



Collaboration networks of arab biomedical researchers

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Abstract

Social networks (SN) consist of a set of actors and connections between them. A collaboration network (ColNet) is a special type of SN, in which the actors represent researchers and the link between them indicate that they have co-authored at least one paper. ColNet analysis reveals how researchers interact and behave. A wide range of applications can be based on such studies. The current works on ColNet usually focus on a specific domain/discipline, country/geographical region or time interval. In our study, we focus on one of the understudied regions (the Arab world), and present a novel study on the ColNet of researchers in this region. The domain of interest in our study is biomedicine. We construct, analyze, and study ColNet of biomedical researchers in the Arab world. We divide the region of interest (the Arab world) into four geographical regions and look into the evolution of ColNet of each region separately over time. Our analysis reveals that there is an increase in the number of both authors and publications over time, and that authors tend to work in increasingly larger groups rather than working individually, which is consistent with what is assumed about the nature of research in this field. Our analysis also reveals that a researcher's productivity is correlated with the amount of change in his/her circle of collaborators over time. For example, researchers working in stable or fixed groups and researchers who have completely different research group every few years are not necessarily the most productive ones.

Keywords Social networks analysis · Collaboration networks · PubMed · Arab researchers

1 Introduction

A Social network (SN) consists of a set of actors (persons, organizations, etc.), and the connections between them (friendship, ownership, etc.). It describes the social structure through the interactions among the actors, defines patterns and regulations hidden in data, and reflects the relationships between groups and individuals [13, 18, 24].

A collaboration network (ColNet), also known as a co-authorship network, is a special type of SN, in which the actors are researchers, scholars or authors and the connections

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between them represent their collaboration in writing papers. Two authors are connected if they authored at least one paper. The study of such networks helps in understanding the formation of the network and the factors affecting them [12, 22, 24, 28, 30].

The current works on ColNet usually focus on a specific domain/discipline, country/geographical region or time interval. In our study, we focus on one of the understudied regions (the Arab world), and present a novel study on the ColNet of researchers in this region. We choose to study the biomedical field because of its importance in addition to being one of the most active research fields in the Arab world in terms of the number of publications, the number of reputable journals, and the amount of research funds invested in it. In this field, the amount of available data is relatively better (larger, more consistent, easier to access, etc.), compared with other fields. This makes it a very good representative of the scientific/ academic/research community in the Arab world.

The problem we are interested in is to build and analyze ColNet of biomedicine researchers in the Arab world. Due to the many challenges associated with it, the research in this area is very limited despite its importance. To the best of our knowledge, the only prior work in this field is [1, 5]. However, [1, 5] focus on a specific part of the Arabic world, which is the Levant region. Here, we consider the entire Arab world. The goal is to answer a lot of questions such as, how does the interaction of an author (in terms of collaborations) affect his/her productivity? What are the patterns that are relevant to the success of certain authors (in terms of the number of publications)? Do the authors prefer to work individually or in groups? Do the authors prefer to collaborate with local authors or international authors?

This paper is arranged as follows. The second section discusses the related work, while the third section discusses the methodology including the measures we use. The next section presents the analysis of the computed measures. Finally, the last section discusses the conclusion and future work.

2 Literature review

The study of ColNet is very old. However, the rapid developments over the past century gave this field a different and new flavor. Below, we focus our discussion on modern ColNet and the studies conducted on them.

Among the earliest works on modern ColNet is Newman's [24, 26]. In [24], he constructed and studied ColNet for the fields of computer science, biomedicine, and physics. He extracted the authors, addresses, journals, and other information in order to construct the network. He considered the timeline 1995-1999 as a base for his study. He collected many statistics for his network, such as the number of collaborating authors, the number of papers written by an author, and the number of authors per paper. In [26], he expanded his work by constructing such networks in other fields, using bibliographical databases, preprint databases in physics in the same period (1995-1999). Moreover, he studied an extended period (1940-2004) for mathematicians. In his works, he answered many questions about collaboration patterns such as who are the authors who tend to be more collaborative, how many papers does an author write on average, how many authors he/she collaborates with, does the field of search affects the size of the network and the collaboration patterns, and the distance between two scientists on average). As a result, he concluded that biologists tend to be more collaborative than physicists or mathematicians.

In [33], the authors used a database of articles on tourism and hospitality in the period 1991-2010. They proposed a new method in order to evaluate the researchers. The main

objectives of this research are to study the collaborative behavior and its effects on the research productivity, discover the characteristics of such networks, and most importantly, find the most important researchers in this field to evaluate them. They considered both levels: macro (network) level, and micro (individual) level. Furthermore, they found that this type of ColNet is less mature and close than other types of networks. Other works in the same field include [6, 15]. In [6], the author discussed patterns of co-authorship and analyzed it using the database of New Zealand and Australian tourism research. In [15], the authors examined the tourism and hospitality research areas. The data collected from four influential and leading hospitality research journals of the time interval of (2001–2005). Their findings showcased the knowledge diffusion patterns and collaborative nature in the hospitality research domain. Moreover, it showed that the social structure affects the acquisition of knowledge.

ColNet of evolutionary computation (EC) researchers was studied in [7]. The data was collected from the Digital Bibliography & Library Project (DBLP) bibliography server. It consisted of more than 610,000 articles and thousands of computer scientists. The authors studied how making conferences, giving grants, etc., provide good hints about central actors in the network, or even building scientific societies. In [32], the studied how the position of an author in the ColNet affects the citation count of his papers. Day et al. [8] investigated the field of intelligence and security informatics (ISI) using social network analysis and visualization to identify main clusters, actors, and main components (subsets).

In [10], the author studied the ColNet in the information retrieval field in the period of 1956–2008. He tried to answer some questions like, do productive researchers tend to collaborate with researchers with the same interest or different interests? The results showed that the productive researchers tend to collaborate with researchers in the same field and interest, and they indirectly collaborate with researchers with different interests.

In [17], the authors examined the research collaborations among the countries of the Association of Southeast Asian Nations (ASEAN) in the economics field for the time period of 1979–2010. They found that the local collaboration between the countries of ASEAN accounted for just 4% of all international collaborations.

In [14], the authors investigated ColNet structured using bibliographic database of papers published in the journals of the Science Citation Index (SCI) in the interval of 1978–2004. They applied social network cluster analysis, co-occurrences analysis, and frequency analysis to explore the center of collaboration of the ColNet, the collaborative fields of the network as whole, and the ColNet microstructure on the scientist's aspects.

In [19], the authors analyzed the ColNet of ACM, IEEE, and joint ACM/IEEE conferences on digital libraries in the interval 1994–2004. They established some network measures and authorRank to indicate individual author in the ColNet, in addition to standard network measures.

In [4], the authors examined complex and social networks to identify and characterize scientific collaboration process. They used a database of the period 2001–2009 of papers, MS and PhD theses, etc. The results showed the influential researchers, and indicated scale-free degree distribution behavior.

As mentioned earlier, our work is unique in the setting it considers (biomedicine research in the Arab world). We expand our earlier work on a subset of the region of interest [1, 5] and consider the entire Arab world. We follow the analysis techniques and measures popular in the ColNet literature in addition to less common techniques and measures such as the ones we proposed in [1, 5]. This study is far from perfect. We can still explore new techniques

such as negative sample mining [23], self-paced learning [21], the use of meta-data [2] or even the linking with other domains such as financial networks [27].

3 Methodology

In this work, we discuss the steps of building a ColNet of biomedical researchers focusing on the Arab world in the time interval of 1991-2010. We confront some challenges and difficulties throughout our work. Let us start by briefly discussing them before getting into our methodology and analysis tools.

3.1 Challenges in network construction

Data collection is the first challenging step of our study. We need find a suitable source of bibliographic data for biomedical research in the Arab world. Unfortunately, these data may contain uncontrolled errors. In our research, we use the PubMed search engine to crawl data due to its comprehensive coverage and ease of use.

The data we collected is restricted in many aspects. The first one is the period of time. We collect the publications in the period of 1991-2010. The main reason for this restriction is the lack of complete data prior to 1991. The second restriction is the geographical region on interest. We consider only the authors affiliated with institutions based in the Arab world. We use a division of the Arab world into the following regions:

- Region one: Jordan, Palestine, Lebanon, Syria, and Iraq.
- Region two: Bahrain, Kuwait, Oman, Saudi, Qatar, Yemen, and UAE.
- Region three: Egypt, and Sudan.
- Region four: Libya, Morocco, Tunisia, Mauritania, and Algeria.

The authors affiliated with an institution based in one of these countries is considered as a local author. Other authors are considered as “undetermined.” We also have to deal with problems associated with authors’ identities. E.g., an author may write his/her name in different ways. Sometimes, parts of the name (such as the middle names) are abbreviated causing us to have a “match” between a certain author name and multiple known authors. In our prior work [1, 5], we ignored such authors. However, here, we try to resolve the confusion caused in these cases by matching the authors affiliations. If this step fails, then these author names are added as separate authors for completeness purposes.

3.2 Overview of methodology

The following paragraphs summarize our methodology. We first query PubMed to collect papers published in the period 1991-2010. Then, we divide the papers based on the intervals 1991-1994, 1995-1998, 1999-2002, 2003-2006, and 2007-2010. We pick this period of time to make sure that our data is consistent and to avoid any gaps. Moreover, this period witnessed a significant growth in the scientific fields in the region of interest as evident by the data we collected. So, it is interesting to study.

In the following step, we employ the tool of [1, 5] to extract the authors, their affiliations, and the papers information in order to construct the network. The tool addresses many problem related to authors names, but it does not properly address the “ignored authors” issue resulting from conflicts in authors names. As mentioned earlier, an author may write his/her

name in different formats. Moreover, the name might be abbreviated leading to some confusion/conflicts. Table 1 shows different formats of the same author name and the numbering we devised for each format in our earlier work [1, 5]. The numbering system gives larger values to more specific names which have lower possibility of creating confusion. When facing different instances of the same author name using different formats, we group the names by defining parent/child relationship where the parent is the instance with the larger number.

After constructing the ColNet, we analyze it using a well-known network analysis tool, Pajek, in addition to the tool developed by our team members [1, 5] and modified for the purpose of this work. The Pajek tool calculates standard measures such as betweenness, closeness, degree, etc. As for the other tool, it calculates the stability measures explained later. The following subsections discuss the measures we compute. Finally, we analyze the results obtained from the previously mentioned tools, and present our findings to answer the research questions mentioned in the introduction.

3.3 Used measures

In this section, we discuss the measures used in this work. We start with topological measures, before discussing papers and authors measures. We finally discuss the measures of [1, 5].

Following are the topological measures we consider.

- Network Size: It refers to the number of nodes (i.e., authors) and the number of edges (i.e., co-authorship relationships) in the network. It is important to study network size since it affects other measures. Density, for example is affected by network size, the larger network size, the lower the density.
- Distances: We consider several measures including shortest paths between all pairs of nodes in the network. We also compute the mean distance and maximum distance (diameter) of the network.
- Main Component: It is the largest connected component in the network. It is measured by the number of nodes in it or their percentage.
- Clustering Coefficient (CC): It is a measure indicating the clustering of the network. It is computed based on triplets of connected nodes as follows [25].

$$CC = \frac{3 \times \text{number of triangles}}{\text{number of connected triples}}$$

- Density: It is the ratio of the ties between nodes to the total number of potential ties that can exist between them. It ranges from 0 to 1, where higher values means denser networks. Density is a good indicator of connectivity between authors, and how strong their relationships are in ColNet [11, 31].

Table 1 Formats for the authors names typically found in PubMed

Convention/Format	Number/Class
Raja'a, Y	1
Raja'a, YA	2
Raja'a, Yahia	3
Raja'a, Yahia A	4
Raja'a, Yahia Ali	5

- Degree: The degree of a node is the number of connections incident on it. It is used to measure network connectivity [29]. In ColNet, the degree of an author can help in determining its centrality. The degree distribution of network is the fraction of vertices in the network with some degree k . In a network with n vertices where n_k of them has degree k , then the degree distribution is $P(k) = \frac{n_k}{n}$.¹
- Betweenness: It refers to how much an author is important or needed in the path to spread information over the network. If we consider the shortest path to be the most likely way to spread information between nodes, then an author who is situated on the shortest paths between many node pairs is important to the flow of the information over the network. This author is more central [16, 31].

The paper measures we use in our study are as follows.

- Number of Papers: It is the number of papers we collected from PubMed databases in the given period of time who has at least have one local author from the region of interest.
- Number of Authors: In our study, we differentiate between two types of authors: local and undetermined. We report the numbers of local authors and total number of authors for each paper.
- Percentage of Local Authors: This measure can help is quantifying the strength of collaboration between local and undetermined authors.
- Average Number of Authors per Paper: Here again, we differentiate between local and undetermined authors.

As for the authors measure we consider, they are as follows.

- Total Numbers of Local and Undetermined Authors.
- Papers per Author: We use this measure to determine the productivity of local authors.
- Collaborators: We compute the total number of collaborators in the collaboration network and average number of collaborators as well. It is a good way of discovering the extent of collaboration of all authors. It is worth mentioning that the collaboration of an author with another author on more than one paper will be counted as one.
- Percentage of Local Collaborators: This is a good indicator for the types of collaboration.

Finally, the stability measures, which were proposed in [1, 5], are as follows.

- New Collaborators: For each author, we compute the percentage of new authors in each year.
- Deleted Collaborators: Similarly, for each author, we compute the percentage of deleted authors in each year. For an author u , a deleted author v at a certain year y is one who co-authored at least one paper with u in year $y - 1$ and did not co-author any paper with u in year y .
- Stability Rate: We compute the change of the set of authors' collaborators among two consecutive years. Let us demonstrate this measure with an example. Let author u_1 have the collaborators u_2, u_3, u_4, u_6 , and U_7 in the first year, and u_2, u_5 in the second year. Then, the stability year of the author would be $1/5=0.2$ since only one collaborator is retained in the set of collaborators in the second year out of the five collaborators in the first year.

¹http://mathinsight.org/degree_distribution

4 Discussion and analysis

In this section, we analyze the measures we compute from our ColNet and discuss them in details.

4.1 Topological measures

Here, we discuss the topological measures of our networks as summarized in Tables 2, 3, 4 and 5.

Network Size As shown in the tables, network sizes are increasing in all regions. This mean that there is a huge increase in the number of collaborating authors over time.

Main Component In all regions, the size of the main component is increasing. On the other hand, the main component represented only 13% of the network in region one (Jordan, Palestine, Lebanon, Syria, and Iraq), in the period of 91-94. In the periods of 95-02, the main component grew to 32% and 33%, and then jumped to 57% and 64% in 2000's. This might be due to the huge interest spike in higher education in this region since a large number of educational institutions were established in these periods. In region two (Bahrain, Kuwait, Oman, Saudi, Qatar, Yemen, and UAE), the main component represented about 62%-71% of the network. As for region three (Egypt and Sudan), the main component represented 52% of the network int the first interval. Then, in 95-98, the main component shrunk to 35%. After that, the main component grew back to 44%-57%. In region four (Libya, Morocco, Tunisia, Mauritania, and Algeria), the main component represented 30% in the first two periods. Then, it made several jumps to 46%, 68% and 78%. In ColNet, the existence of a giant main component allows scientific information and news of new discoveries to reach most researchers of the network, hence, the information circulate faster.

Distances In all networks examined here, the mean distance is about 6-7 in first intervals and increases to about 9 in the last intervals. In addition, the maximum diameter is increasing to a certain point, and then starts decreasing for all the networks. These values are close to those of [20]. Moreover, Newman in [20] stated that the typical separation between two

Table 2 Topological measures for region one (Jordan, Palestine, Lebanon, Syria, and Iraq)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Number of vertices	1640	2730	4918	7162	11111
Number of edges	4816	10618	21020	35288	61764
Size of main component	215	892	1656	4133	7147
% of main component	13.11%	32.67%	33.67%	57.71%	64.32%
Avg distance	6.01	6.76	6.7	8.91	8.47
Diameter	18	17	22	25	32
CC	0.19	0.19	0.23	0.22	0.23
Density	0.001	0.001	0.001	0.001	0.0004
Avg degree of ColNet	4.7	6.12	6.88	7.63	8.81
Degree of ColNet	0.032	0.03	0.02	0.02	0.01
Betweenness of ColNet	0.007	0.04	0.04	0.16	0.14

Table 3 Topological measures for region two (Bahrain, Kuwait, Oman, Saudi, Qatar, Yemen, and UAE)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Number of vertices	4343	5874	7139	10068	14444
Number of edges	19083	26566	30576	48496	76422
Size of main component	2846	4215	4626	6296	8958
% of main component	65.53%	71.76%	64.8%	62.54%	62.02%
Avg distance	7.42	7.18	9.33	9.15	8.24
Diameter	22	18	28	28	24
CC	0.2	0.21	0.26	0.28	0.29
Density	0.001	0.001	0.0004	0.0004	0.0002
Avg degree of ColNet	6.71	7.15	6.87	7.64	8.46
Degree of ColNet	0.02	0.019	0.013	0.013	0.009
Betweenness of ColNet	0.12	0.08	0.07	0.08	0.05

researchers is about six. Of course that makes the operation of spreading the information and exchanging experience and knowledge faster.

Clustering Coefficient Real world networks have local communities within them. One way to explore such communities is to compute the CC by computing the transitive triples in the network. In the tables, the values of CC are reported for each network. For example, networks constructed for regions one, two, and four have acceptable CC. As for region three, higher CC appear. All values of CC of our networks are lower than the values of CC in the networks of [20]. Perhaps, this is due to the differences across scientific domains.

Density In the networks of region one, the density was close in all time intervals (0.001 to 0.0004). The networks of region two have a low density as well. In fact, it ranges from 0.001 in the first and second intervals to 0.0004 in third and fourth intervals before dropping down to 0.0002 in the last interval. In region three, the density ranges between 0.0003 to 0.002 in

Table 4 Topological measures for region three (Egypt, and Sudan)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Number of vertices	2291	2403	3712	5651	5651
Number of edges	9406	9126	13782	27178	52270
Size of main component	1199	858	1662	2711	6117
% of main component	52.34%	35.71%	44.77%	47.97%	57.14%
Avg distance	7.73	7.17	9.22	13.5	9.69
Diameter	25	19	26	40	33
CC	0.27	0.31	0.33	0.37	0.36
Density	0.002	0.001	0.001	0.001	0.0003
Avg degree of ColNet	6.89	6.47	6.52	7.7	8.42
Degree of ColNet	0.049	0.034	0.02	0.013	0.013
Betweenness of ColNet	0.12	0.054	0.07	0.06	0.082

Table 5 Topological measures for region Four (Libya, Morocco, Tunisia, Mauritania, and Algeria.)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Number of vertices	444	560	1289	3764	9064
Number of edges	1050	1768	4524	20576	78300
Size of main component	134	184	601	2568	7141
% of main component	30.18	32.86	46.63	68.23	78.78
Avg distance	7.27	4.99	9.12	6.46	5.9
Diameter	18	11	24	20	20
CC	0.12	0.19	0.24	0.28	0.27
Density	0.0047	0.0043	0.0023	0.0012	0.00069
Avg degree of ColNet	4.17	4.84	5.83	8.69	12.49
Degree of ColNet	0.06	0.037	0.03	0.02	0.015
Betweenness of ColNet	0.04	0.07	0.11	0.07	0.06

all intervals. In region four, it varies from 0.0047 to 0.00069. Compared with [9], we have lower density in all networks. This means that our networks are sparser.

Average Degree The average degrees of our networks are particularly high. Compared to [20], our results are so close to their results. In region one, the average degrees are 4.7, 6.12, 6.88, 7.63, and 8.81 for the five periods under considerations, respectively. In region two, the average degrees are 6.71, 7.15, 6.87, 7.64, and 8.46m respectively. In region three, the average degrees are 6.89, 6.47, 6.52, 7.7, and 8.42, respectively. In region four, the average degrees are 4.17, 4.84, 5.83, 8.69, and 12.49, respectively.

Degree Degree of network in region one starts with 0.032 in the first interval, and falls down to 0.01 in the last interval. In region two, it starts with 0.02 before it falls down to 0.009 in the last interval. As for region three, the degree of network starts with 0.049 before it flows down to 0.013 in the last period. Finally, the fourth region has the largest degree in the interval of 1991-1994. Our results indicate the coherence of the networks; it differs from interval to interval and from region to region, due to different political and social circumstances. We note the larger size of the network the lower density the lower degree.

Betweenness For region one, betweenness starts with 0.007 and grows up to 0.16, before it drops down to 0.14. In the second region, betweenness starts with 0.12 dropping down to 0.05 in the last interval. In the third region, betweenness starts with 0.12 before it drops down to 0.082. Finally, in region four, betweenness starts with 0.04 and increases to 0.07, before it drops down to 0.06 in the last interval.

4.2 Papers measures

In this section, we discuss the paper measures for our ColNet as summarized in Tables 6, 7, 8 and 9.

Number of Papers In all regions, the number of papers is increasing over time due to the increase of authors productivity. It starts with small number of papers in the first interval, and ends with huge number of authors in the last interval. In all regions, we can see that number of papers jump in early 2000's, which is due to the growth of academic institutions.

Table 6 Measures of the articles in the ColNet for region one (Jordan, Palestine, Lebanon, Syria, and Iraq)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Total papers	965	1532	2645	3780	5322
Single-local-authored papers	69%	58%	55%	49%	44%
Two-local-authored papers	18%	25%	27%	28%	28%
Three-local-authored papers	4%	7%	9%	12%	14%
Many-local-authored papers	1%	2%	4%	6%	9%
% of local authors in Papers:					
1-20	9%	9%	8%	8%	8%
21-40	29%	32%	27%	24%	25%
41-60	22%	21%	23%	25%	26%
61-80	7%	8%	11%	13%	15%
81-100	25%	21%	25%	25%	21%
Single-authored papers	21%	18%	18%	16%	13%
Two-authored papers	22%	20%	22%	21%	17%
Three-authored papers	24%	22%	20%	20%	20%
Many-authored papers	33%	40%	40%	43%	50%
Avg local authors/paper	1.21	1.34	1.52	1.68	1.85
Avg undetermined authors/paper	1.86	2.11	1.95	1.98	2.16
Avg authors/paper	3.07	3.46	3.51	3.69	4.05

Table 7 Measures of the articles in the ColNet for region two (Bahrain, Kuwait, Oman, Saudi, Qatar, Yemen, and UAE)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Total papers	3033	3889	4270	5676	7437
Single-local-authored papers	55%	55%	54%	49%	47%
Two-local-authored papers	25%	25%	26%	28%	27%
Three-local-authored papers	9%	8%	11%	13%	14%
Many-local-authored papers	2%	3%	4%	6%	9%
% of local authors in papers:					
1-20	7%	8%	6%	6%	5%
21-40	25%	26%	23%	21%	21%
41-60	24%	22%	26%	26%	24%
61-80	10%	9%	11%	14%	14%
81-100	25%	27%	29%	30%	32%
Single-authored papers	22%	22%	22%	21%	21%
Two-authored papers	20%	19%	21%	20%	18%
Three-authored papers	20%	18%	18%	18%	18%
Many-authored papers	38%	40%	38%	41%	43%
Avg local authors/paper	1.39	1.42	1.54	1.71	1.84
Avg undetermined authors/paper	1.76	1.84	1.63	1.62	1.69
Avg authors/paper	3.2	3.32	3.27	3.41	3.6

Table 8 Measures of the articles in the ColNet for region three (Egypt, and Sudan)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Total papers	1147	1207	1911	2574	4695
Single-local-authored papers	47%	50%	45%	39%	34%
Two-local-authored papers	28%	28%	28%	28%	28%
Three-local-authored papers	13%	12%	14%	20%	21%
Many-local-authored papers	7%	6%	6%	11%	14%
% of local authors in Papers:					
1-20	4%	5%	3%	4%	3%
21-40	22%	20%	18%	19%	15%
41-60	26%	24%	24%	23%	22%
61-80	17%	15%	16%	22%	25%
81-100	26%	32%	31%	29%	33%
Single-authored papers	18%	24%	21%	16%	14%
Two-authored papers	18%	15%	18%	15%	16%
Three-authored papers	22%	19%	22%	20%	21%
Many-authored papers	44%	42%	37%	48%	49%
Avg local authors/paper	1.75	1.69	1.69	2.04	2.26
Avg undetermined authors/paper	1.6	1.52	1.37	1.56	1.35
Avg authors/paper	3.39	3.25	3.19	3.65	3.71

Table 9 Measures of the articles in the ColNet for region four (Libya, Morocco, Tunisia, Mauritania, and Algeria)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Total papers	120	167	388	1159	3287
Single-local-authored papers	80%	75%	57%	46%	26%
Two-local-authored papers	9%	16%	26%	26%	27%
Three-local-authored papers	2.5%	4%	8%	13%	20%
Many-local-authored papers	0	1%	3%	12%	26%
% of local authors in papers:					
1-20	46%	39%	30%	23%	12%
21-40	32%	34%	35%	40%	32%
41-60	31%	16%	20%	23%	30%
61-80	0	1%	4%	7%	17%
81-100	7%	7%	4%	4%	8%
Single-authored papers	7.5%	8%	3%	2%	1%
Two-authored papers	7.5%	8%	9%	6%	5%
Three-authored papers	11%	10%	14%	12%	10%
Many-authored papers	74%	74%	74%	80%	83%
Avg local authors/paper	1.06	1.24	1.43	1.93	2.5
Avg undetermined authors/paper	4.02	3.84	3.78	3.67	3.23
Avg authors/paper	5.09	5.09	5.22	5.78	6.14

Papers Authored by Local Authors The tables show that the number of papers authored by two local authors or more is increasing almost in all regions in all time intervals. Papers authored by single local authors are reducing over time in all regions in all time intervals, this indicates that most local authors prefer work in groups rather than working individually. In contrast, papers authored by more than three authors have minimum value in all regions in all time intervals. We notice that local authors in early 90's tend to work individually or with small groups of two or three authors, and in early 2000's authors start to work in groups.

Papers Authored by Local or Undetermined Authors Here we discuss the number of papers in which their authors collaborated with local and undetermined authors. Papers with single authors are reducing over time in all regions. On the other hand, papers with two or three authors have a stable number. However, authors with more than three authors are increasing over time.

Percentage of Local Authors In all regions, less than 20% of authors are local, which means that the majority of authors are non-local authors. However, local authors form 21%-40% of about 30% of total papers. Thus, the contributions of local authors are reasonable in all regions, but still the non-local authors have larger presence.

Authors per Paper In all regions, the number of local authors per paper is more or less increasing over time.

4.3 Authors measures

In this subsection we discuss authors measures of our networks as listed in Tables 10, 11, 12 and 13.

Total Local Authors The number of local authors grows over time in all regions. Starting with region one, the number of local authors jumps in early 1995 up to 2010. In third region, a huge jump of local authors in 2006-2010, same as region four.

Papers per Author Here we discuss a number of papers per author (productivity) for local authors. In the first region, the average number of papers per local author exhibit a stable behavior, and it varies between 2.05 and 2.28. In the second region, the average number of papers per local author is in the range [2.13,2.61] with an abnormal value in the period of 1999-2002. As for region three, the average number of papers per local author changes between 2.05 and 1.82. Finally, in the last region, the averages of both papers per local are increasing from 1.35 to 2.64. In [20], the productivity was four papers per author which is much larger than we have here.

Table 10 Measures of the local authors in the ColNet in region one (Jordan, Palestine, Lebanon, Syria, and Iraq)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Local authors:	569	920	1850	2717	4325
Avg papers/local author:	2.05	2.23	2.17	2.34	2.28
Avg collaborators/local author:	3.8	5.23	5.5	6.2	7
Local collaborative rate:	0.23	0.26	0.33	0.37	0.39

Table 11 Measures of the local authors in the ColNet in region two (Bahrain, Kuwait, Oman, Saudi, Qatar, Yemen, and UAE)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Local authors:	1617	2888	2160	4214	6430
Avg papers/local author:	2.61	1.91	3.05	2.31	2.13
Avg collaborators/local author:	5.4	4.4	6.9	5.7	6.1
Local collaborative rate:	0.33	0.33	0.36	0.29	0.44

Collaborators Here we study number of collaborators for local authors, and the average number of authors with whom a local author collaborated (the average degree). The number of collaborators in all regions increases in all time intervals. It is worth mentioning that there is a jump in the number of collaborators in all regions starting in early 2000's till the end of the period. On the other hand, the average number of collaborators per author does not increase as fast as the number of collaborators. The network of [20] has an average that is a bit higher than our networks.

Percentage of Local Collaborators For all regions, the percentage of local collaborators is increasing over time. In the first region, the percentage of local collaborators was 0.23 in the first interval and 0.39 in the last interval. The following ranges of values: [0.33,0.44], [0.44,0.58], and [0.04,0.43] are for regions two, three and four, respectively.

4.4 Stability measures

In this section, we discuss the new measures proposed in [1, 5], which consider the new and deleted collaborators and the stability rate for each author. The details of these measures and their values are not presented here to avoid cluttering the paper and distracting the readers. Interested readers are referred to [3] to get the missing details.

Collaborators of Local Authors Here, we discuss a number of collaborators for each local author in all time periods. We compute the number of collaborators for each author in each year and divide authors into groups based on these numbers. The first group has authors with 0 collaborators, while the second group has authors with 1-25 collaborators. The remaining groups have authors with the following ranges of collaborators: 25-50, 51-74 and 75-100. Then, we compute the percentage of each group. In our networks, we observe that the set of 1-25 collaborators has the vast majority of collaborators. Thus, we can say most local authors have 1-25 collaborators. This applies for all regions. On the other hand, there is reasonable percentage of single collaborators, those who have no collaborators. However, region one, two, and three have no authors with 75-100 collaborators, except for region four,

Table 12 Measures of the local authors in the ColNet in region three (Egypt, and Sudan)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Local authors:	980	1071	1810	2794	5827
Avg papers/local author:	2.05	1.9	1.78	1.88	1.82
Avg collaborators/local author:	5.17	4.63	4.4	5.2	5.4
Local collaborative rate:	0.44	0.43	0.48	0.5	0.58

Table 13 Measures of the local authors in the ColNet in region four (Libya, Morocco, Tunisia, Mauritania, and Algeria)

	1991-1994	1995-1998	1999-2002	2003-2006	2007-2010
Local authors:	94	124	337	1193	3473
Avg papers/local author:	1.35	1.67	1.68	1.88	2.64
Avg collaborators/local author:	5.1	5.8	6.1	8.1	10.4
Local collaborative rate:	0.04	0.1	0.18	0.31	0.43

which has a very small percentage. Authors with 51-74 and 75-100 collaborators have very small percentage as well.

New Collaborators Here we discuss a number of new collaborators for each local author in all time periods. We compute the percentage of new collaborators for each local author in each year aside. In all regions, the vast majority of local authors added 1-25 collaborators. On the other hand, a small number of local authors added 26-50 authors, and very small number of authors added 51-74 authors. Finally, there are no local authors who added 75-100 collaborators.

Deleted Collaborators Here we discuss a number of deleted collaborators for each local author in all time periods. We compute the percentage of deleted collaborators for each local author in each year. Note that the vast majority of local authors deleted up to 25 collaborators in all regions. On the other hand, a small number of local authors deleted 26-50 authors, and a very small number of authors deleted 51-74 authors in all regions. Finally, there are no local authors who deleted 75-100 collaborators in all regions.

Stability Rate of Collaborators Here, we present the stability rates of collaborators for each local author in all time periods. See Tables 14, 15, 16, 17, 18, 19, 20 and 21.

4.5 Highly productive and influential authors

In this section, we focus on the top authors in terms of productivity and influence in our ColNet and analyze their records thoroughly.

Top Authors We choose the top 20 local authors in terms of productivity, new and deleted authors, degree centrality, betweenness centrality, and closeness centrality. As a case study,

Table 14 Local authors and rate of their stabilities with collaborators from 1991 till 2000 in region one (Jordan, Palestine, Lebanon, Syria, and Iraq)

	91	92	93	94	95	96	97	98	99	000
=0%	–	2.46%	6.16%	4.31%	–	4.52%	4.15%	6.72%	–	3.65%
1–25%	–	1.03%	1.64%	2.87%	–	2.56%	3.3%	2.56%	–	2.61%
26-50%	–	1.64%	2.29%	4.52%	–	2.69%	2.93%	4.1%	–	3.16%
51-74%	–	0.62%	1.23%	0.62%	–	0.12%	1.47%	0.85%	–	0.73%
75-100%	–	1.85%	0.82%	2.67%	–	1.71%	1.22%	1.47%	–	1.88%
Rest	–	92.4%	87.86%	85.01%	–	88.4%	86.93%	84.3%	–	87.97%

Table 15 Local authors and rate of their stabilities with collaborators from 2001 till 2010 in region one (Jordan, Palestine, Lebanon, Syria, and Iraq)

	001	002	003	004	005	006	007	008	009	010
=0%	4.86%	4.44%	–	3.51%	4%	4.65%	–	2.76%	3.36%	4.71%
1–25%	2.74%	3.28%	–	2.41%	2.86%	2.98%	–	2.22%	3.07%	3.35%
26–50%	2.55%	3.34%	–	2.53%	3.35%	4%	–	3.19%	3.24%	4.04%
51–74%	0.91%	1.34%	–	0.65%	1.27%	1.92%	–	0.92%	0.8%	1.04%
75–100%	2.19%	1.03%	–	1.8%	2.08%	2.25%	–	1.57%	1.31%	1.52%
Rest	86.75%	86.3%	–	89.25%	86.44%	84.2%	–	89.34%	88.22%	85.34%

Table 16 Local authors and rate of their stabilities with collaborators from 1991 till 2000 in region two (Bahrain, Kuwait, Oman, Saudi, Qatar, Yemen, and UAE)

	91	92	93	94	95	95	97	98	99	000
=0%	–	6.15%	5.74%	5.53%	–	5.52%	5.83%	6.14%	–	4.13%
1–25%	–	3.39%	3.8%	3.67%	–	3.32%	3.99%	2.86%	–	2.1%
26–50%	–	3.67%	4.5%	3.39%	–	3.17%	3.17%	4.04%	–	2.1%
51–74%	–	1.11%	1.24%	1.11%	–	0.72%	0.36%	0.97%	–	0.54%
75–100%	–	1.52%	2.28%	2.9%	–	1.99%	1.69%	1.33%	–	1.53%
Rest	–	84.16%	82.44%	83.4%	–	85.28%	84.96%	84.66%	–	89.6%

Table 17 Local authors and rate of their stabilities with collaborators from 2001 till 2010 in region two (Bahrain, Kuwait, Oman, Saudi, Qatar, Yemen, and UAE)

	001	002	003	004	005	006	007	008	009	010
=0%	4.59%	4.09%	–	4.03%	4.6%	4.6%	–	3.2%	3.4%	4.43%
1–25%	2.49%	3.18%	–	2.31%	2.42%	2.57%	–	1.79%	2.02%	2.68%
26–50%	2.91%	3.9%	–	3.35%	2.94%	3.25%	–	1.9%	2.48%	3.22%
51–74%	0.8%	0.84%	–	1.07%	0.99%	1.7%	–	0.54%	0.92%	1.06%
75–100%	1.45%	1.42%	–	1.56%	2.42%	1.51%	–	1.31%	1.33%	1.85%
Rest	87.76%	86.57%	–	87.68%	86.63%	86.37%	–	91.26%	89.85%	89.98%

Table 18 Local authors and rate of their stabilities with collaborators from 1991 till 2000 in region three (Egypt, and Sudan)

	91	92	93	94	95	96	97	98	99	000
=0%	–	3.25%	5.53%	4.44%	–	3.65%	3.65%	3.65%	–	3.22%
1–25%	–	2.17%	1.63%	1.63%	–	1.72%	1.72%	1.32%	–	1.28%
26–50%	–	1.73%	2.17%	2.71%	–	1.62%	2.23%	1.62%	–	1.4%
51–74%	–	0	0.43%	0.76%	–	0.61%	0.61%	0.71%	–	0.18%
75–100%	–	0.98%	0.87%	0.4%	–	0.71%	1.01%	2.03%	–	0.61%
Rest	–	91.87%	89.37%	90.06%	–	91.69%	90.78%	90.67%	–	93.31%

Table 19 Local authors and rate of their stabilities with collaborators from 2001 till 2010 in region three (Egypt, and Sudan)

	001	002	003	004	005	006	007	008	009	010
=0%	3.83%	4.61%	–	2.53%	3.43%	4.21%	–	2.18%	3.23%	9.96%
1–25%	1.58%	1.28%	–	0.86%	1.95%	1.83%	–	1.39%	0.98%	1.95%
26–50%	1.58%	1.58%	–	1.29%	2.61%	1.95%	–	1.3%	1.64%	2.41%
51–74%	0.49%	0.43%	–	0.39%	0.31%	0.7%	–	0.29%	0.46%	0.45%
75–100%	0.61%	1.03%	–	1.09%	0.93%	0.86%	–	0.8%	0.93%	1.23%
Rest	91.91%	91.07%	–	93.84%	90.77%	90.45%	–	94.04%	92.76%	84%

Table 20 Local authors and rate of their stabilities with collaborators from 1991 till 2000 in region four (Libya, Morocco, Tunisia, Mauritania, and Algeria)

	91	92	93	94	95	96	97	98	99	000
=0%	–	1.14%	2.27%	0	–	0	1.74%	1.74%	–	0.9%
1–25%	–	0	0	2.27%	–	0	0	0.87%	–	1.2%
26–50%	–	1.14%	1.14%	1.14%	–	1.74%	1.74%	4.35%	–	1.82%
51–74%	–	0	0	0	–	0	0.87%	3.48%	–	1.51%
75–100%	–	2.27%	0	1.14%	–	4.35%	6.09%	0	–	1.51%
Rest	–	95.45%	96.59%	95.45%	–	93.91%	89.56%	89.56%	–	93.06%

Table 21 Local authors and rate of their stabilities with collaborators from 2001 till 2010 in region four (Libya, Morocco, Tunisia, Mauritania, and Algeria)

	001	002	003	004	005	006	007	008	009	010
=0%	0.9%	1.2%	–	2.12%	2.39%	2.03%	–	1.85%	1.91%	2.6%
1–25%	1.82%	3.61%	–	1.59%	2.3%	3.45%	–	2.03%	2.95%	4.6%
26–50%	3.01%	1.51%	–	2.03%	1.95%	3.18%	–	2.72%	5.3%	6.39%
51–74%	0.6%	2.11%	–	0.71%	2.12%	1.86%	–	1.82%	2.78%	3.07%
75–100%	2.41%	0.6%	–	0.97%	1.15%	1.77%	–	1.56%	2.08%	2.23%
Rest	91.26%	90.97%	–	92.58%	91.09%	87.71%	–	90.02%	84.98%	81.11

Table 22 The matching ratio between the top local authors in terms of the used measures and the top local authors in terms of productivity in region one

Measures	Matching ratio
Number of new collaborators	9/20
Number of deleted collaborators	7/20
Number of collaborators	9/20
The common local authors	6/20
Betweenness	4/20
Closeness	1/20

Table 23 The matching ratio between the top local authors in terms of the used measures and the top local authors in terms of productivity in region two

Measures	Matching ratio
Number of new collaborators	2/20
Number of deleted collaborators	8/20
Number of collaborators	9/20
The common local authors	5/20
Betweenness	8/20
Closeness	6/20

Table 24 The matching ratio between the top local authors in terms of the used measures and the top local authors in terms of productivity in region three

Measures	Matching ratio
Number of new collaborators	8/20
Number of deleted collaborators	8/20
Number of collaborators	8/20
The common local authors	6/20
Betweenness	4/20
Closeness	4/20

Table 25 The matching ratio between the top local authors in terms of the used measures and the top local authors in terms of productivity in region four

Measures	Matching ratio
Number of new collaborators	12/20
Number of deleted collaborators	8/20
Number of collaborators	11/20
The common local authors	7/20
Betweenness	7/20
Closeness	7/20

Table 26 Impact of all factors on the productivity in years of 2007-2010 in region four (Libya, Morocco, Tunisia, Mauritania, and Algeria)

Case	Author	Year	No of collaborators	No of new collaborators	No of deleted collaborators	Stability rate	Productivity
First	2188	2009	60/high	44/high	21/high	40%/low	10/high
Second	202	2010	57/high	44/high	16/high	40%/low	11/high

Table 27 Impact number of collaborators on the productivity in years of 2007-2010 in region four (Libya, Morocco, Tunisia, Mauritania, and Algeria)

Case	Author	Year	No of collaborators	No of new collaborators	No of deleted collaborators	Stability rate	Productivity
Third	1082	2009	39/high	—	—	—	14/high
Fourth	1082	2007	16/low	—	—	—	4/low

Table 28 Impact of stability rate on the productivity in years of 2007-2010 in region four (Libya, Morocco, Tunisia, Mauritania, and Algeria)

Case	Author	Year	No of	No of new	No of deleted	Stability	Productivity
	ID		collaborators	collaborators	collaborators	rate	
Fifth	33	2010	–	–	–	30%/low	11/high

we choose the top 20 local authors in terms of productivity in the period of 2007-2010, and match them with the top local authors in terms of the measures discussed above. Tables 22, 23, 24 and 25 show these matchings. The details are presented in [3].

Top 20 Local authors in Terms of Productivity We now discuss the effect of productivity on some measures. First we find the top 20 authors in terms of productivity, and then we compute its effect on some measures such as the number of new collaborators, the number of deleted collaborators, stability rate, degree and productivity. Here are some examples from region four with time interval 2007-2010. In these examples, we illustrate the impact of multiple measures on the productivity of authors. See Tables 26, 27 and 28.

Finally, we find that these factors affect authors' productivity in different ways. The ups and downs of new, deleted and stability rates of collaborators have a big role in the productivity of an author.

5 Conclusion and future work

In this work we construct, analyze, and study the ColNet of biomedical researchers in the Arab world. We considered the publications published in PubMed for the years of 1991 to 2010. We divide the Arab world into four geographical regions, as customary in many studies about this part of the world. This division is based on the homogeneity of the people living in each region. Note that we ignore some countries, such as Djibouti and Somalia, due to the lack of data on them. Then, we analyze these networks using standard analysis measures and using new technique of analysis based on the productivity of the authors. Our results show that there is an increase of both researchers and publications over time and that researchers prefer to collaborate with other researchers than working individually. Moreover, our results reveal that researchers' productivity is affected by several measures, such as adding new collaborators, deleting old collaborators, and the stability rate of collaborators in different ways.

Our study can take other issues to be considered. The first issue is to take a region as whole or a country as a case study, and discuss the main issues and circumstances that affect the ColNet. We can also consider questions such as: which researcher (groups of researchers) is (are) the best? What are the communities within the ColNet? What are the levels of collaboration between different countries in different times?

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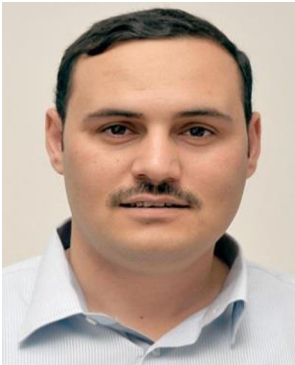
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