

Evolutionary longitudinal network dynamics of global zoonotic research

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Abstract At global and local levels, we are observing an increasing range and rate of disease outbreaks that show evidence of jumping from animals to humans, and from food to humans. Zoonotic infections (i.e. Hendra, swine flu, anthrax) affect animal health and can be deadly to humans. The increasing rate of outbreaks of infectious diseases transferring from animals to humans (i.e. zoonotic diseases) necessitates detailed understanding of the education, research and practice of animal health and its connection to human health. These emerging microbial threats underline the need to exploring the evolutionary dynamics of zoonotic research across public health and animal health. This study investigates the collaboration network of different countries engaged in conducting zoonotic research. We explore the dynamics of this network from 1980 to 2012 based on large scientific data developed from Scopus. In our analyses, we compare several properties of the network including density, clustering coefficient, giant component and centrality measures over time. We also map the network over different time intervals using VOSviewer. We analyzed 5182 publication records. We found United States and United Kingdom as the most collaborative countries working with 110 and 74 other countries in 1048 and 599 cases, respectively. Our results show increasing close collaboration among scientists from the

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United States, several European countries including United Kingdom, Italy, France, Netherland, Switzerland, China and Australia with scientists from other parts of the world.

Keywords Collaboration · Evolution · Network dynamics · Longitudinal study · Zoonotic research

Background

Zoonosis can be referred to as the transmissible diseases between vertebrate animals and humans (WHO 1959), which comprises 75 % of emerging infectious diseases (Taylor et al. 2001). Therefore, successful management of zoonotic diseases risks and outbreaks require the understanding of the complex interaction network of humans, animals and their living environments (WHO 2013b). Previous bibliometric studies on relevant topics either investigated specific infectious diseases such as acquired immune deficiency syndrome (AIDS) (Patra and Chand 2007; Uthman 2008), tuberculosis (Ramos et al. 2008), and malaria (Garg et al. 2009) or examined infectious diseases in general (Bliziotis et al. 2005; Ramos et al. 2004, 2009; Takahashi-Omoe and Omoe 2012). The latter studies examined the research productivity and contribution of different countries and regions of the world in infectious diseases showing a gradual increase in research on infectious diseases in the US, the EU and other regions in the world. Our investigation focuses on the contribution and collaboration of countries in exploring the intersection between animal and human health. We provide an investigation of the dynamics of zoonotic research networks over 33 years by constructing and using large scientometric data.

The study first explains the process of developing scientometric data for exploring research collaboration on this topic. These data are based on the extracted publication information from Elsevier's Scopus in the span of 1980–2012. It proceeds with exploring these data by extracting a bibliometric networks (i.e. countries network). Several social network measures such as network density and centrality are employed to analyze this network. The countries collaboration trend, network maps and measures, and their dynamics over this period of time are then discussed.

Zoonotic research network dataset

Elsevier's Scopus (www.scopus.com) as one of the main sources of bibliometric data covering the greatest number of journals (Abbasi and Hossain 2011; Abbasi et al. 2011; Romo-Fernández et al. 2013) is used to build the database of this study. The search for publications has been carried out with 240 search queries using combinations of keywords including “coordination, collaboration, cooperation, communication, preparedness, surveillance, emergency response, crisis management, containment, recovery, zoonotic, zoonosis, animal human, disease outbreak, illness outbreak, epidemic, pandemic and social network” occurring in the articles' titles, abstracts and keywords. This initial set of keywords was selected after consulting with two experts in the field. The focus of the keywords was on three concepts including coordination, zoonotic diseases, and disease outbreaks at the various stages of disease prevention, detection, effective response and elimination.

The publications information [e.g., author(s), document title, year, source title, citation count, source and document type, affiliations, publisher] were extracted using Scopus export option. The publications used in the subsequent analysis were restricted to the ones in English. It is theoretically possible to miss out certain publications in the search process explained earlier. In order to minimize any missed out document and to account for any important keyword that was not included in the first stage, another set of keywords were identified to run a second round of search. As such, in the second stage, the keywords used in the extracted publications from the first stage were analyzed for their frequency. The frequency analysis of the keywords included identifying the most frequent “single word” and “multiple words” keywords. The latter keywords were the original keywords used by the authors and the former keywords were produced by splitting the “multiple words” ones. Table 1 shows the top ten most frequent “single and multiple words” keywords.

Another set of keywords including “avian influenza, West Nile virus, H5N1, control, risk” were used in combination with “coordination, collaboration, cooperation, communication, preparedness, surveillance, emergency response, crisis management, containment, recovery, outbreak, epidemic, pandemic and social network” for a second round of search for publications (216 search queries). The keywords that were too generic or used in the previous stage such as virus were not included in this round of search. The extracted publication data from this round was added to the previous results. The search span in both stages consisted of the period from 1980 to 2012. The search for the publications was conducted in July 2013. The two rounds of search resulted in 5800 publications of different types (e.g., article, conference paper, review) after filtering the publications with the same title. An application program was developed to extract bibliometric networks from these data, discussed in the next section.

At least four bibliometric networks can be built using the database of publications developed in this study including networks involving authors, keywords, countries, and affiliations. Figure 1 shows these networks. In order to build these network (i.e. identify the links between the nodes) from the information available in the database, an application program is written in Matlab. The algorithm of this application is explained here for the co-

Table 1 Top ten most frequent keywords

Keywords (single word)	Frequency	Keywords (multiple words)	Frequency
Influenza (Flue)	417	Surveillance	132
Virus	261	Epidemiology	101
Disease (s)	301	Avian influenza	70
Surveillance	217	Influenza	68
Avian	163	Pandemic	55
Epidemiology	154	West Nile virus	50
Health	117	Zoonosis (Zoonoses)	82
Pandemic	117	H5N1	40
Control	111	Control	35
Animal	77	Outbreak	38
Risk	74		

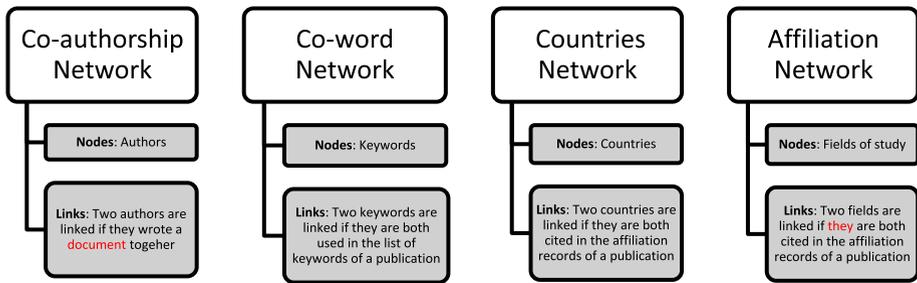


Fig. 1 Bibliometric networks

authorship network. The process of building the other networks including co-word, countries, and affiliation uses the same algorithm.

There is a co-authorship relation between two authors if they wrote a document together. As such, in social network terms, there is a link (edge) from node A (author A) to node B (author B). To map the data exported from Scopus into a co-authorship network, the following algorithm was developed where its variables are presented below:

- *Max-No-Papers* Maximum number of papers in the database with known authors
- *Max-No-Aut-Paper* Maximum number of authors in a paper in the database
- *Max-No-authors* Maximum number of authors in the database
- *List-All-Authors* A list containing the name of all the authors in the database
- *List-Max-No-Authors-Per-Paper* A list indicating the maximum number of authors for each paper in the database
- *List-All-Papers-with-All-their-Authors* A list of all authors for each paper in the database
- *Co-authorship-Initial* A matrix with the size of (*Max-No-Papers*, *Max-No-Aut-Paper*) that its cell (i, j) indicates whether author j in *List-All-Authors* participated in writing paper i in the database
- *Weighting* A matrix with its cell (i, j) indicating the number of papers wrote by authors i and j in *List-All-Authors*
- *Co-authorship* A matrix with its cell (i, j) indicating whether authors i and j in *List-All-Authors* wrote a paper together or not

For $i = 1$ to *Max-No-Papers*

For $j = 1$ to *Max-No-Aut-Paper* (i)

For $k = 1$ to *Max-No-Authors*

If *List-All-Papers-with-All-their-Authors* (i, j) **equals** *List-All-Authors* (k)

Co-authorship-Initial (i, k) = *Co-authorship-Initial* (i, k) + 1

End

End

End

End

For $i = 1$ to *Max-No-authors*

For $j = 1$ to *Max-No-authors*

 Sum = 0

```

For  $k = 1$  to Max-No-Papers
  If Co-authorship-Initial ( $k,i$ )  $\geq 1$  and Co-authorship-Initial ( $k,j$ )  $\geq 1$ 
    Sum = Sum + 1
  End
End
Weighting ( $i,j$ ) = Sum
If Weighting ( $i,j$ )  $> 1$ 
  Co-authorship ( $i,j$ ) = 1
End
End
End

```

Countries network

In order to build the network of collaborating countries, the affiliation records of each publication were processed to extract the countries cited. In Table 2 below, we show some examples of the affiliation records in the database. The name of the countries, when reported, appears at the end of the record. In order to extract the countries associated with each publication, the steps explained below were followed:

- Reverse the affiliation record string,
- Count the number of characters till the first occurrence of a space (e.g., X characters),
- Extracting the first “X” characters identified in the previous step from the reversed string,
- Reverse the string extracted in step three which gives the name of the country reported.

592 publications contained no affiliation information. These publications were excluded from the countries network analysis. Further data cleaning process in this stage included identifying the variations in the name of the countries reported (e.g., United States, USA, US, United Kingdom, UK) and unifying them. If an affiliation entry did not include the name of the country or useful information (e.g., the name of an institution) to search for the correct country of origin, it was excluded from further analysis (26 publications). Some other cases of data cleaning included finding the relevant country associated with a university, institution, company, state, or city where the name of the country was missing. This resulted in 5182 publications to carry out the data analysis.

Table 2 Examples of affiliation records

	Affiliation record
1	School of Life Sciences, University of Warwick, Coventry CV4 7AL, United Kingdom
2	Dept. of Geography/Earth Science, Shippensburg University, Shippensburg, PA, United States
3	Department of Biotechnologies, Section of Microbiology, University of Siena, Italy
4	Rabies and Wildlife Zoonoses Group, Veterinary Laboratories Agency, Woodham Lane, New Haw, Surrey, Addlestone KT15 3NB, United Kingdom
5	Medical Entomology Laboratory, Illinois Natural History Survey, Champaign, IL, United States

Research method

In this study, we apply the following network measures to perform our analysis:

Network density

The density measure “describes the general level of linkage among the points in a graph” (Scott 2000, p. 69). In social network analysis terms, this is the number of links in a network, expressed as a proportion of the maximum possible number of links (Scott 2000). The density of a network increases as the number of linkages between its nodes grows. The densest network (with all its nodes linked together) has a density of 1 and the least dense network (with no node linkage) has a density of 0.

Network centralization

Degree centrality-Freeman (1979) defined degree centrality of a node as the number of its adjacent nodes. Two nodes are adjacent if an edge links them together. Therefore, degree centrality of a node counts the number of other nodes that are directly connected to it.

Closeness centrality

The closeness centrality of a node is the sum of the graph-theoretic distances of that node to all other nodes in the network. The distance of a node from another is the length of the shortest path (geodesic path) between them (Borgatti 2005; Freeman 1979). Normalized closeness centrality value of a node is calculated by dividing the number of all other nodes in the network by the sum of the distances of the node to all others (Freeman 1979; Leydesdorff 2007).

Betweenness centrality

The betweenness centrality of a node is defined as the frequency with which it settles in the shortest path connecting any other pair of nodes in the network (Freeman 1979)

The giant component

In many cases, large and complex networks are seen to have a connected component that includes a substantial portion of the nodes in those networks. This connected component is referred to as the giant component. If a network has a giant component, it is usually only one (Easley and Kleinberg 2010).

Clustering coefficient

The clustering coefficient of a node (e.g., node A) refers to the probability that two randomly selected adjacent nodes of A are adjacent to each other. In other words, it is the fraction of the pairs of A’s adjacent nodes that are linked together (Easley and Kleinberg, 2010).

Clustering and mapping

VOSviewer 1.5.4 is used for displaying the structure of countries network. VOSviewer provides both mapping and clustering of networks (especially bibliometric networks) in a unified approach as an alternative to combining the mapping and clustering techniques with different assumptions. Its clustering technique is based on a weighted and parameterized variation of modularity-based clustering, and it uses visualization of similarities (VOS) as its mapping technique (Waltman et al. 2010). VOS is a distance-based mapping technique rather than a graph-based one. While in the latter technique the distance between two nodes is not necessarily meaningful, in the former technique this distance represents the strength of their relationship (van Eck and Waltman 2010).

VOSviewer provides different visualizations of networks. In the label views, the size of a nodes' circle and label portray its importance. Larger circles and labels represent more important nodes in terms of their weight (van Eck and Waltman 2013). The weight of the nodes in the countries networks in our study are determined based on the number of other countries associated with them and the strength of the associations. The color of the circles also depicts the cluster the node belongs to (van Eck and Waltman 2013). The density view is helpful for identifying the most important areas of a map. In this view, the nodes are represented with the same label structure as the label view. The color of the point a node is placed in depends on the number of nodes around that point and their weights (i.e. their density). More nodes with greater weight neighboring a node lead to greater density for that node. According to the default color scheme used by VOSviewer, three color (red–green–blue) represent density where red and blue are assigned to the highest and lowest densities respectively (van Eck and Waltman 2010).

Results and discussions of collaboration countries for zoonotic research

Publication trend

As shown in Fig. 2, the trend of publications on zoonotic research has been increasing since 1980. While before 1991, the number of extracted publications is constantly low, an increasing trend starts after that. This increase in the number of publications continues gradually and accelerates after 2002. This observation provides three time intervals to examine detail changes in the collaboration networks including 1980–1990, 1991–2001, and 2002–2012. The dynamic analysis in this study focuses on the last two time intervals as the number of publications in the first period is limited.

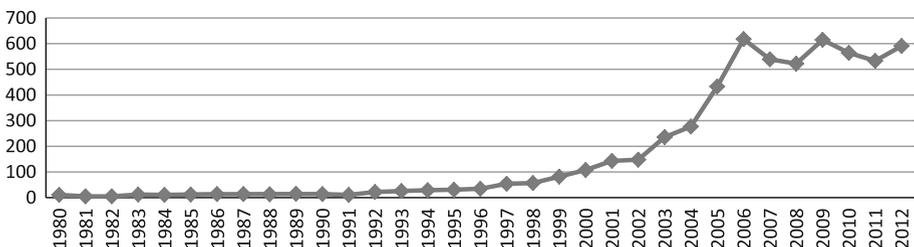


Fig. 2 Frequency of publications per year

Another interesting point of time in Fig. 2 is 2006. Up to this year the number of publications is increasing but this upward trend halts here with occasional rises. To have a better understanding of the possible underlying reasons for such a trend in the zoonotic research output, the frequency of zoonotic research publications and WHO's disease outbreak news per year (WHO 2013a) since 1996 are depicted in Fig. 3.

Three highest points of disease outbreak news occurred in 2003 [due to Suspected Severe Acute Respiratory Syndrome (SARS) pandemic], 2005 (due to Avian Influenza pandemic) and 2009 (due to H1N1 pandemic). After 2002, with SARS and Avian Influenza pandemics, the publications on zoonotic research grew rapidly, and then started to decline after 2006, but again raised in 2009 with the spread of the H1N1 pandemic to decrease again with the reduction in the disease outbreak incidences. It seems that the output of scientific research in the zoonotic disease outbreaks have reached a saturation level since 2006 and only occurrence of global disease outbreaks triggers increases in quantity of the related publications. As such, the changes of zoonotic research collaboration networks will also be examined for another two periods including 1999–2005 and 2006–2012.

Table 3 also shows the top ten journals publishing on this topic over the 33 years examined in this study, in which *Emerging Infectious Diseases*, *Veterinary Record*, *Euro Surveillance: European Communicable Disease Bulletin*, and *PloS ONE* hold the first three positions.

Countries collaboration trend

Figure 4 below illustrates the changes in collaboration among the countries over time in terms of the number of collaborating countries, distinct collaboration links between them, and total number of collaboration links per year. The first instances of international collaboration start from 1995 and steadily increase although the number of collaboration links among countries experiences some rises and falls over the years. The highest amount of collaborations (324 distinct links and 569 total occurrences) takes place in 2011 among 71 countries. In 2012, the amount of collaborations drops to 261 distinct collaboration ties while the number of participating countries increases to 80. Since 2006–2012 the collaborating countries consist of 53–80 countries which are nearly 50 % of all the countries (159) in our database. In other words, the countries collaboration network at its most collaborative status comprises half of the publishing countries. In addition, the trend of recruiting more collaborating countries each year although is overall growing; its pace

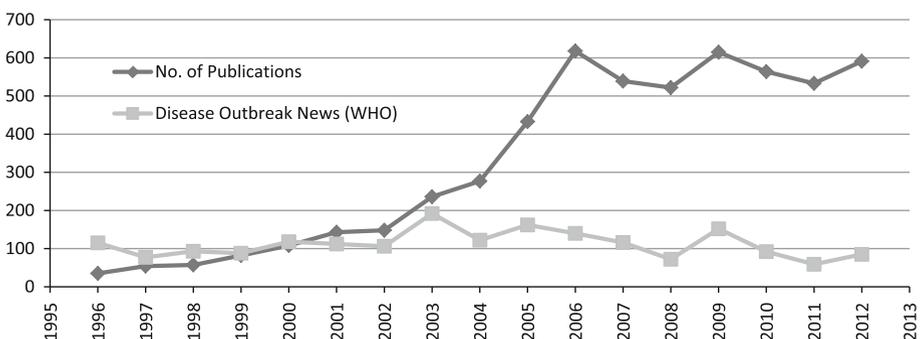


Fig. 3 Frequency of publications and WHO's disease outbreak news per year

Table 3 Top ten journals with the largest number of publications

	Journal name	No. of Publications
1	Emerging Infectious Diseases	187
2	Veterinary Record	123
2	Euro Surveillance: Bulletin Européen sur les Maladies Transmissibles = European Communicable Disease Bulletin	123
3	PLoS One	119
4	Avian Diseases	118
5	Vaccine	109
6	OIE Revue Scientifique et Technique	92
7	Nature	91
8	Science	89
9	Journal of Infectious Diseases	81
10	Epidemiology and Infection	70

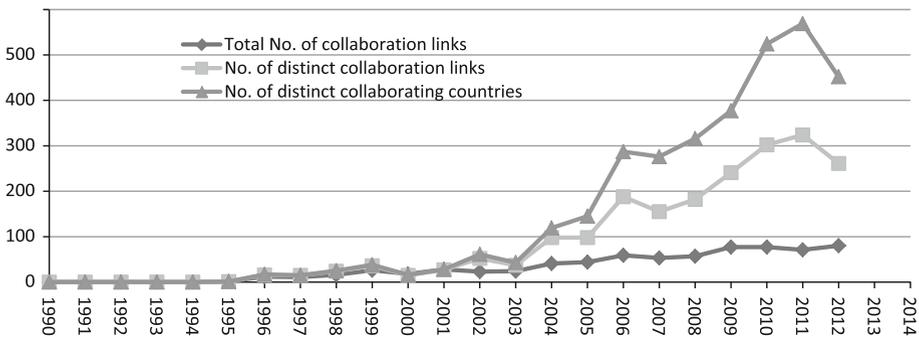


Fig. 4 Frequency of distinct collaborating countries and their collaboration links

Table 4 Measures of countries network in different periods

Measures	1991–2001	2002–2012	1999–2005	2006–2012	1980–2012
Density	3.9 %	8.1 %	5.5 %	8.3 %	7.4 %
Clustering coefficients	71.1 %	73.2 %	70.6 %	71.8 %	72.9 %
Number of components	21	5	16	7	9
Giant component size	52	145	80	136	151
Centrality measures					
Degree	48.1 %	62.3 %	52.5 %	60.6 %	63.0 %
Closeness	74.9 %	73.3 %	74.7 %	73 %	75.8 %
Betweenness	36.4 %	33.0 %	39.8 %	31.8 %	33.7 %

slows down after 2006. However, the number of collaboration links between the present countries and the frequency of such collaborations shows fast increase (with occasional declines). As such, it seems that after 2006 the community of collaborating countries is more focused on having more collaboration with other existing countries in the community and strengthening these collaborative relationships.

Countries network measures and maps over time

Table 4 demonstrates the measures of countries network in different periods. In the first period (1991–2001), the density of the network is very low (3.9 %) indicating that a limited number of all possible collaboration links among countries are realized (see Fig. 5a). In addition, the high clustering coefficient (71.1 %) implies the high possibility of collaboration among two adjacent countries of a third country. Figure 5a, pertaining to this period, illustrates this implication in the form of several triangles in the network. The network also has a giant component and several other small components. The network's degree of centrality is average (48.1 %).

As shown in Fig. 5a, the countries are gathered around a few central nodes in the network including the United States and United Kingdom. They also possess the largest

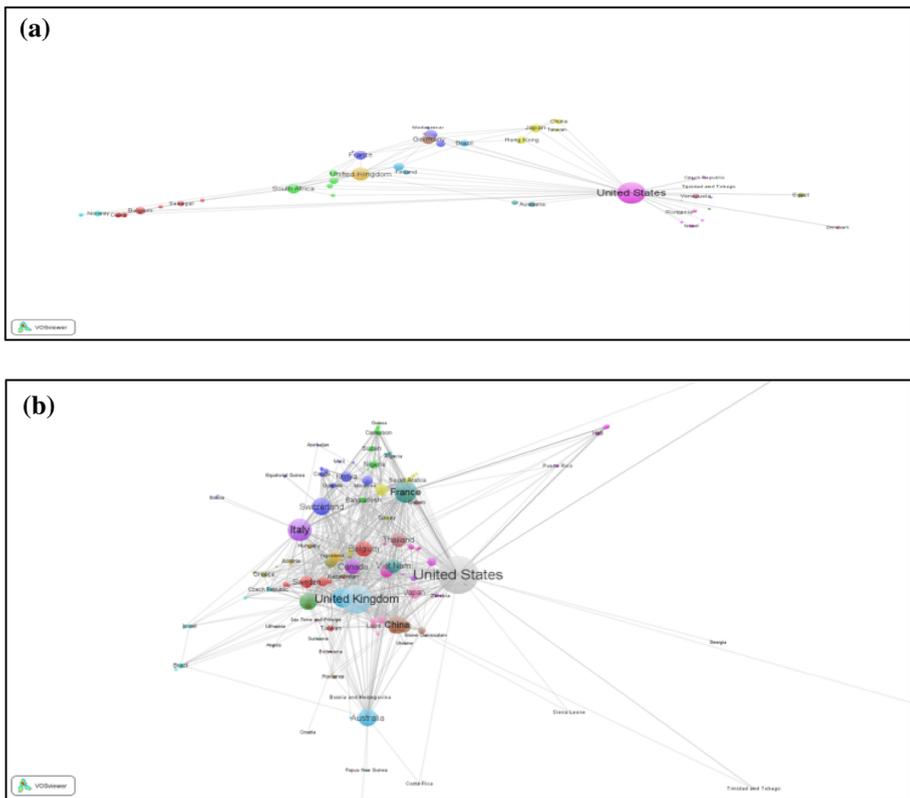


Fig. 5 Countries network map during (1991–2001) and (2002–2012). **a** Label view of countries network (1991–2001), **b** label view of countries network (2002–2012)

labels. South Africa, Germany, and Italy (overlaid by Germany in the map illustration), and France are the next countries with large labels which indicate their importance in the zoonotic research in this period. There is also a split evident in the map which separates countries around United States from countries around United Kingdom. In other words, there is low density between the two areas. This is an implication of less collaboration among these two important areas of the network.

In the second period (2002–2012), the density of the network has improved (almost doubled) although it is still low. There is also a slight improvement in the clustering coefficient value (73.2 %). The degree centrality shows considerable improvement (62.3 %). As shown in Fig. 5b, the countries are coming closer together compared to the previous period. The network closeness and the betweenness have decreased. The high value of closeness (73.3 %) and low value of betweenness (33.0 %) measures implies the low distance between the countries. The network measure for the whole period of time

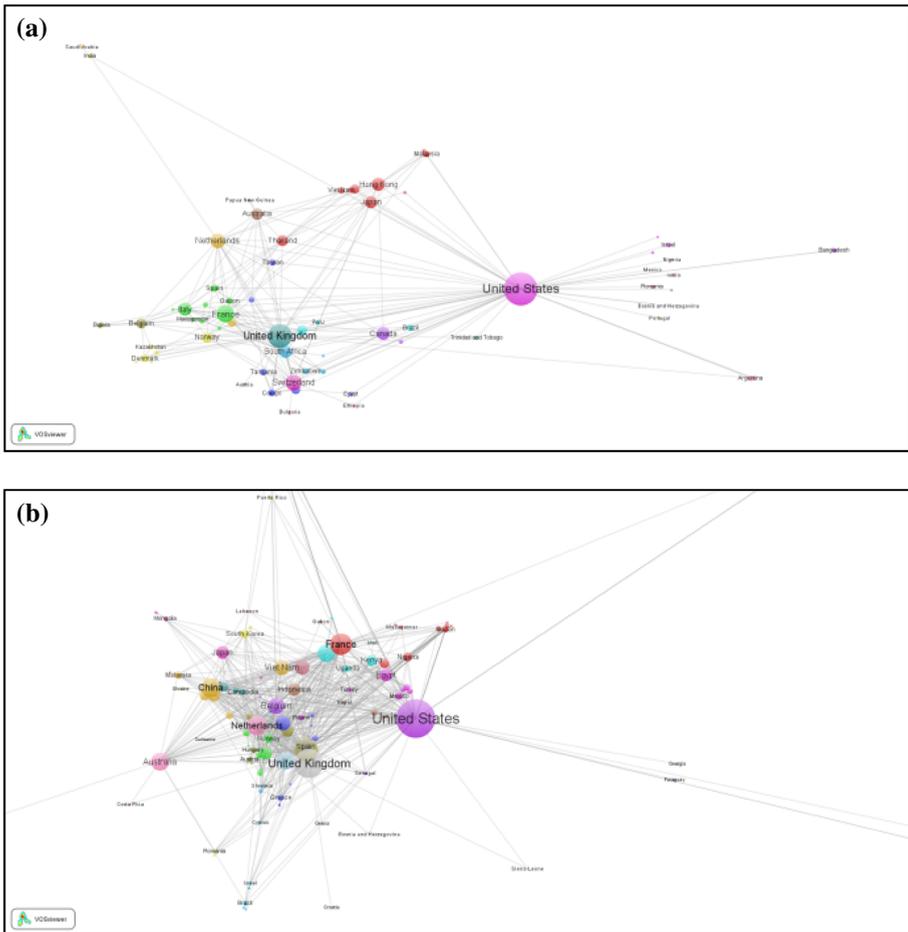


Fig. 6 Countries network map during (1999–2005) and (2006–2012). **a** Label view of countries network (1999–2005), **b** label view of countries network (2006–2012)

(1980–2012) is similar to the second time period, which is expected given that most of the publications belong to this period. Similar trend in the values of the network measures are observed in the other two periods (1999–2005 and 2006–2012).

The interesting observation here together with the information from Fig. 4 is the high value of clustering coefficient (71.8 %), density (8.3 %) and degree centrality (60.6 %) in 2006–2012 period which indicates the high probability that two collaborators of a country will be collaborating with each other and countries having more collaborations and collaborators. These values are higher than the seven years before 2006. In other words, in the recent years, the countries were putting more effort in strengthening their relationship with more other countries (see Figs. 6a, b).

The label views of the network in the whole period (Fig. 7a) shows that United States and United Kingdom are the major collaborating countries. Italy, France and Netherlands are the next main countries. As evident in the density view (Fig. 7b), United States and United Kingdom are depicted in red indicating their high density; although United

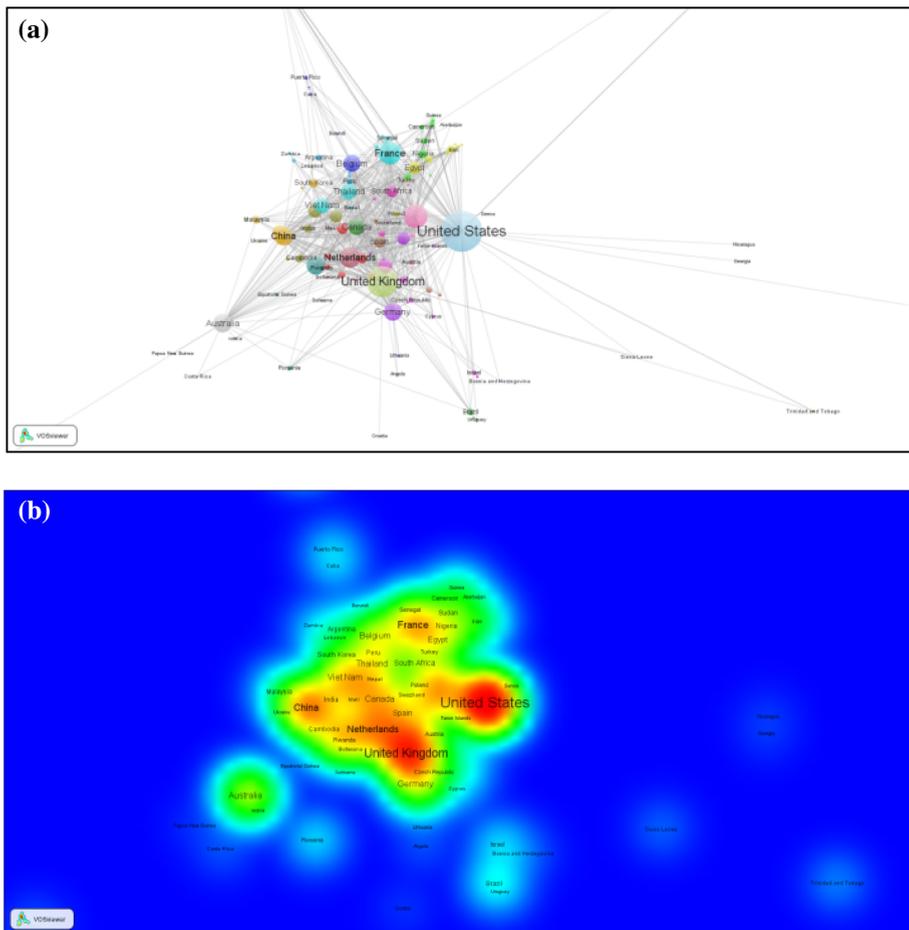


Fig. 7 Countries network map during (1980–2012). **a** Label view of countries network (1980–2012), **b** Density view of countries network (1980–2012). (Color figure online)

Kingdom is nearer to other moderate density areas of the map while United States is placed farther from this part of the map. These countries as well as the others shown in red or orange comprise the important part of the world in terms of research, publication, and collaboration on zoonotic research.

Top collaborating countries

Table 5 lists the countries with 50 or more total collaborations and the corresponding number of countries they collaborated with. According to this list, United States and United Kingdom are the first and second most collaborative countries working with 110 and 74 other countries in 1048 and 599 cases, respectively. In addition, the number of countries they collaborate with exceeds the others. Italy, France and Netherland are the next most collaborative countries; although France’s collaborating countries (70) are slightly more than Italy (68). This result complements previous studies on the output of infectious disease research community. Previous studies show that the United States and the western European countries productivity exceed the other countries in terms of publication on infectious disease research (Bliziotis et al. 2005; Takahashi-Omoe and Omoe 2012), and United Kingdom, France, and Germany lead the European countries in terms of number of publication on this topic (Ramos et al. 2004, 2009). Our results show a similar pattern in terms of collaboration efforts on zoonotic research. The United States, United Kingdom, France, Italy and Netherlands are the leading collaborative countries in zoonotic research.

Strong collaborations

Table 6 presents the list of the strongest collaboration links among the countries. Strength of a collaboration link is defined as the frequency of its occurrence during the 33 years.

Table 5 Top collaborating countries (1980-2012)

	Country	No. TCol ^a	No. ColC ^b		Country	No. TCol	No. ColC
1	United States	1048	110	14	Hong Kong	130	23
2	United Kingdom	599	74	15	Japan	122	30
3	Italy	355	68	16	Sweden	106	33
4	France	324	70	17	Egypt	102	33
5	Netherlands	266	47	18	Indonesia	101	28
6	China	229	31	19	Denmark	99	37
7	Switzerland	218	47	20	Spain	84	25
8	Australia	215	37	21	South Africa	82	28
9	Germany	206	50	22	Kenya	80	25
10	Belgium	173	41	23	Norway	68	25
11	Canada	160	37	24	Singapore	65	21
12	Thailand	146	29	25	South Korea	55	21
13	Viet Nam	139	27	26	India	50	22

^a Total collaborations

^b Number of collaborating countries

Table 6 Strongest collaboration among the countries (1980–2012)

	Country	ColC ^a	No. Col ^b		Country	ColC	No. Col
1	United States	United Kingdom	105	11	United Kingdom	Netherlands	38
2	United States	China	70	12	United Kingdom	Switzerland	37
3	United States	Canada	63	13	United States	Hong Kong	36
4	United States	Italy	57	14	United States	Japan	33
5	United Kingdom	Italy	52	15	United Kingdom	Australia	32
6	United States	Australia	44	16	United States	Netherlands	31
7	United States	France	42	17	United Kingdom	Germany	29
8	United States	Switzerland	42	18	United States	Egypt	28
9	United Kingdom	France	40	19	China	Hong Kong	27
10	United States	Thailand	38	20	Italy	France	24

^a Collaborating country

^b Number of collaborations

Table 7 Top collaborating countries during 1991–2001 and 2002–2012

1991–2001				2002–2012			
	Country	No. TCol ^a	No. ColC ^b		Country	No. TCol	No. ColC
1	United States	62	37	1	United States	986	103
2	United Kingdom	23	14	2	United Kingdom	576	73
3	Germany	13	9	3	Italy	343	65
4	Italy	12	8	4	France	313	69
5	South Africa	12	10	5	Netherlands	260	47
6	France	11	8	6	China	225	31
7	Japan	10	8	7	Switzerland	215	47
8	Canada	9	7	8	Australia	211	37
9	Belgium	8	8	9	Germany	193	49
10	Hong Kong	8	3	10	Belgium	165	39
11	Netherlands	6	6	11	Canada	151	35
12	Brazil	6	5	12	Thailand	144	29
13	Ireland	6	5	13	Viet Nam	139	27
14	Norway	5	5	14	Hong Kong	122	23
15	Zimbabwe	5	4	15	Japan	112	27
16	Puerto Rico	4	4	16	Sweden	106	33
17	China	4	3	17	Indonesia	101	28
18	Australia	4	2	18	Egypt	99	33
19	Senegal	4	4	19	Denmark	97	36
20	Venezuela	4	1	20	Spain	84	25

^a Total collaborations

^b Number of collaborating countries

United States and United Kingdom have the strongest link with 105 total collaborations. United States collaboration links with China, Canada and Italy are the next strongest collaborations with 70, 63 and 57 collaborations respectively.

Dynamic analysis

During the period (1991–2001), United States, United Kingdom, Germany, Italy, and South Africa are the top collaborating countries. In the second period (2002–2012), the number of collaborators and frequency of collaborations increase. While the United States and United Kingdom still hold their position at the top of the list of most collaborative countries, some changes are observed in the countries that follow them. South Africa is no longer among the top 20 countries. Italy, France and Netherlands have progressed further up the list. China, Australia and Switzerland also managed to appear among the top ten collaborating countries (see Table 7 for further details).

Top growing collaborative countries

To identify their collaboration growth rates, first the average amount of collaboration for each country in each of two time periods ($AV = \text{Total collaborations/years}$) are calculated which is presented in Table 8. The growth rate is then obtain as the quotient of the second and first periods' average collaborations ($\text{Growth rate} = AV2/AV1$). If a country did not have any collaboration in the first period its average collaboration for the second period is considered as the growth rate. The collaboration growth rates of the countries are identified for the 1999–2005 and 2006–2012 periods as they represent more recent data compared to the other time periods (1991–2001 and 2002–2012) examined in this study. Nigeria, Mexico, Portugal, Egypt and Singapore collaboration growth rates exceed the other countries.

Table 8 Top growing collaborative countries

	Country	AV1	AV2	Growth		Country	AV1	AV2	Growth
1	Nigeria	0.14	6.86	48.00	16	Philippines	0.14	1.43	10.00
2	Mexico	0.14	5.71	40.00	17	Belgium	2.43	22.29	9.18
3	Portugal	0.14	4.00	28.00	18	Denmark	1.43	12.43	8.70
4	Egypt	0.57	13.71	24.00	19	Bangladesh	0.43	3.71	8.67
5	Singapore	0.43	8.86	20.67	20	Australia	3.29	27.14	8.26
6	Viet Nam	1.00	18.86	18.86	21	Chile	0.14	1.14	8.00
7	India	0.43	6.71	15.67	22	Finland	0.43	3.14	7.33
8	China	2.00	30.57	15.29	23	Sri Lanka	0.14	1.00	7.00
9	Czech Republic	0.14	2.14	15.00	24	South Korea	1.00	6.86	6.86
10	Austria	0.14	2.00	14.00	25	Spain	1.57	10.43	6.64
11	Saudi Arabia	0.29	4.00	14.00	26	Sweden	2.00	13.14	6.57
12	Indonesia	1.00	13.43	13.43	27	Netherlands	5.00	32.14	6.43
13	Mauritania	0.14	1.71	12.00	28	Peru	0.57	3.57	6.25
14	Italy	4.14	45.43	10.97	29	Sudan	0.57	3.43	6.00
15	Germany	2.43	25.43	10.47	30	Thailand	3.00	17.71	5.90

Conclusions

This study provides longitudinal analysis of countries networks of zoonotic research during 1980–2012 based on large scientific data developed from Scopus. The overall properties of these networks as well as their dynamics over these 33 years are examined in detail. The countries network shows steady increase in collaboration among different countries. The United States is the most collaborative country having links with 110 countries and 1048 total instances of collaborations. Several European countries including United Kingdom, Italy, France, Netherlands, Switzerland, Germany and Belgium are among the top ten collaborating countries. China and Australia are also among the ten most collaborating countries. Nevertheless, the density of the network is still low which means that limited numbers of countries are collaborating. However, this trend is improving such that almost half of the 159 countries had at least one collaboration link in the recent years. In addition, in spite of the recent lower rate of addition of more countries into the network, within the current network, the countries are increasingly initiating new collaborations as well as enhancing these collaborating relations (strengthening them).

Conflict of interest None.

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