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Diffusion of nanotechnology knowledge in Turkey and its network structure

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Abstract This paper aims to assess the diffusion and adoption of nanotechnology knowledge within the Turkish scientific community using social network analysis and bibliometrics. We retrieved a total of 10,062 records of nanotechnology papers authored by Turkish researchers between 2000 and 2011 from Web of Science and divided the data set into two 6-year periods. We analyzed the most prolific and collaborative authors and universities on individual, institutional and international levels based on their network properties (e.g., centrality) as well as the nanotechnology research topics studied most often by the Turkish researchers. We used co-word analysis and mapping to identify the major nanotechnology research fields in Turkey on the basis of the co-occurrence of words in the titles of papers. We found that nanotechnology research and development in Turkey is on the rise and its diffusion and adoption have increased tremendously thanks to the Turkish government's decision a decade ago identifying nanotechnology as a strategic field and providing constant support since then. Turkish researchers tend to collaborate within their own groups or universities and the overall connectedness of the network is thus low. Their publication and collaboration patterns conform to Lotka's law. They work mainly on nanotechnology applications in Materials Sciences, Chemistry and Physics, among others. This is commensurate, more or less, with the global trends in nanotechnology research and development.

This paper is based on earlier papers presented at ISSI 2015 in Istanbul, Turkey (Darvish and Tonta 2015a, b). Findings reported here are based on the findings of the first author's PhD dissertation entitled "Assessing the diffusion of nanotechnology in Turkey: A Social Network Analysis approach" (Darvish 2014).

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Introduction

Nanotechnology is a relatively new field studying materials at atomic levels within the 1- to 100-nanometer (nm) range (one nm is equal to one billionth of a meter, or, 10^{-9}) (Nanotechnology 2015). It involves physics, chemistry, medicine, and biotechnology, among others, and promises a great deal of innovation for, and benefit to, society as a whole. Braun et al. (1997) studied the growth of terms with the prefix "nano" in the titles of journal papers published between 1986 and 1995. They identified more than 200 different such terms and calculated the exponential doubling time as 1.6 years (p. 322). Schummer (2004) noted that governments did not even consider funding nanoscience and nanotechnology research separately in those years whereas things have changed starting from late 1990s. The growth rate has not slowed down and nanoscience and nanotechnology has even become a more inter- and multidisciplinary field of research since then. Information scientists studied the nanotechnology research literature and its structure (Kostoff et al. 2006, 2007); the evolution, cognitive content and socio-cognitive structure of the field (Milojević 2009, 2012); and the scientific collaboration patterns of nanoscience and nanotechnology researchers (Schummer 2004; Ovalle-Perandones et al. 2013).

Turkey identified nanotechnology early on (2003) as one of the eight strategic fields to support (Ulusal 2004). Nanotechnology strategies were developed as part of the Vision 2023 Project (Nanobilim 2004). Turkey invested considerably in nanotechnology infrastructure and education since then and set up several "centers of excellence" in universities for nanotechnology research and development (R&D). The Turkish Scientific and Technological Research Council (TUBITAK) and the Ministry of Development (MoD) are the main supporters of nanotechnology projects financially. For example, the MoD continues for more than a decade to invest to set up and improve the infrastructure of nanotechnology research facilities. Among them are the Research Center for Nanotechnology and Biotechnology of the Middle East Technical University (METU) and the National Nanotechnology Center in Bilkent University, both centers being operational for almost a decade. Since 2006, several universities initiated multidisciplinary nanotechnology degree programs (MSc and PhD). Altogether, there are currently more than 20 nanotechnology research centers and over 100 private companies developing and commoditizing nanotechnology products in Turkey (Bozkurt 2015; Denkbaş 2015; Erkoç 2007; Özgüz 2013).

The substantial interest and investment in nanotechnology triggered nanotechnology research in Turkey. Turkey is among the top three countries in the world in terms of the growth rate of nanotechnology research (Bozkurt 2015, p. 49). More than 2000 researchers are active in this field producing some 2500 papers in 2014 alone[1] (Bozkurt 2015, p. 49; Denkbaş 2015, p. 84; Özgüz 2013). In this paper, we investigate the diffusion and adoption of nanotechnology knowledge in Turkey by analyzing the co-authorship patterns using three centrality measures (e.g., degree, betweenness and closeness centrality coefficients) and co-words contained in more than 10,000 nanotechnology papers authored by Turkish researchers between 2000 and 2011. We use bibliometric and social network analysis (SNA) techniques to compare the diffusion of nanotechnology research output between

[1] Search on WoS was carried out on January 11, 2015.

2000 and 2005 and 2006–2011, and identify the most prolific and collaborative researchers and universities for each period along with the major nanotechnology research strands in Turkey.

Literature review

Scientists have investigated the diffusion of ideas, innovations and knowledge in societies using deterministic, stochastic and epidemic models, among others (Vitanov and Ausloos 2012). In early 1960s, Rogers (1962) studied the diffusion of innovations from the perspective of the sociology of science. He defines the diffusion of an innovation as "the process by which an innovation is communicated through certain channels over time among the members of a social system" (Rogers 2003, p. 5). Social interactions between scientific domains and practitioners are instrumental to the diffusion of innovation and knowledge. According to Rogers, the key elements in the diffusion process are: innovation/knowledge, communication channels, time and social systems (p. 7). An innovation starts with a few people and has a few adopters, but eventually it gains the momentum until it reaches its peak. Rogers likens the diffusion process of an innovation to a mathematically-based bell curve (also known as "Rogers adoption/innovation curve") and categorizes the adopters accordingly (i.e., starting from the left tail of the curve to the right, 2.5 % of the adopters are called "innovators", 13.5 % "early adopters", 34 % "early majority", 34 % "late majority", and the remaining 16 % on the right tail of the curve as "laggards").

Social network analysis (SNA) combining social theory and mathematics (graph theory) is used to study the interactions and patterns of relationships among group members. The "small world" phenomenon conjectures that each actor (node) in a society is linked to others (edges) through friends. Literally, every node in a small world is connected through an acquaintance. Milgram (1967) proved that it takes a maximum of six steps from one node (person) in a social network structure for a message to be passed along to another node no matter how complex the network structure is (see also Watts 2003). Newman (2001) found out that average distance from one person to the other by an acquaintance is proportional to the logarithm of the size of the community, implying one of the small world properties.

According to Otte and Rousseau (2002, p. 443), betweenness, closeness and degree centrality are well known measures used in analyzing the structures of networks. Betweenness centrality is defined as the number of shortest paths going through a node. Thus, a node with high betweenness centrality will have a large impact on the diffusion of knowledge in the network (assuming that knowledge diffusion follows the shortest paths). Centrality is the total number of links that a node has. Degree centrality identifies the most influential node in the diffusion of knowledge in the social network. Closeness centrality measures how far a node is from other nodes in the network structure and how long it will take to diffuse the knowledge in a network (Centrality 2015).

Betweenness centrality plays an important role in the structures of social networks. According to Freeman (2004), the discovery of the structural properties of scientific papers is measured by the betweenness centrality. Actors with a high level of betweenness centrality play a pivotal role in connecting different groups within the network. Betweenness centrality characterizes preferential attachments, cliques, or brokers. Preferential attachments play an important role in network development (Barabasi and Albert 1999, p. 509). In other words, people in social networks tend to work with well-known people that lead to the concept of “strong and weak ties”, characterizing a group of people attached to one node with high centrality. This is called the “star network model” (Moody 2004; Scott 2000).

Newman (2001) stated that collaboration among scientists in networks is a good example of showing preferential attachment. As mentioned earlier, if two nodes have high degrees of centrality, the probability of being acquainted with a mutual friend gets higher. Only a small percentage of people in a social network are well connected (Lotka’s law). The productivity of authors in a network resembles Lotka’s law in that a small number of researchers publish the majority of papers while large numbers of researchers publish one or two papers (Martin et al. 2013). Each group of authors creates a community in which a node with a high degree of centrality is the central node. Therefore, collaboration networks consist of separate clusters representing different scientific fields where they may connect through lower degree connectors. Each community comprises several star networks and a node of lesser degree may connect these clusters. Newman (2001) referred to clustering as “community structure”. PageRank measuring the popularity of web pages is a similar metric (Page and Brin 1998) in that the appearance of a certain author in the references of a corpus of articles reflects the prestige of that author in the network structure.

Börner et al. (2007) review network science, an interdisciplinary field “concerned with the study of networks, be they biological, technological, or scholarly in character” (p. 537). Mali et al. (2012) classified the levels of analysis of scientific collaboration and analyzed the dynamic co-authorship networks with a view to model them. Watts (2003) and Moody (2004) studied the structure of social networks and social science collaboration networks while Hou et al. (2008) focused more specifically on the collaboration between scientometricians at macro level and mapped the co-authorship network of scientometricians using social network analysis.

While Rogers’ diffusion of innovation theory and social network analysis are based on the sociology of science as they mainly deal with the innovators/adopters/members and the interactions between them, bibliometrics and scientometrics are based on a “literary model of science” as they focus on the scholarly communication outputs (Scharnhorst and Garfield 2010). Scharnhorst and Garfield (2010) categorized bibliometric and scientometric studies under two main units of analysis, namely the texts (i.e., publications) and their creators (i.e., authors and institutions). The former deals with the words and references in texts to identify the hot topics and new research strands using co-word maps, semantic maps and (co-)citation networks. The latter is used to measure the productivity and performance of the creators of the texts as well as to study the collaboration between them on individual, institutional and international levels to identify the key “actors”.

“Scientific collaboration occurs within the larger context of science” (Sonnenwald 2007, p. 646) because it involves not only scientific but also political and socio-economical factors as well as social networks. Collaboration creates networks of scientists that can be categorized in terms of organization, disciplines and geography. For instance, collaborative research is more common in some disciplines (e.g., chemistry) than others (e.g., philosophy) (Sonnenwald 2007, p. 672).

Co-authorship networks indicate some kind of collaboration among scientists in carrying out research (Hou et al. 2008) while (co-)citation analysis helps identify the influential scientists in the network (White and McCain 1998). Co-authorship analysis is also used by bibliometricians to study the temporal and topological diffusion of innovation and knowledge as co-authorship stimulates the knowledge diffusion in scientific communities (Chen et al. 2009, p. 192). For example, Özel (2010) assessed the diffusion of knowledge in business management among academia in Turkey from 1928 to 2010 by studying the co-authorship relationships of academics in business management.

Co-word analysis of texts, on the other hand, is used to study the literature over time in terms of the frequencies or co-occurrences of words in titles, abstracts, or more generally, in texts (Callon et al. 1983). It helps map scientific domains and reveal their cognitive structures (Chen 2004). Moreover, semantic mapping of the co-word analysis in contexts reveals the meaning in the discourse in texts (Leydesdorff and Welbers 2011). Semantic mapping has been enhanced further by the development of the Latent Semantic Analysis (LSA) technique (Landauer et al. 1998). LSA has been integrated into several software packages including CiteSpace developed by Chen (2006).

Bibliometric and scientometric studies have been carried out to review the development and growth of nanoscience and nanotechnology on a global scale with a view to find out the most prolific authors, journals, institutions, countries and the most cited authors/papers/journals (Kostoff et al. 2006, 2007). China, Far Eastern countries and USA, Germany, and France were the most productive countries in terms of number of publications. Ovalle-Perandones et al. (2013) did a similar study for the European Union countries (EU-27) using bibliometric methods and social network analysis. Authors mapped the frequency of co-occurrences of collaboration of EU countries on nanotechnology and found that the level of collaboration of EU countries among themselves has decreased between 2001 and 2011, as they sought collaboration with countries beyond EU such as China.

As mentioned earlier, the growth rate of nanotechnology research in Turkey is quite encouraging, and the contribution of Turkish researchers to nanoscience and nanotechnology literature became evident at the global level starting from 2002 (Kostoff et al. 2007). Although the state of the art of nanotechnology centers and companies has been studied quantitatively (Aydogan-Duda and Sener 2010; Aydogan-Duda 2012), the research output they produced in terms of scientific papers has yet to be studied in detail. This is the first such study to investigate the diffusion and adoption of nanotechnology in Turkey and the level of collaboration among the most prolific researchers and universities using social network analysis, co-authorship analysis and co-word analysis.

Methods

This paper aims to depict the development of nanotechnology in Turkey between 2000 and 2011 by identifying the network structure of nanotechnology papers authored by Turkish researchers and finding out the most productive researchers and universities who help diffuse the nanotechnology knowledge by collaborating with their peers. We use centrality measures of SNA to study the diffusion of nanotechnology knowledge through collaboration of researchers in Turkey along with the characteristics of collaboration networks that exist in nanotechnology literature authored by Turkish researchers. Further, we use co-authorship and co-word analyses as network analytics to identify the collaboration patterns among nanotechnology researchers on macro level and to create a semantic map of nanotechnology network structure. We attempt to answer the following research questions:

1. How is the rate of diffusion of nanotechnology knowledge and its adoption within universities between 2000 and 2011?
2. Which researchers and universities contribute most to the diffusion of nanotechnology research in Turkey by collaboration?

3. Do co-authorship networks in nanotechnology literature exhibit a “small world” network structure?
4. What are the main nanotechnology research interests of Turkish scholars?

To answer these questions, we used a compound textual query on nanotechnology based on Kostoff’s[2] (see “Appendix”). Thomson Reuters’ Web of Science (WoS) was chosen as the main database as it is the most comprehensive one covering the majority of refereed science journals (Testa 2004). We retrieved a total of 10,062 records of nanotechnology papers (articles and reviews) from Web of Science (WoS) published between 2000 and 2011 with at least one author based in Turkey.[3] Having noticed that the number of new adopters of nanotechnology knowledge has increased fivefold from 2005 to 2006 and that almost three quarters of papers (7398 papers or 73.5 %, to be exact) were published after 2006, we divided the data set into two equal periods (2000–2005 and 2006–2011) to better identify the trends and make comparisons. The distributions of universities/nanotechnology research centers and researchers publishing nanotechnology papers were rather skewed. We decided to investigate the diffusion of nanotechnology knowledge through core universities/nanotechnology research centers and prolific researchers in Turkey. We first identified the top 15 most prolific universities and authors by means of frequency and co-occurrence methods embedded in Bibexcel. We then identified the scientists with the highest coefficients of centrality in the network structure. As the institutional addresses and the authors’ names were sometimes misspelled or recorded in different forms in WoS (e.g., use of abbreviated addresses and authors’ maiden names, changes of authors’ affiliations, among others), the data was cleaned, and the author names were disambiguated before analysis.

We used co-authorship and co-word analyses to track the collaboration patterns and research interests of Turkish nanotechnology scholars between the two periods. Factor analysis helped us interpret the co-word relations better, thereby enabling us to create a semantic map of nanotechnology network structure. We used a geocoder[4] to get the geo-coordinates for each city listed in the address field of authors and Google Maps to overlay the relationships among cities on a geographic map. Bibexcel (Persson et al. 2009), VOSviewer (Van Eck and Waltman 2010), Pajek[5] and Gephi[6] were used to create files and map the bibliometric data, calculate the properties of the social network structure (e.g., the betweenness, closeness, and degree centralities and the PageRank of each node) and depict the network’s features visually.

Data

WoS indexes twice as many nanotechnology papers authored by Turkish scientists compared to other bibliographic databases, although it certainly does not index such papers written in Turkish. Figures reported here are believed to be highly representative nonetheless, as nanotechnology papers tend to be published primarily in English language journals. The number of Turkey’s scientific publications on nanotechnology increased

[2] Personal communication with Prof. Ronald N. Kostoff (20 April 2012).

[3] We used the command “AD = TURKEY” that is available in WoS.

[4] Available from http://www.gpsvisualizer.com/geocoder/.

[5] http://mrvar.fdv.uni-lj.si/pajek/.

[6] http://gephi.github.io/.

from 215 papers in 2000 to 1748 in 2011, more than an eightfold increase (Fig. 1). Almost three quarters (7398) of all papers (articles and reviews) were published between 2006 and 2011 while the rest (2664) were between 2000 and 2005. This increase is mainly due to Turkey's making nanotechnology a priority field in its 2003–2023 strategic plan (Ulusal 2004) and providing state support to nanotechnology R&D starting from 2007.

The number of newly-established universities, hence the number of researchers studying nanotechnology, has almost tripled in this period from 73 in the year 2000 to 165 in 2011 (Günay and Günay 2011, pp. 4–6), although not all of them have been involved in nanotechnology research per se. Currently, there are about 200 universities in Turkey, two-thirds being state-funded. We used the fractional counting method to identify the top ranked universities based on the number of nanotechnology papers they published between 2000 and 2011 (Fig. 2). The Middle East Technical, Hacettepe, İstanbul Technical, Gazi and Bilkent Universities are the top ranking ones. All but four (Bilkent, Koç, Fatih and Sabancı) universities in Fig. 2 are state funded. Note that figures reported here do not reflect the papers published by these universities in journals that are not indexed in WoS.

We examined the diffusion of nanotechnology knowledge in Turkey using a more refined approach and identified the new authors collaborating each year in order to find out the adoption rate of nanotechnology research. Note that by "new author" we mean an author who published for the first time a nanotechnology paper as reflected in WoS. Some of these authors may not be new however, as they may have published nanotechnology papers in journals that are not indexed by WoS. Each new Turkish author encountered in the following year was counted as a "new adopter" and added to the count of previous years. Needless to say, the new adopters that are not reflected in WoS data are not reported here.

Findings

Diffusion of nanotechnology knowledge in Turkey

The number of unique authors publishing nanotechnology papers was just 214 at the beginning (2000) whereas it rose to 2989 in 2011 (Table 1 and Fig. 3). The number of new adopters was rather slow in the first period (2000–2005) with an average of 227 new adopters per year, but the "tipping point" seems to have been reached in 2006 when the number of new adopters jumped from 282 in 2005 to 1622, an almost sixfold increase. The average number of new adopters in the second period (2006–2011) rose to 2055, more than nine times of what it was in the first period. Altogether, the number of cumulative new adopters soared in 12 years and was 13,692 in 2011. The annual rate of cumulative increase in percentages ranged between 11 % (2004) and 54 % (2006).

Just as the number of newly established Turkish universities tripled between 2000 and 2011, the number of faculty members (assistant, associate and full professors) steadily increased and doubled during the same period from *circa* 20,000 to well over 40,000 (Günay and Günay 2011, p. 16, Fig. 5). We do not have the detailed figures on the research fields of faculty members. Yet, figures reported above clearly show that the rate of increase of the number of authors publishing nanotechnology papers is much higher than that of the number of faculty members. Needless to say, the increase in the number of new adopters is primarily due to nanotechnology becoming a major research field in Turkey and nanotechnology research being supported by government funds.

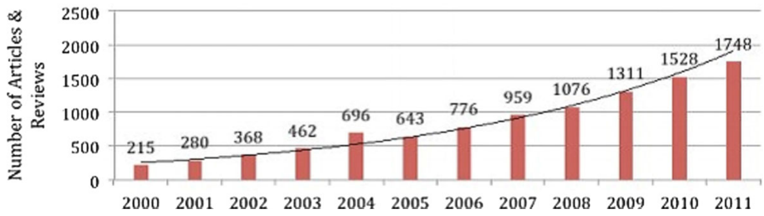

Fig. 1 Number of nanotechnology papers of the top Turkish universities between 2000 and 2011. *Source*: Web of Science as of November 2013

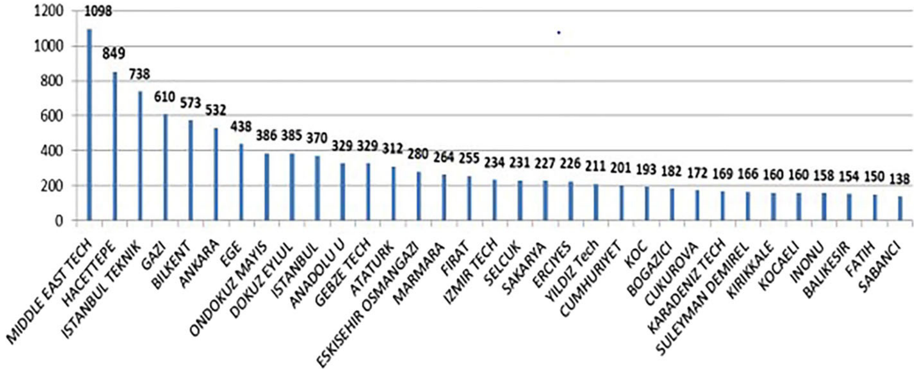

Fig. 2 Number of nanotechnology papers of the top Turkish universities between 2000 and 2011. *Source*: Web of Science as of November 2013

Table 1 Number of new and cumulative adopters between 2000 and 2011

Year	# of new adopters	# of cumulative adopters	Rate of cumulative increase (%)
2000	214	214	0
2001	177	391	45
2002	193	584	33
2003	381	965	39
2004	115	1080	11
2005	282	1362	21
2006	1622	2948	54
2007	1668	4652	37
2008	1907	6559	29
2009	1919	8478	23
2010	2225	10,703	21
2011	2989	13,692	22

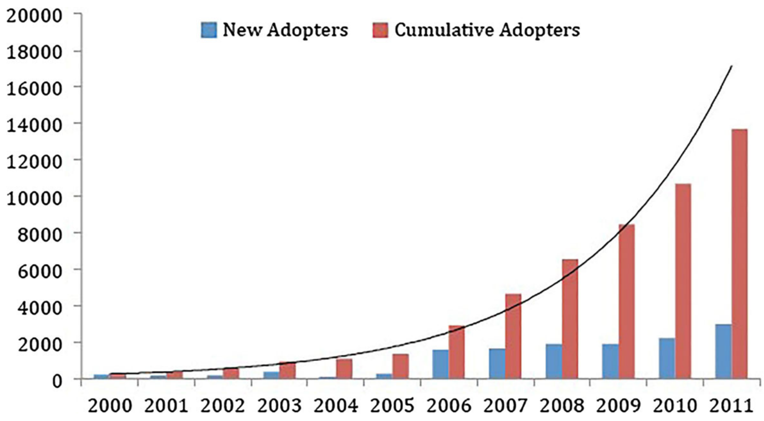

Fig. 3 The growth of adoption of nanotechnology knowledge based on the number of collaborating authors (2000–2011)

The most prolific Turkish nanotechnology researchers

Table 2 shows the top 20 nanotechnology researchers between 2000 and 2011 along with their total number of publications and co-authors in each period. Fractional counting

Table 2 The most prolific Turkish nanotechnology scholars (2000–2011)

2000–2005			2006–2011		
N	First author and affiliation	# of co-authors	N	First author and affiliation	# of co-authors
53	Erkoc S (METU)	29	149	Buyukgungor O (Ondokuz Mayis)	37
49	*Sokmen I (Dohuz Eylül)*	*16*	*78*	*Yagci Y (ITU)*	*19*
42	*Ciraci S (Bilkent)*	*13*	*75*	*Denizli A (Hacettepe)*	*18*
39	*Denizli A (Hacettepe)*	*12*	72	Yakuphanoglu F (Firat)	28
38	*Yagci Y (ITU)*	*10*	*67*	Ozkar S (METU)	23
37	Celik E (Bilkent)	11	*67*	*ToppareL (METU)*	15
37	*Sari H (Bilkent)*	*11*	*64*	*Ozbay E (Bilkent)*	13
36	Turker L (METU)	28	62	Yesilel OZ (Osmangazi)	17
30	*Yilmaz VT (Dohuz Eylül)*	*8*	*61*	*Sokmen I (Dohuz Eylül)*	17
30	*Toppare L (METU)*	*7*	58	Ozcelik S (Gazi)	12
29	Hascicek YS (Gazi)	8	52	Demir HV (Bilkent)	13
28	Ovecoglu ML (ITU)	7	49	Baykal A (Bilkent)	10
27	Elmali A (Ankara)	8	45	Turan R (METU)	10
26	Elerman Y (Ankara)	8	44	Sahin E (Bilkent)	11
26	Piskin E (Hacettepe)	8	*44*	*Yilmaz VT (Dohuz Eylül)*	13
26	*Kasapoglu E (Cumhuriyet)*	*8*	43	Caykara T (Gazi)	15
26	Balkan N (Bilkent)	5	*41*	*Sari H (Ankara)*	9
22	Yilmaz F (METU)	6	*40*	*Ciraci S (Bilkent)*	12
22	Turan S (Marmara)	8	*39*	*Kasapoglu E (Cumhuriyet)*	12
22	*Ozbay (Bilkent)*	*5*	39	Albayrak C (Ondokuz Mayis)	11

Source Web of Science (as of November 2013) method was used for co-authored papers. The total number of papers authored or co-authored by the top 20 researchers almost doubled between 2006 and 2011 (from 645 to 1189). Nine researchers appeared in both periods with different ranks (italicized in the table). This means that 11 new researchers became more productive than they were in the first period and replaced the less productive ones in the second period or they entered the field anew. O. Buyukgungor of Ondokuz Mayis University, for instance, is at the top of the second period with 149 papers to his credit even though he did not appear in the top 20 of the first period. The top 20 most prolific researchers co-authored more papers with their colleagues in the second period (216 and 315, respectively). The number of co-authors of nine researchers who appeared in both periods increased 42 % in the second period, indicating that they were influential in diffusing the nanotechnology knowledge to their colleagues. The same can probably be said for the remaining 11 researchers who appeared in the top 20 list in the second period.

Individual collaboration and the co-authorship network

Next, we studied the co-authorship network structures in each period (2000–2005 and 2006–2011) using social network analysis (SNA) techniques to identify the level of individual collaboration between nanotechnology researchers in Turkey. SNA enabled us to discern the nodes that might be crucial to the diffusion of nanotechnology knowledge. The network consists of 470 nodes and 1042 edges in 2000–2005 and 945 nodes and 4915 edges in 2006–2011. The rates of growth for nodes and edges (ties) increased two- and fourfolds, respectively, between the two periods. However, the level of collaboration has not changed so much. There is a minimal change in density (from 0.0225 to 0.0104) between the two periods, but the network is still quite sparse. The lack of intense collaboration among researchers working in the same field (e.g., scientific collaboration) was also observed in other disciplines (Hou et al. 2008), which might be due to competition among researchers. Nonetheless, the average degree and clustering coefficients show that clusters within the network are somehow connected for both periods. For example, the average clustering coefficient for 2000–2005 is 0.75, indicating that 75 % of the nodes were connected. Since the network has grown in the second period, the rate of connectedness has decreased (0.51), indicating that newly formed clusters were not that cohesive yet even though the rate of collaboration intensified (Fig. 4).

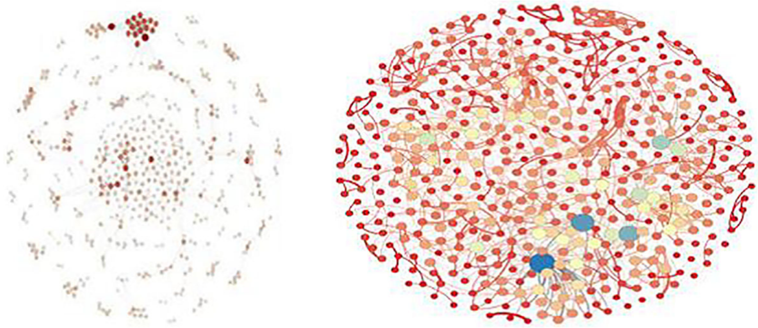

Fig. 4 Co-authorship network of scientists working on nanotechnology between: (*l*) 2000–2005 and (*r*) 2006–2011. Nodes represent authors while edges (ties) between them represent individual collaboration through co-authorship

We further studied the co-authorship networks in both periods to identify the most collaborative nanotechnology researchers. Table 3 shows the top 15 Turkish authors and their affiliations with the highest centrality coefficients (closeness, betweenness, degree, and PageRank) between 2000 and 2005 that contributed to the diffusion of nanotechnology with their scientific papers. Some scientists appear in more than one columns of centrality due to their high collaboration level in the network structure. For example, Yakuphanoğlu F (Fırat University), Yağcı Y and Övecoğlu MN (İTU), Çelik E (Dokuz Eylül) and Denizli A (Hacettepe) appeared in three columns with high degree (collaborator), betweenness (broker and gatekeeper), and PageRank coefficients (prolific author) while Yılmaz F and Toppare L (METU), Morkoç H (Atatürk), Özdemir I (Dokuz Eylül) and Pişkin E (Hacettepe) appeared at least in two columns out of four (degree, betweenness, closeness and PageRank centralities). They were highly influential in the diffusion of nanotechnology in Turkey between 2000 and 2005. This may be due to the fact that some researchers tend to be active in more than one nanotechnology subfields (e.g., physics, chemistry, materials science).

Similarly, Table 4 shows the top 15 authors who were influential in the diffusion of nanotechnology in Turkey between 2006 and 2011. Interestingly, Büyükgüngör O of Ondokuz Mayıs University has the highest centrality coefficients in all four categories but

Table 3 Network properties of the top 15 Turkish authors based on co-authorship degree *c*entralities: 2000–2005

Rank	Degree centrality	Betweenness centrality	Closeness centrality	PageRank
1	Balkan N (Fatih)	Yilmaz F (METU)	San H (Bilkent)	Ovecoğlu MN (ITU)
2	Teke A (Balıkesir)	Gencer A (Hacettepe)	Sökmen I (Dokuz Eylül)	Çelik E (Dokuz Eylül)
3	Yağci Y (ITU)	Koralay H (Firat)	Kasapoğlu E (Cumhuriyet)	Denizli A (Hacettepe)
4	Yakuphanoğlu F (Firat)	Okur S (Izmir Inst Tech)	Çiraci S (Bilkent)	Hasçiçek YS (Gazi)
5	Ovecoğlu MN (ITU)	Denizli A (Hacettepe)	Aytor O (Bilkent)	Yağci Y (ITU)
6	Çelik E (Dokuz Eylül)	Yavuz H (Hacettepe)	Biyikli N (METU)	Yakuphanoğlu F (Firat)
7	Yilmaz F (METU)	Güneş M (Kirikkale)	Özbay E (Bilkent)	Toppare L (METU)
8	Toppare L (METU)	Yakuphanoğlu F (Firat)	Doğan S (Bilkent)	Yilmaz VT (Ondokuz Mayis)
9	Doğan S (Bilkent)	Balkan N (Fatih)	Morkoç H (Atatürk)	Pişkin E (Hacettepe)
10	Morkoç H (Atatürk)	Çelik E (Dokuz Eylül)	Sari B (Gazi)	Erkoç Ş (METU)
11	Denizli A (Hacettepe)	Pişkin E (Hacettepe)	Talu M (Gazi)	Kurt A (Koç)
12	Erol A (Istanbul)	Güven K (Erciyes)	Kartaloğlu (Bilkent)	Elmali A (Ankara)
13	Özdemir I (Dokuz Eylül)	Yağci Y (ITU)	Yilgor E (Koç)	Hincal AA (Hacettepe)
14	Turan R (METU)	Ovecoğlu MN (ITU)	Yilgor I (Koç)	Ozdemir I (Dokuz Eylül)
15	Dag O (Bilkent)	Menceloğlu YZ (Sabancı)	Andaç O (Ondokuz Mayis)	Oral A (Sabancı)

Affiliations of authors are given in parentheses

Table 4 Network properties of the top 15 Turkish authors based on co-authorship degree centralities: 2006–2011

Rank	Degree centrality	Betweenness centrality	Closeness centrality	PageRank
1	Büyükgüngör O (Ondokuz Mayis)	Yilmaz F (METU)	Büyükgüngör O (Ondokuz Mayis)	Büyükgüngör O (Ondokuz Mayis)
2	Şahin E (Gazi)	Büyükgüngör O (Ondokuz Mayis)	Yeşilel ÖZ (Osmangari)	Özbay E (Bilkent)
3	Toppare L (METU)	Özçelik S (Gazi)	Demir HV (Bilkent)	Özçelik S (Gazi)
4	Yilmaz F (METU)	Toppare L (METU)	Nizamoğlu S (Bilkent)	Toppare L (METU)
5	Özçelik S (Gazi)	Yağci Y (ITU)	Çağlar Y (Anadolu)	Denizli A (Hacettepe)
6	Yağci Y (ITU)	Şahin E (Gazi)	İlican S (Anadolu)	Turan R (Ege)
7	Özbay E (Bilkent)	Yildiz A (Fatih)	Çağlar M (Anadolu)	Şahin E (Gazi)
8	Turan R (Ege)	Çakmak M (Koç)	Özbay (Bilkent)	Çiracı S (Bilkent)
9	Çabmak M (Kirikkale)	Şahin O (Dokuz Eylül)	Özçelik S (Gazi)	Yeşilel ÖZ (Osmangazi)
10	Yerli A (Sakarya)	Yilmaz M (Istanbul)	Baykal A (Fatih)	Yağci Y (ITU)
11	Yildiz A (Fatih)	Turan R (METU)	Köseoğlu Y (Fatih)	Sökmen I (Dokuz Eylül)
12	Çetin K (Ege)	Bacaksiz E (Karadeniz Technical)	Toprak MS (Fatih)	Arslan h (Hacettepe)
13	Çiraci S (Bilkent)	Denizli A (Hacettepe)	Çiraci S (Bilkent)	Oskar S (METU)
14	Denizli A (Hacettepe)	Şen S (Yalova)	Durgun E (Bilkent)	Çakmak M (Koç)
15	Sari H (ITU)	Balkan A (Fatih)	Akgol S (Adnan Menderes)	Baykal A (Fatih)

Affiliations of authors are given in parentheses

one (the betweenness centrality) even though he was not in the top 15 authors in the first period. His name appears in the center of the 2006–2011 network of Fig. 5 below as a prestigious researcher playing an important role in the dissemination of nanotechnology knowledge in the network structure (his research field is Crystallography). Likewise, Özçelik S of Gazi University is at the top 15 in all four categories. Six authors appear in at least three columns: Denizli A (Hacettepe), Şahin E (Gazi), Yağcı Y (İTU) and Toppare L (METU) in degree, betweenness and PageRank columns, and Özbay E and Çıracı S (Bilkent) in degree, closeness and PageRank columns. An additional six authors appear in at least two columns: Yeşilel ÖZ (Osmangazi) and Baykal A (Fatih) in closeness and PageRank columns; Yıldız A (Fatih) and Yılmaz F (METU) in degree and betweenness columns; Çakmak M (Koç) in betweenness and PageRank columns; and Turan R (Ege) in degree and PageRank columns. It should be pointed out that even though Fatih and Karadeniz Technical Universities failed to have the highest degree centrality coefficients in neither period, some of their scientists (e.g., Yildiz A and Bacaksız E, respectively) played an important role nonetheless in the diffusion of nanotechnology knowledge in the network.

The centrality coefficients of four authors were high in both periods: Yağcı Y (İTU), Denizli A (Hacettepe), and Toppare L and Yılmaz F (METU). They were highly active in spreading the nanotechnology knowledge in Turkey between 2000 and 2011 as prolific authors, collaborators, brokers and gatekeepers, and diffusers.

A co-authorship network structure of scientists based on VOSviewer illustrates a cluster view of collaborations. Co-authorship map of the first authors for each period is shown on

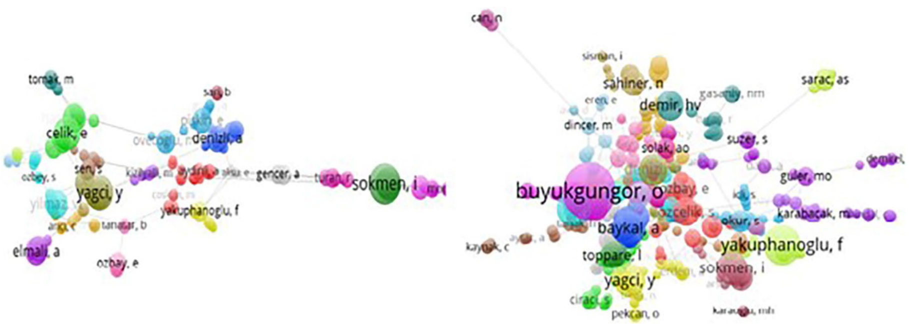

Fig. 5 Co-authorship map of Turkish nanotechnology scientists between: (*l*) 2000–2005 and (*r*) 2006–2011

the left and right-hand side of Fig. 5, accordingly. Most authors listed in Table 3 and Table 4 are also on the map. Co-authorship network of prolific authors in each period exhibited the characteristics of a small size network.

We shared the co-authorship network map with five senior and five junior nanotechnology researchers whose publications appeared in leading journals and solicited and recorded their comments with respect to their places in the network. The latent semantic analysis of their comments indicated that the co-authorship network map reflected their views to some extent with regards to their roles in collaborative nanotechnology research.[7]

Lotka's law

The collaboration network of Turkish scientists who work on nanotechnology seems to be well connected at the micro level but not so much at the macro level. In other words, researchers tend to collaborate within their own sub-clusters (i.e., groups or universities) more often. The frequencies of the total number of publications authored or co-authored by Turkish nanotechnology researchers adhere to Lotka's law:

$$f(y) = .2459 \div y^{1.2881} \qquad (1)$$

where $f(y)$ denotes the relative number of authors with y publications (the K-S DMAX = 0.6323) (Rousseau 1997), indicating that a small number of well-known scientists have stronger positions in the network.

Institutional collaboration

We also studied the network structure of the nanotechnology research output from an institutional perspective and analyzed the level of collaboration between universities. Table 5 shows the network properties of the top 15 selected universities in each period (2000–2005 and 2006–2011) ranked by the degree centrality coefficients of their nanotechnology papers. Middle East Technical (METU), Bilkent and Hacettepe Universities are at the pinnacle of the list and they contributed to the network with the highest number of nanotechnology papers. İstanbul Technical (İTU), Erciyes and Kocaeli Universities are at the bottom of the list with the lowest degree centrality coefficients in the 2000–2005

[7] More detailed findings of the latent semantic analysis used in this research are reported elsewhere (Darvish 2014).

Table 5 Centrality coefficients of nanotechnology papers of the top 15 universities between 2000–2005 and 2006–2011

2002–2005					2006–2011				
University	# of papers	Degree centrality	Closeness centrality	Betweenness centrality	University	# of papers	Degree centrality	Closeness centrality	Betweenness centrality
Middle East Technical	353	0.523	0.467	0.113	Bilkent	356	0.620	0.588	0.069
Bilkent	183	0.515	0.495	0.124	Gebze Institute of Technology	227	0.603	0.541	0.068
Hacettepe	283	0.401	0.495	0.072	Hacettepe	552	0.574	0.524	0.022
Ondokuz Mayis	65	0.357	0.359	0.041	Middle East Technical	646	0.562	0.511	0.054
Dokuz Eylül	108	0.333	0.393	0.109	Istanbul Technical	481	0.534	0.468	0.031
Gebze Institute of Technology	71	0.314	0.499	0.110	Anadolu	224	0.470	0.379	0.042
Kirikkale	36	0.288	0.457	0.119	Gazi	490	0.457	0.373	0.070
Ege	84	0.276	0.359	0.126	Ondokuz Mayis	309	0.450	0.415	0.067
Abant İzzet Baysal	11	0.252	0.612	0.184	Tstanbul	245	0.445	0.394	0.045
Gazi	127	0.244	0.373	0.156	Ege	315	0.431	0.382	0.035
Marmara	64	0.225	0.336	0.215	Ankara	348	0.418	0.363	0.071
Ankara	181	0.224	0.373	0.072	Dokuz Eylül	270	0.323	0.429	0.060
Kocaeli	21	0.218	0.325	0.425	Firat	185	0.317	0.452	0.051
Erciyes	58	0.162	0.466	0.098	Erciyes	166	0.256	0.452	0.049
Istanbul Technical	214	0.109	0.363	0.151	Atatürk	219	0.230	0.316	0.091
Avg		0.296	0.425	0.141	Avg		0.446	0.439	0.055

period. Nodes with higher degree centralities participate more in the network than that with the lower ones and the network structure adheres to the small world phenomenon.

Note that the average degree centrality for the top 15 universities rose from 0.296 in the first period to 0.466 in the second period, indicating an almost 60 % increase (Table 5). Istanbul Technical University's degree centrality increased five times between the two periods, making it one of the top nodes in the second period. Kırıkkale, Abant İzzet Baysal, Marmara and Kocaeli Universities with relatively fewer number of papers did not make it to the top 15 universities in the 2006–2011 period and were replaced by Anadolu, İstanbul, Fırat and Atatürk Universities. Bilkent University is at the top of the 2006–2011 list with the highest closeness centrality coefficient (0.588) followed by Gebze Institute of Technology (0.541) (which was in the 6th place in the first period). Their high closeness centrality coefficients indicate that sub-networks within the whole network are almost 60 % connected. However, their betweenness centrality coefficients are relatively low, which means that the flow of information among sub-clusters within the whole network is slow. Hacettepe and Middle East Technical Universities are also at the top of the 2006–2011 list. These four universities form a cohesive network structure in 2006–2011. However, the average closeness centrality coefficient stayed almost the same for both periods (0.425 and 0.439, respectively). In other words, it took equally long to spread nanotechnology knowledge for the top 15 universities in each period.

In general, betweenness centrality coefficients are much lower for all universities. In fact, the average betweenness centrality has decreased from 0.141 to 0.055 in the second period, indicating that sub-clusters in the network structure became less connected in the second period for the top 15 universities. Atatürk, Ankara, Gazi, Bilkent, Gebze Institute of Technology and Ondokuz Mayıs Universities have the highest betweenness centrality coefficients in the second period, an indication of relatively higher flow of information among sub-clusters within the network than the rest. Dokuz Eylül, Hacettepe and Ankara Universities have the lowest betweenness centrality coefficients in the first period and Hacettepe, Technical and Ege Universities in the second period.

International collaboration

We believe that, in addition to local collaboration among universities, international collaboration with institutions in other countries also accelerates the diffusion process of nanotechnology among scientists. Figure 6 shows that the level of international collaboration has increased tremendously in the second period. In fact, the network density of Turkish scientists' collaborations doubled in the second period, indicating growth in the network structure as well. While Turkish nanotechnology scientists collaborated mostly among themselves and with their colleagues in a few European countries and in the USA in the first period, they expanded their collaboration network so as to include almost all European countries, USA, Asian and Middle Eastern countries, South Africa and Australia.

Topical diffusion of nanotechnology research in Turkey

In addition to the network structure of nanotechnology collaboration from individual, institutional and international perspectives, we also studied the topical diffusion of nanotechnology research in Turkey. We carried out a co-word[8] analysis on the words that

[8] The co-word analysis was conducted based on software:http://www.leydesdorff.net/software/fulltext/index.htm.

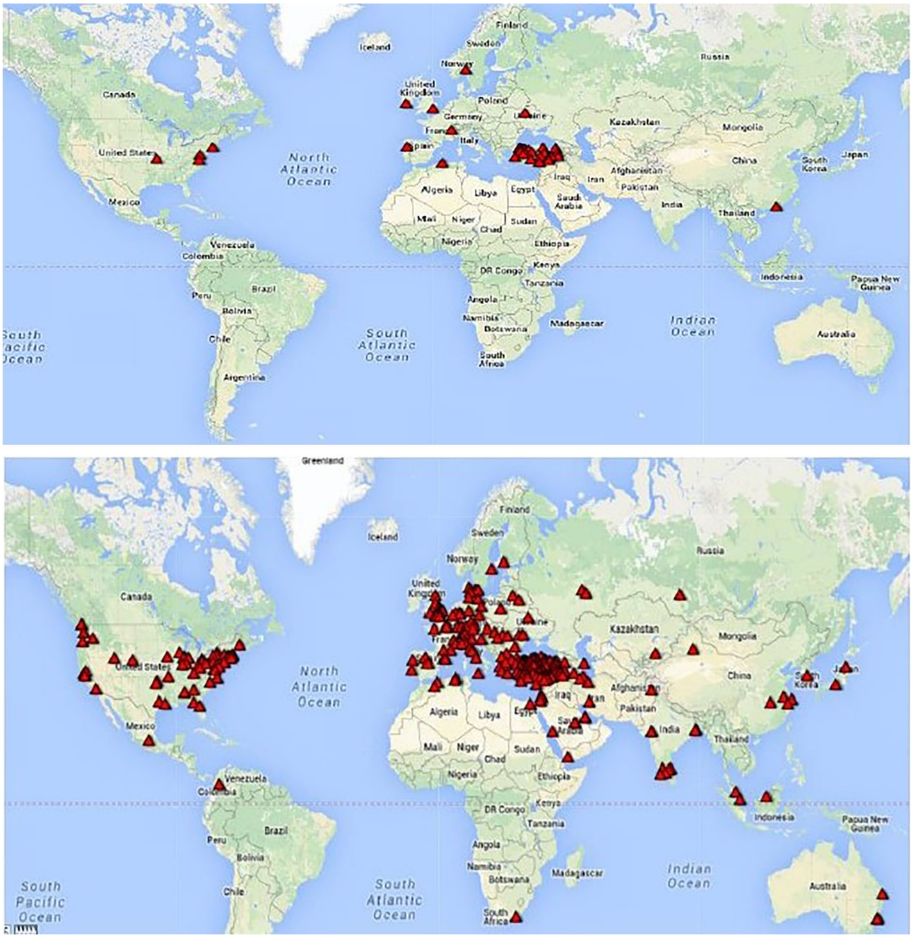

Fig. 6 The network of co-authors of international and Turkish scientists working on nano-related technologies: (*top*) between 2000 and 2005; (*bottom*) (2006–2011)

appear in the titles of articles extracted from WoS to find out the most frequently used terms between 2000 and 2005, and between 2006 and 2011. The first 75 most frequently occurring words in each period were collected, processed and compiled by the software. Stop words were eliminated. In order to analyze the word/document occurrence matrix in terms of its latent structure, SPSS software version 16.0 was used to factor analyze the co-occurrence of words. Factor analysis maps each word to a different component (research strand) with the highest factor loading. SPSS created two factors from the list of the co-words. Tables 6 and 7 show the output of factors for the periods of 2000–2005 and 2006–2011 along with the loadings of different words in each factor (not all 75 words are listed in the tables). According to eigenvalues, the first factor explains 56 % of the variance in the entire data set for the period of 2000–2005 while the second one explains the rest of the variance (44 %). For the 2006–2011 period, the first factor explains 35 % of the variance in the entire data set while the second and third ones explain 33 and 32 % of the variance, respectively.

Table 6 Factor analysis of co-words in titles of nanotechnology papers (2000 and 2005)

Words	Factor 1	Words	Factor 2
Chemical	.999	Plasma	.999
Quantum	.999	Treatment	.999
Steel	.998	Conducting	.990
Hydrogen	.997	Ceramic	.982
Copolymer	.992	Sol–gel	.982
Field	.992	Layer	.945
Properties	.984	Optical	.945
Electrical	.973	Surface	.945

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization
Rotated component matrix: rotation converged in three iterations

Table 7 Factor analysis of co-words in titles of nanotechnology papers (2006 and 2011)

Words	Factor 1	Words	Factor 2	Words	Factor 3
Copolymer	.766	Steel	.673	Dot	.687
Complexes	.697	Well	.655	Morphology	.676
Crystal	.674	Aqueou	.651	Adsorption	.654
Thermal	.653	ZNO	.642	Energy	.644
Spectroscopic	.650	Particle	.626	Prepared	.641
Characteristic	.643	Material	.625	Quantum	.620
Copolymer	.766	Temperature	.620	Electrical	.619
Metal	.636	Cell	.618	Modified	.610

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization
Rotated component matrix: rotation converged in three iterations

We then produced a normalized cosine extraction of the words and mapped the network structure of co-word analysis in each period using cluster analysis method embedded in VOSviewer (Van Eck and Waltman 2010) (Fig. 7). Words that appear in both periods belong mainly to Multidisciplinary Science and Materials Science. Represented fields in both periods are as follows: Surface Materials ("Doped", "Alloy", and "Plasma"); Chemistry and its subfields ("Coating", "Crystal" "Catalyst", and "Sol–Gel"); and Physics ("Quantum", "Dot" and "Nanotube"). It appears that Turkish nanoscientists work primarily in Material Sciences, followed by Physics and, to some extent, Biotechnology.

Discussion and conclusion

Our analysis that nanotechnology R&D in Turkey is flourishing. The number of nanotechnology papers published by Turkish scientists in journals covered by WoS has tripled once the Turkish government has identified nanotechnology as one of the eight strategic fields in its national science and technology policy of 2003–2023 and decided to invest in nanotechnology accordingly. This decision has tremendously increased the diffusion and adoption of nanotechnology as a research field. Nanoscientists became more collaborative

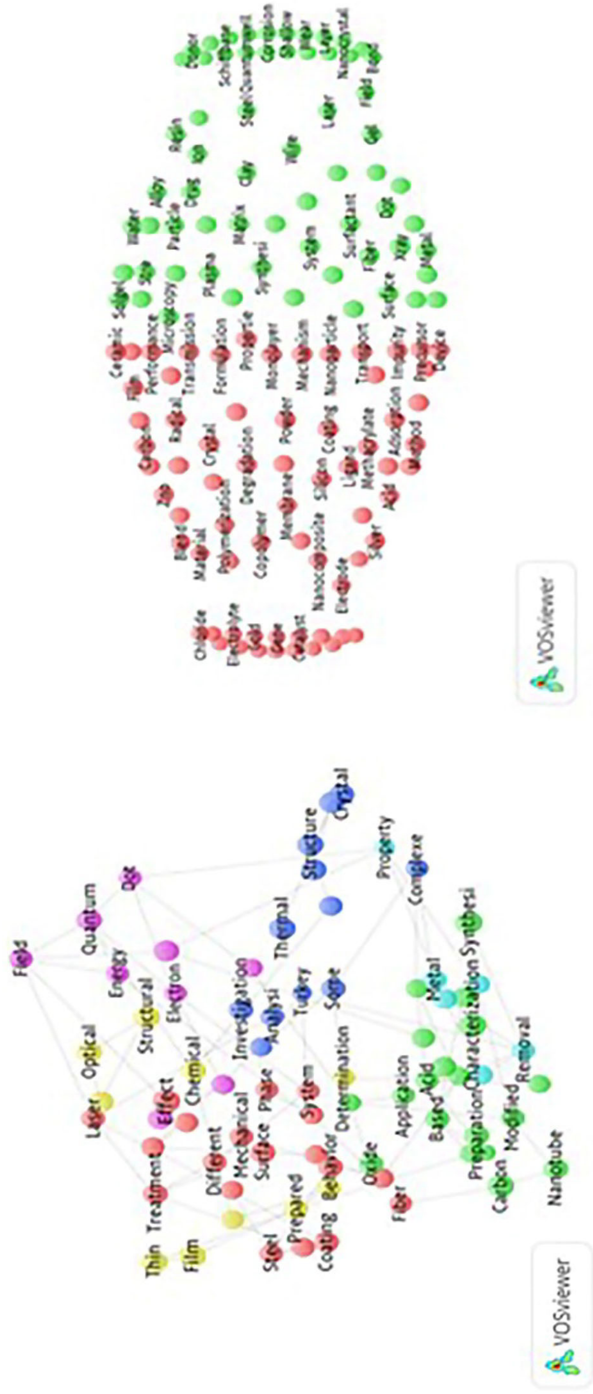

Fig. 7 Network of co-word analysis in nanotechnology in Turkey: (*l*) 2000–2005 and (*r*) 2006–2011)

and more prolific in their research. Consequently, as pointed out earlier, the relatively high growth rate of nanotechnology research made Turkey one of the top three most prolific countries in the world in terms of number of papers published (Bozkurt 2015, p. 49). This is somewhat similar to the experience of India, China, Iran and Latin American countries in that the importance of nanotechnology has increased once they identified it as a promising technology in their national development plans (Aydogan-Duda 2012).

Our analysis of the network structure of nanotechnology papers authored by Turkish scientists between 2000 and 2011 indicates that the degree of collaboration in individual, institutional and international levels intensified in the second period. The number of nodes in the network has increased considerably in the second period (2006–2011), yet the overall connectedness of the network structure is still low. The centrality coefficients of the network structure of the top 15 universities revealed that the social network structure is denser at the micro level than that at the macro level. While the betweenness centrality remained low and the closeness centrality did not change much, the degree centrality increased almost 60 % in the second period, which is an indication of the "small world phenomenon" in the network structure. The research output of Turkish nanoscientists and collaboration among them conforms to some extent to Lotka's law in that a few researchers tend to publish the bulk of nanotechnology papers while the rest are less prolific. This indicates that Turkish scientists tend to collaborate with prolific authors, as envisaged by Lotka's Law. The taxonomy identified by the co-word analysis shows that Turkish nanoscientists mainly work in Materials Sciences, Chemistry and Physics, which is similar to some extent to the global trends in nanotechnology research and development.

Nanotechnology research continues to flourish due to collaborations at the micro level within the Turkish scientific community and the diffusion of nanotechnology knowledge is accelerating. It is expected that bibliometric indicators and network properties reported in this research will not only help policy-makers understand the interdisciplinary character of nanoscience and nanotechnology better and develop funding mechanisms accordingly, but also provide a yardstick to measure the progress and guide the Turkish science and technology policy covering the period of 2003 and 2023.

Acknowledgments We thank the anonymous reviewers for their detailed and constructive comments, which helped us improve the paper. Remaining errors are of course our own.

Appendix: Query used to search Thomson Reuters' Web of Science database

In this "Appendix", 9 queries are listed. The last one (#9) is the union of all the preceding ones.

#1.

TS = (NANOPARTICLE* OR NANOTUB* OR NANOSTRUCTURE* OR NANO-COMPOSITE* OR NANO-COMPOSITE* OR NANOWIRE* OR NANOCRYSTAL* OR NANOFIBER* OR NANOFIBRE* OR NANOSPHERE* OR NANOROD* OR NANOTECHNOLOG* OR NANOCLUSTER* OR NANOCAPSULE* OR NANO-MATERIAL* OR NANOFABRICAT* OR NANOPOR* OR NANOPARTICULATE* OR NANOPHASE OR NANOPOWDER* OR NANOLITHOGRAPHY OR NANO-PARTICLE* OR NANODEVICE* OR NANODOT* OR NANOINDENT* OR NANO-INDENT* OR NANOLAYER* OR NANOSCIENCE OR NANOSIZE* OR NANO-SIZE* OR NANOSCALE* OR NANO-SCALE* OR NANOROBOT*) AND

AD = (TURKEY) NOT TS = (NANOMET* OR NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANOSEC* OR NANOSECOND* OR NANOMETERSCALE* OR NANOMETER LENGTH*)

#2.

TS = ((NM OR NANOMETER* OR NANOMETRE*) SAME (SURFACE* OR FILM* OR GRAIN* OR POWDER* OR SILICON OR DEPOSITION OR LAYER* OR DEVICE* OR CLUSTER* OR CRYSTAL* OR MATERIAL* OR SUBSTRATE* OR STRUCTURE* OR ROUGHNESS OR MONOLAYER* OR RESOLUTION OR PARTICLE* OR ATOMICFORCE MICROSCOP* OR TRANSMISSION ELECTRON MICROSCOP* OR SCANNING TUNNELING MICROSCOP*)) AND AD = (TURKEY) NOT TS = (NANOMET* OR NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANOSEC* OR NANOSECOND* OR NANOMETERSCALE* OR NANOMETER LENGTH*)

#3.

TS = (nano*) AND SO = ((BULK “AND” GRADED NANOMETALS OR CURRENT NANOSCIENCE OR FROM NANOPOWDERS TO FUNCTIONAL MATERIALS OR FULLERENES NANOTUBES “AND” CARBON NANOSTRUCTURES OR FULLERENES NANOTUBES “AND” CARBON NANOSTRUCTURES OR FUNCTIONAL MOLECULAR NANOSTRUCTURES OR IEEE TRANSACTIONS ON NANOBIOSCIENCE OR IEEE TRANSACTIONS ON NANOTECHNOLOGY OR INORGANIC POLYMERIC NANOCOMPOSITES “AND” MEMBRANES OR JOURNAL OF COMPUTATIONAL “AND” THEORETICAL NANOSCIENCE OR JOURNAL OF NANOPARTICLE RESEARCH OR JOURNAL OF NANOSCIENCE “AND” NANOTECHNOLOGY OR MICROSYSTEM TECHNOLOGIES MICRO “AND” NANOSYSTEMS INFORMATION STORAGE “AND” PROCESSING SYSTEMS OR NANO LETTERS OR NANOPOROUS MATERIALS IV OR NANOTECHNOLOGY OR ON THE CONVERGENCE OF BIO INFORMATION ENVIRONMENTAL ENERGY SPACE “AND” NANO TECHNOLOGIES PTS 1 “AND” 2 OR PHYSICA E LOW DIMENSIONAL SYSTEMS NANOSTRUCTURES OR PRECISION ENGINEERING JOURNAL OF THE INTERNATIONAL SOCIETIES FOR PRECISION ENGINEERING “AND” NANOTECHNOLOGY OR SYNTHESIS “AND” REACTIVITY IN INORGANIC METAL ORGANIC “AND” NANO METAL CHEMISTRY OR JOURNAL OF NANOSCIENCE AND NANOTECHNOLOGY OR NANOTECHNOLOGY OR ACS NANO OR NANO LETTERS OR JOURNAL OF NANOPARTICLE RESEARCH OR NANOSCALE OR NANOSCALE RESEARCH LETTERS OR SMALL OR PHYSICA E LOW DIMENSIONAL SYSTEMS NANOSTRUCTURES OR INTERNATIONAL JOURNAL OF NANOMEDICINE OR JOURNAL OF COMPUTATIONAL AND THEORETICAL NANOSCIENCE OR JOURNAL OF NANOMATERIALS OR MICRO NANO LETTERS OR MICROSYSTEM TECHNOLOGIES MICRO AND NANOSYSTEMS INFORMATION STORAGE AND PROCESSING SYSTEMS OR IEEE TRANSACTIONS ON NANOTECHNOLOGY OR JOURNAL OF BIOMEDICAL NANOTECHNOLOGY OR SYNTHESIS AND REACTIVITY IN INORGANIC METAL ORGANIC AND NANO METAL CHEMISTRY OR NANO RESEARCH OR DIGEST JOURNAL OF NANOMATERIALS AND BIOSTRUCTURES OR NATURE NANOTECHNOLOGY OR NANOMEDICINE OR NANOMEDICINE NANOTECHNOLOGY BIOLOGY AND MEDICINE OR NANOSCIENCE AND NANOTECHNOLOGY LETTERS OR MICROFLUIDICS AND NANOFLUIDICS OR PRECISION ENGINEERING JOURNAL OF THE INTERNATIONAL

SOCIETIES FOR PRECISION ENGINEERING AND NANOTECHNOLOGY OR CURRENT NANOSCIENCE OR JOURNAL OF NANOPHOTONICS OR NANO OR NANOTOXICOLOGY)) AND AD = (TURKEY) NOT TI = (NANOMET* OR NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANOSEC* OR NANOSECOND* OR NANOMETERSCALE* OR NANOMETER LENGTH*)

#4.

TS = ((NSOM OR CHEMICAL VAPOR DEPOSITION OR CVD OR CHEMICAL VAPOUR DEPOSITION OR X-RAY PHOTOELECTRON SPECTROSCOPY OR DIFFERENTIAL SCANNING CALORIMETRY OR X-RAY DIFFRACTION OR XRD OR SURFACE PLASMON RESONANCE OR “NEAR” FIELD SCANNING OPTICAL MICROSCOP*) SAME (SURFACE* OR FILM* OR LAYER* OR SUBSTRATE* OR ROUGHNESS OR MONOLAYER* OR MOLECUL* OR STRUCTURE* OR RESOLUTION OR ETCH* OR GROW* OR SILICON OR SI OR DEPOSIT* OR PARTICLE* OR FORMATION OR TIP OR ATOM* OR GOLD OR AU OR POLYMER* OR COPOLYMER* OR GAAS OR INAS OR SUPER-LATTICE* OR ADSORPTION OR ADSORB* OR ISLAND* OR SIZE OR POWDER OR RESOLUTION OR QUANTUM OR MULTILAYER* OR ARRAY* OR NANO*)) AND AD = (TURKEY) NOT TS = (NANOMET* OR NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANOSEC* OR NANOSECOND* OR NANOMETERS-CALE* OR NANOMETER LENGTH*)

#5.

TS = ((AFM OR ATOMIC FORCE MICROSCOP* OR SCANNING ELECTRON MICROSCOP* OR SEM OR SCANNING TUNNELING MICROSCOP* OR STM OR SELF-ASSEMBL* OR SELF-ORGANIZ* OR TRANSMISSION ELECTRON MICROSCOP* OR TEM) SAME (SURFACE* OR FILM* OR LAYER* OR SUBSTRATE* OR ROUGHNESS OR MONOLAYER* OR MOLECUL* OR STRUCTURE* OR RESOLUTION OR ETCH* OR GROW* OR SILICON OR SI OR DEPOSIT* OR PARTICLE* OR FORMATION OR TIP OR ATOM* OR GOLD OR AU OR POLYMER* OR COPOLYMER* OR GAAS OR INAS OR SUPER-LATTICE* OR ADSORPTION OR ADSORB* OR ISLAND* OR SIZE OR POWDER* OR RESOLUTION OR QUANTUM OR MULTILAYER* OR ARRAY* OR NANO*)) AND AD = (TURKEY) NOT TS = (NANOMET* OR NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANOSEC* OR NANOSECOND* OR NANOMETERSCALE* OR NANOMETER LENGTH*)

#6.

TS = (NANOMECHANICAL OR NANOELECTRONIC* OR NANOHARDNESS OR NANORIBBON* OR NANOBELT* OR NANOGRAIN* OR NANOCABLE* OR NANOCHANNEL* OR NANOSHEET* OR NANODIAMOND* OR NANOMAG-NET* OR NANODISK* OR NANOSHELL* OR NANOCONTACT* OR NANOR-EACTOR* OR NANOIMPRINT* OR NANOHOLE* OR NANOWHISKER* OR NANOCHEMISTRY OR NANOGRAPHITE OR NANOELECTRODE* OR NANO-GRANULAR OR NANOFOAM* OR NANOMETER-SIZE* OR NANOCOLLOID* OR NANORING* OR NANOPHOTONIC* OR NANOSENSOR* OR NANOELEC-TROSPRAY* OR NANOBRIDGE* OR NANOMETER-SCALE* OR NANOBIO* OR BIONANO* OR HIPCO) AND AD = (TURKEY) NOT TS = (NANOMET* OR NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANOSEC* OR NANOSECOND* OR NANOMETERSCALE* OR NANOMETER LENGTH*)

#7.

TS = (MOLECUL* MOTOR* OR MOLECUL* RULER* OR MOLECUL* DEVICE*

OR MOLECULAR ENGINEERING OR MOLECULAR ELECTRONIC* OR COULOMB STAIRCASE* OR QUANTUM DOT* OR QUANTUM WELL* OR QUANTUM WIRE* OR COULOMB BLOCKADE* OR MOLECULAR WIRE*) AND AD = (TURKEY) NOT TS = (NANOMET* OR NANO2 OR NANO3 OR NANO4 OR NANO5 OR NANOSEC* OR NANOSECOND* OR NANOMETERSCALE* OR NANOMETER LENGTH*)

#8.

TS = (NANO*) AND AD = (NANO* NOT NANOPHOTON*) AND AD = (TURKEY)

#9.

#8 OR #7 OR #6 OR #5 OR #4 OR #3 OR #2 OR #1

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