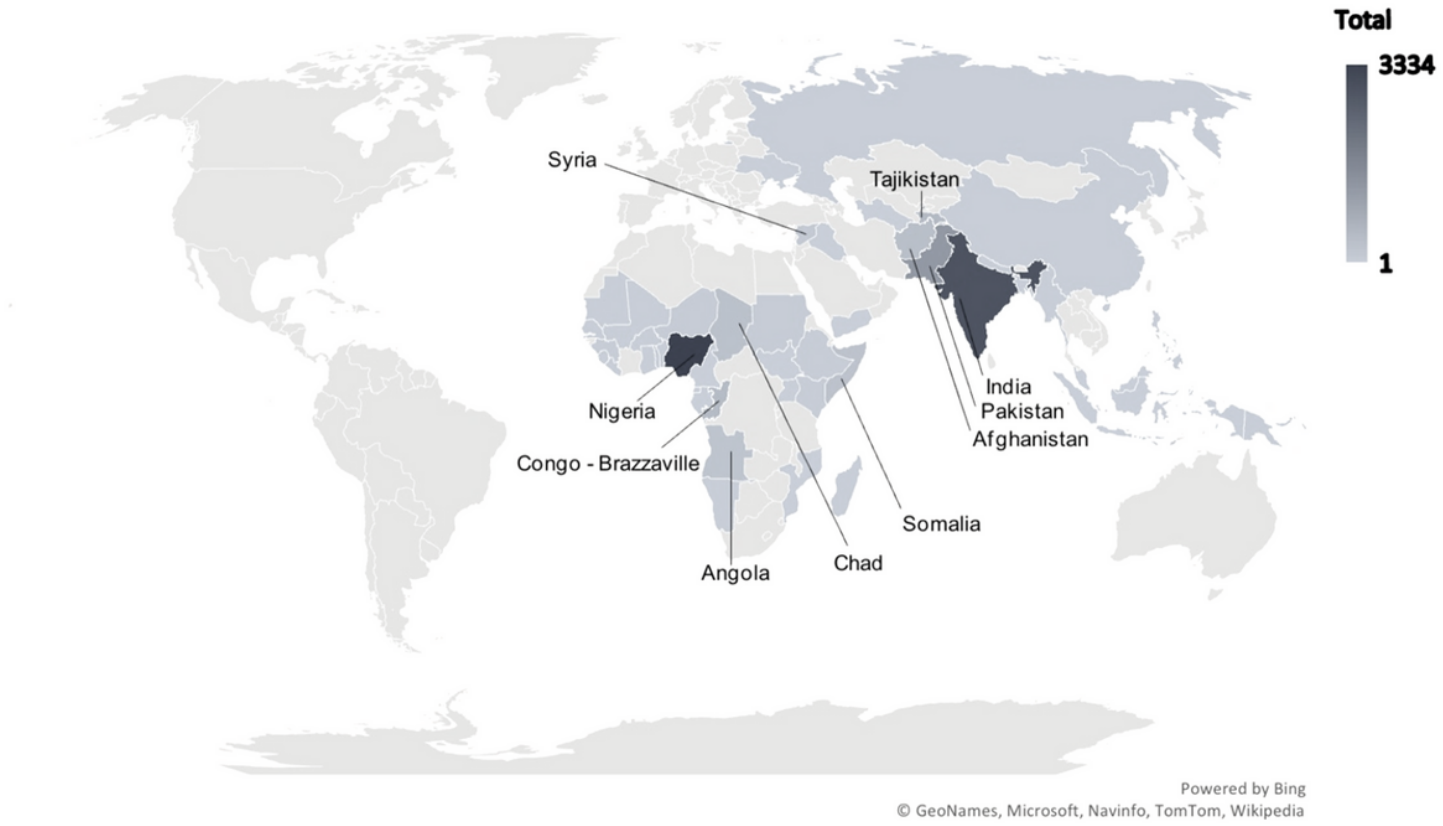

Figure 1

Geographic heat map of the global distribution of polio cases from 2006 to 2019. Global distribution of polio cases from 2006 to 2019. Map generated from data provided by the World Health Organization (2020) Immunization, Vaccines and Biologicals. https://www.who.int/immunization/monitoring_surveillance/data/en. Accessed 20 September 2020. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

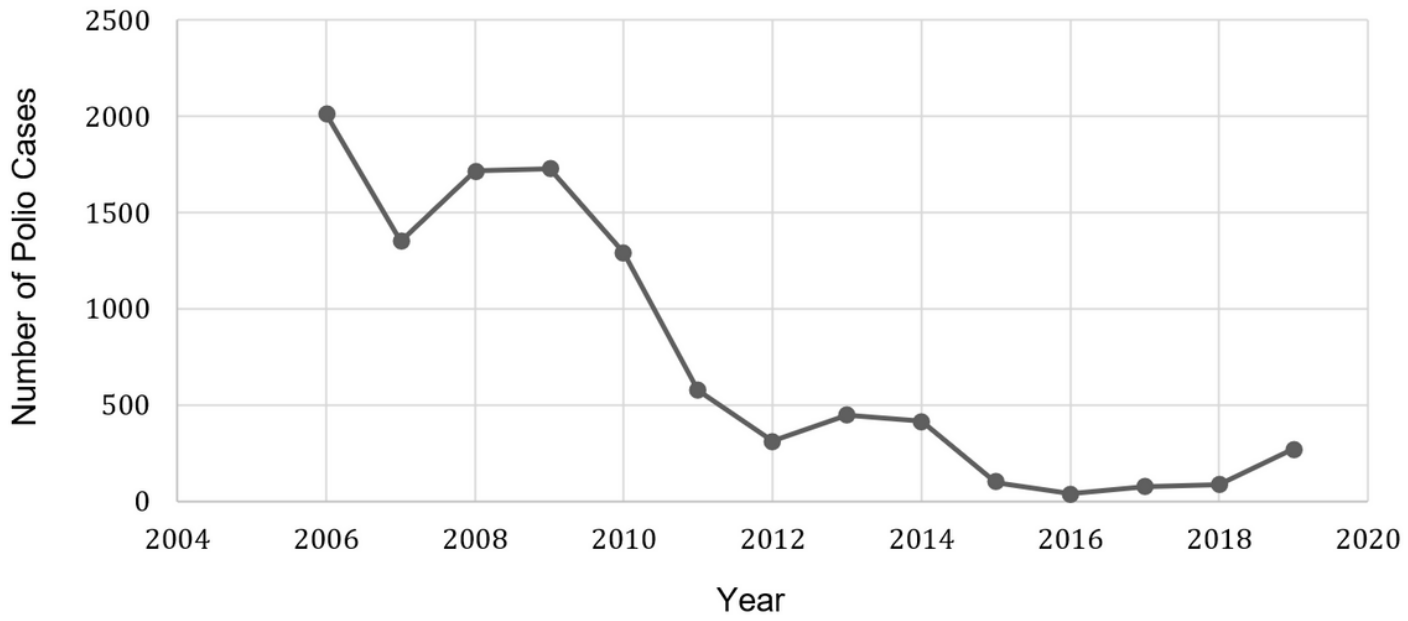

Figure 2

Annual global polio incidence from 2006 to 2019. Data obtained from the World Health Organization (2020) Immunization, Vaccines and Biologicals. https://www.who.int/immunization/monitoring_surveillance/data/en. Accessed 20 September 2020.

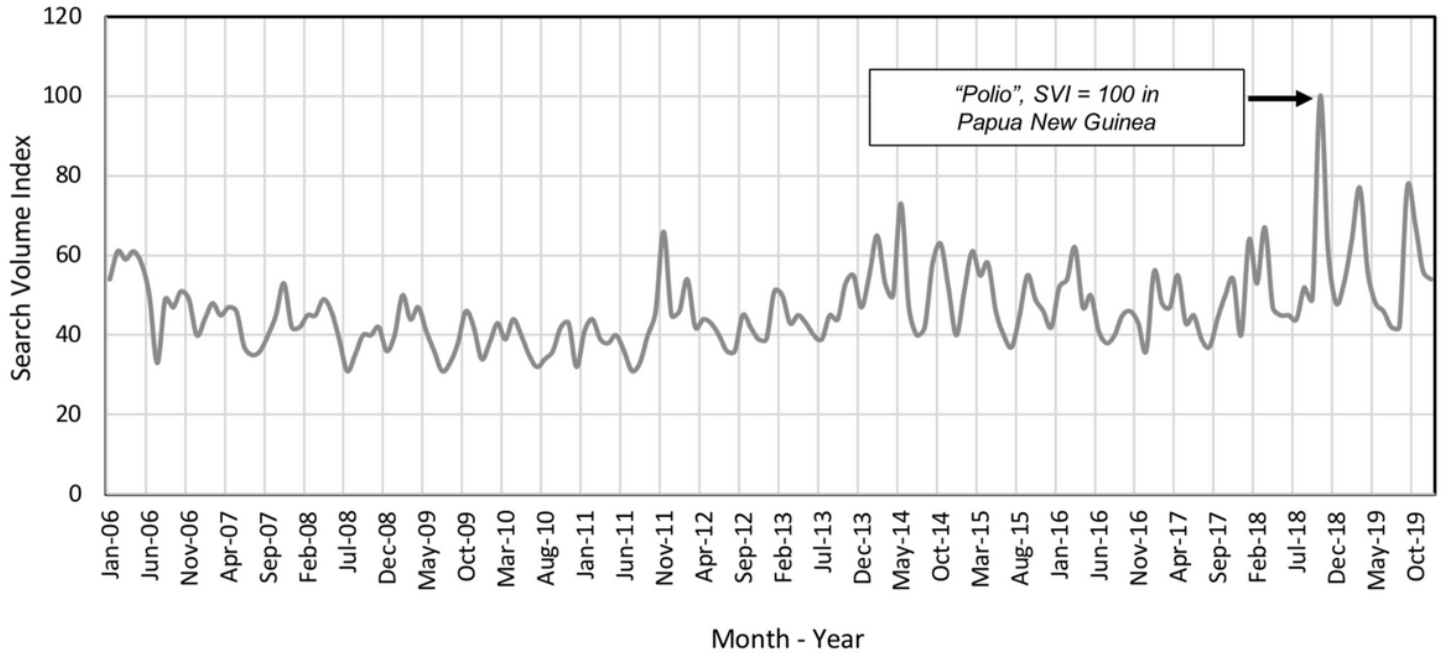

Figure 3

Google Trend’s search volume indices for the term “polio” normalized from years 2006 to 2019. Search volume indices (SVI) for the term “polio” normalized from years 2006 to 2019. Data obtained from Google Trends. http://www.google.com/trends. Accessed 10 October 2020.