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Original Research

Evaluating Research Output Using Scientometric and Social Network Analysis: A Case of Alagappa University, India

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Abstract

This study analyzed the research productivity of Alagappa University (AU), India, in terms of scientometric and social network analysis measures. The primary aim of this study is to construct two types of networks, co-authorship, and citation, with three levels of network measures to divulge the social and intellectual structure of AU and to identify their research hubs, social interactions, the knowledge diffusion pattern, which will help to strengthen their research areas, fund allocation and to formulate appropriate policy strategies. It revealed that AU produced 99.45 % of research articles in collaboration, particularly 88.41% of the articles were the outcome of international scientific collaboration, remaining 11.04% of them have collaborated domestically. It found that the main path of the most cited publications constituted the mainstream of development of the Department of Bio-Technology, AU.

Keywords: Social Network Analysis, Scientometrics, Citation Network Analysis, Co-Authorship Network Analysis, Research Evaluation, Alagappa University, India.

Introduction

Social Network Analysis (SNA), related to network theory, has emerged as a key technique in modern sociology (Scott, 2017) and gained importance in many disciplines (Kleinberg, 1999), including information science. It analyzes the social structure or network consisting of actor/author/node and their linkages/ties/relationships, aiming to identify and interpret the pattern of relationship prevailing among them and help visualize the social structure of any entities. It can be a group of people, organization, nation, community, or society, which transmits information, behavior, attitude, or goods (De Nooy, Mrvar & Batagelj, 2018). The metrics or techniques used in SNA aid in studying the position and roles of the nodes, their connectors or collaborators, and the pattern or structure of the relationship among the nodes in the complete, personal or egocentric network at different aggregate levels. The bibliometric indicators predominantly use statistical techniques to analyze the character and attributes of the entities. However, SNA mainly analyzes the pattern or structure of relationships prevailing among the nodes/actors, and the attributes of actors are secondary. Employing a network perspective, one can also study patterns of relational structures directly without reference to the attributes of the individuals involved (Wasserman & Faust, 1994).

With the advent of information and communication technologies, the discipline of information science started utilizing the techniques of SNA to map the research productivity, evaluate the research performance, support the development of science policy, and study the intellectual and social structure of knowledge. Multifarious unit is studied independently or by group or in a combination of one or more unit aggregates and various levels of network metrics such as micro, meso, and macro. This article analyzes the research productivity of Alagappa University (AU) for 20 years (2000-2019), using scientometric and social network analysis measures, to suggest some ideas for the university authorities to have understanding and insights into the general pictures to make policies to supports and funds their researchers and faculty members. The results can be helpful for them to have competitive advantages over other universities and institutions in that "the extent of formal research evaluation, at all levels from the individual to the multiversity has increased dramatically" (Mingers, Hanley & Okunola, 2017).

AU is 35 years deep-rooted institution located in the urban area of the Karaikudi district in India to serve the educational needs of 120,000 students through 16 schools, 40 departments, 3 institutes, 9 centers, 3 constituent colleges, 3 directorates, and 40 affiliated colleges in Sivaganga and Ramanathapuram Districts. The university has secured the 104th position in the QS (Quacquarelli Symonds) ranking of 2019 BRICS nations. The researchers of AU attracted about 1.83 million US dollars worth of research projects from various organizations, including the Department of Science & Technology (DST), Department of Bio-Technology (DBT), University Grant Commission (UGC), Council of Scientific & Industrial Research (CSIR), Indian Council of Medical Research (ICMR), Defence Research and Development Organization (DRDO), Ministry of Human Resource & Development (MHRD), etc.

The core function of any university is to impart higher education and promote research activities which are an essential element of every national innovation system (Hicks, 2016). The co-publication of the research literature of the university explicitly indicates its contribution to innovation and internationalization; the citation impact of its research literature indicates the research excellence. These indicators are predominantly used to evaluate the research performance of the AU.

This article is structured as follows: The reviewed literature in section 2 illuminates the effectiveness of the social network analysis measures at all levels of aggregation. Section 3 defines the objectives of the article drawn from the previous studies. Section 4 describes the method of data retrievals and outlines social network analysis measures. Section 5 analyzes the construction collaboration and citation networks with centrality measures and validates them by scientometric measures. Besides, the most prolific authors' productivity over a period and the authors' most preferred and cited journals are also studied to evaluate the university's research performance. The article concludes with a discussion on the findings, the research implications, limitations of the study, recommendations to the authorities, and future research in related areas.

Literature Review

There are corpora of literature generated by combining different units aggregated. Various network metrics have been analyzed to evaluate the conceptual (co-occurrence), knowledge (citations), and social (co-authorship) structure of the bibliographic data. For example, scientists as a unit of study from supply chain management, physics, biomedical research, and computer science were analyzed with different network measures (Giannakis, 2001, Newman, 2001). Similarly, collaboration networks were constructed to study diseases and disorders like psoriasis, chromosomal disorder, and neglected diseases (Nishavathi & Jeyshankar, 2018). Journals are also considered as a unit of study to evaluate the research quality of an organization and the factors influencing the quality of research through network measures (Fang, Dai & Tang, 2020) and to identify the central authors of the journal (Erfanmanesh, Hosseini, 2015; Santos & Santos, 2016). Kumar (2012) analyzed the research publications of Alagappa University for 1999-2012 and interpreted that the highest publication received in 2011 and 0.0026 articles were produced under the collaboration. In addition, the knowledge flows between inter-organization, intra-organization, national and international were analyzed through co-authorship networks (Gazni, Sugimoto & Didegah, 2012; Lu & Ma, 2017; Glänzel & Schubert, 2004). Further, various studies at different levels of network metrics generated a variety of co-authorship networks.

Similarly, a document or article as a unit of study is represented by a node or vertex connected through the link or edge as citation relationship evolved citation networks. Articles as basic units aggregated to other units like institutions, disciplines, journals, authors at the national-international level were analyzed with micro-level metrics like centrality measures, page rank, and weighted citations, short path method (Breznik & Skrbinjek, 2017; Waltman, Yan & van Eck, 2011). In addition, meso level metrics such as clustering, cliques, hub, and authority were also deployed to analyze the citation network (Batagelj, Doreian, Ferligoj & Kejzar, 2014; Nishavathi & Jeyshankar, 2020). Baskaran (2020) determined Citations and h-Index for research accreditation of the faculty members in Alagappa University based on both WoS and GSM during 1989-2018, which received the highest output in 2018 with the highest output h-index of 7, mostly contributed by Central Electrochemical Research Institute researchers (Jeyshankar Babu & Rajendran, 2011).

In the previous study, a co-authorship network was constructed to map the research productivity and collaborative pattern of Alagappa University (AU) authors as reflected through Scopus and Web of Science database for 10 years from 2009 to 2018. It mainly focused on basic centrality measures such as degree, closeness, and betweenness to analyze co-authorship network and the compatibility of above mention database concerning the productivity, coverage of journals, and most preferred journals of AU. However, this study intended to delve deeper into the knowledge diffusion pattern, social interactions, and research hubs of AU by constructing citation and co-authorship networks for the research productivity of two-decade from 1990 to 2019. The constructed networks were further analyzed with micro and meso network measures. The findings will support the authorities in formulating appropriate policy strategies, allocating funds to strengthen research activities, and creating new scientific methodologies for collaborative research.

Objectives of the Study

The primary aim of this study is to construct two types of networks, co-authorship, and citation, with three levels of network measures to divulge the social and intellectual structure of AU. This study analyzed the co-authorship network with the following objectives:

- To identify the core authors who generate, control, and manipulate the flow of knowledge in the co-authorship network;
- To trace the productivity of authors throughout times;
- To find out the social interaction of the university at a global level;
- To validate bibliometric and SNA metrics, and
- To reveal the ten most productive authors' most preferred and referenced journals.

This study also examined the citation network with the following objectives (Maltseva & Batagelj, 2019):

- To identify the top 10 cited documents and authors by centrality measures;
- To explore the research hubs and authorities of the cited documents;
- To describe the pattern of knowledge diffusion from source to citations, and
- To trace the main path accountable for the flow of intellectual knowledge through search path count.

Materials and Methods

The dataset for the study was retrieved from the Web of Science database consisting of 2,562 bibliographical data for 20 years from 2000 to 2019. The keyword “Alagappa University” was used in the author affiliation field to retrieve the relevant dataset. The downloaded dataset was analyzed with bibliometric software, Bibexcel (Persson, Danell, Schneider & Wiborg, 2019), to create necessary network files, standardization names, and frequency distribution. The statistical tool R (Aria & Cuccurullo, 2017) analyzed the three-fold data and mapped international collaborations. The network metrics/measurements were normalized and calculated by the UCINET 6 (Borgatti, Everett & Freeman, 2002) software. Pajek was used to visualize the networks. Before constructing the networks, the data were standardized and cleaned. Out of 2,562 records, 22 were removed from the dataset due to ambiguity in publication.

The following network metrics and basic scientometrics were deployed in this study to evaluate the AU's intellectual, conceptual, and social structure.

(1) Micro network measures: Micro or node level measures like centrality were used to identify the most important or prominent central node, one involved in many network ties. This measure is more appropriate for a non-directional network with no direction in the relationship (Wasserman & Faust, 1994), such as co-authorship or co-occurrence network. In the co-authorship network, degree centrality indicates the number of times an author collaborated with others to produce or publish a research article. Similarly, it also indicates the number of times the keywords occurred together in the co-occurrence network.

(2) Degree centrality: It is simply the number of ties or relationship of a node in the non-directional network expressed as $C_D(n_i) = d(n_j)$ is standardized to $C_D(n_i) = d(n_i)/g\text{-}1$. Where $C_D(n_i)$ is the degree centrality index for the node I; $d(n_j)$ is the total number of ties it has; g is the total number of nodes in the network and set maximum to g-1 (Wasserman & Faust, 1994), Degree centrality can also be calculated for a directional network such as citation networks by deriving in degree and out-degree centralities. In the citation network, in-degree is nothing but some documents cited a particular document or vertex (inward link), and out-degree is the number of citing documents to a particular document or vertex (outward link). For example, if A is the document cited by documents B and C, then A's in-degree is 2 (B, C) and out-degree is 0 because A cites no documents. If C cites documents A and B, then out-degree for C is two (A, B), and in-degree is zero. If B is cited by C and cites A, then in-degree for B is 1(C), and out-degree is 1 (A).

(3) Closeness centrality: It focuses on how close an actor (author) is to all the other actors (authors) in the set of actors (authors) (4). "The closeness of a vertex is based on the total distance between one vertex and all other vertices, where larger distances yield lower closeness centrality scores" (de Nooy, 2018). This can be computed by $C_C(n_i) = \left[\sum_{j=1}^{g} d\ (n_i, n_j)\right]^{-1}$, representing the vertex I's closeness centrality index and the distance between the two vertices I and j (Wasserman & Faust, 1994). The closeness centrality of the network cannot be computed when there are disconnected vertices or presences of isolated nodes in the network. However, closeness can be calculated for connecting components.

(4) Betweenness centrality: The number of shortest paths passing through a node. This measure considers the connectivity of the neighbors of the node, giving a higher value for nodes that bridge clusters. It reflects the number of people connecting indirectly through their direct links. The betweenness index for the n_i is simply the sum of estimated probabilities over all vertices, not including the *i*th vertex. The standardized formula for computation of betweenness is $C_B\ (n_i)\ = C_B\ (n_i)\ /\ [(g\text{-}1)(g\text{-}2)/2]$ where $C_B(n_i)$ $C_B(n_i)$ is the betweenness centrality for the node i, (g-1)(g-2)/2, which is the number of nodes not including new. Betweenness can be computed even if the graph is not connected (Wasserman & Faust, 1994).

(5) Eigenvector centrality: It is an extension of degree centrality. Degree centrality merely calculates the inward link or degree of a node and treats all inward links similarly. However, eigenvector centrality considers the importance of all inward links adjacent to the node in the whole network. In the above example, the eigenvector centrality values for documents A, B, and C are zero because document C has no inward links and document B has one from C, and document A has two inward links from B and C whose eigenvector values are zero. A high value of the eigenvector centrality of a node implies a connection between the fewer numbers of inward links with a high degree of nodes. It shows the connection between the nodes which "themselves important" (Newman, 2010).

(6) Hub and authority centrality: One of the drawbacks of the eigenvector centrality identified by (Kleinberg, 1999) is that it only finds the important document by its inward citations. However, hub and authority measures consider both inward and outward citations to detect the most authoritative document on the network. The authority score for a document depends on the number of documents it cites and the quality of the document it cites. Likewise, the hub score for a document depends upon the number of documents it cites and the quality of cited documents. In other words, the authority centrality of a document is proportional to the sum of the hub centralities of the document. The hub centrality is proportional to the sum of the authority centrality of the document.

(7) Meso network measures: Various clustering techniques are used to analyze the network's behavior of nodes/document/author. The most common clustering technique exploited in this study is the component. A component is a subgraph with a path between all nodes (all pairs of nodes in a component are reachable). If there is only one component in a graph, the graph is connected. If "there is more than one component, the graph is disconnected" (Wasserman & Faust, 1994). The non-directional network like co-authorship and co-occurrence networks deploy weak components but in the direct network (like citation network), depending upon the direction of the arc, strong and weak components are used to partition the whole network into sub-network or graphs (Kleinberg, 1999)

(8) Macro network measures: They are useful in analyzing the structural features of the whole network. It includes density, connectedness, average diameter distance, transitivity, average geodesic distance, and clustering coefficient.

Results

This study analyzed 95.4% of research articles published by the scholars of AU since its inception, indexed in the Web of Science database. The compound annual growth rate of research productivity was estimated at 11.79 % during 2000-2019. Totally, 3,109 authors published 2,562 research works scattered in 690 journals, including the compiled books. Totally, 11,758 journals were cited for publishing 92.3% of articles and 2.5 % of reviews, and 5.2 % of editorial matters, letters, abstracts, and other sources. The intellectual linkages between the published and cited articles were found more than 28 times. The average citations per document were 14.98 %, normalized by the mean total citation per year (41.2 % for 20 years). 99.45 % of articles resulted from collaborative works being validated by the degree of collaboration (0.99) and collaboration index (1.22). 0.2% of authors were either transients or terminators (Table 1).

Table 1
Scientometric statistics for research productivity of AU

Period of study	2000-2019
Annual growth rate	11.79%
Total no. of documents	2,562
Total no of sources (Journals, Books, etc.)	690
Total no. of authors	3,109
Author Appearances	11,541
Authors of single-authored documents	6
Authors of multi-authored documents	3,103
Single-authored documents	14
Multi-authored documents	2,548
Documents per author	0.824
Authors per document	1.21
Co-Authors per documents	4.5
Collaboration index	1.22
Degree of collaboration	0.99
Total no. of citation	38,074
Average citations per document	14.98
Total no. of cited sources	11,758
Average cited sources per document	4.59
Total no. cited references	72,605
Average cited references per documents	28.34

Social structure: Co-authorship network structure: A co-authorship network is constructed for the authors of AU in which the nodes are authors, and the two authors are connected if they have co-authored a paper (Newman, 2001). It is a non-directional network reflecting scientific interaction between the authors. The network consists of 3,908 nodes connected by 15,138 collaborative ties, with an average degree of 9.74 (Table 2), which indicates that authors have more professional linkages with others. The density of 0.003 implies the connectivity of the whole network. The network clustered into 31 components or sub-networks represents the authors collaborating from the same discipline or department and not connected to other components. The multi-disciplinary research paves the way to collaborate authors from different disciplines and departments, enabling collaboration with those outside the component. It is evident from the giant network size, consisting of 95% of authors (2,956) from various departments. The diameter of a network is the length (in the number of edges) of the longest geodesic path between any two vertices (Newman, 2004). The geodesic path between Yadavalli and Patra is the longest diameter at 10. The average distance of the co-authorship network implies that authors needed 3.93 steps to reach each other. The high average distance resulted in low density. The clustering coefficient of 0.83 denotes greater cliquishness, which means the authors' co-authors are well connected (Table 2). In- and out- degrees centrality cannot be computed for the undirected co-authorship network. Similarly, closeness centralization cannot be computed since the network is not weakly connected.

Table 2
Network properties: Co-author and citation network of AU

Network Measures	Co-authorship Network	Citation Network
Network type	Undirected Network	Directed Network
No. of nodes	3,108	1,926
No. of edges / links	15,138	4,522
Average degree	9.74	4.69
Density	0.003	0.001
Components	31	92
Size of the giant component	2,956 (95.1%)	1,522 (79%)
Connectedness	0.9	0.005
Diameter	10	10
Average distance	3.93	2.6
Transitivity	0.25	0.109
Average Geodesic distance	3.9	2.6
Watts-Strogatzclustering Coefficient	0.83	0.129
Centrality Measures		
All degree centrality	0.075	0.01
In-degree centrality	NIL	0.018
Out-degree centrality	NIL	0.01
Closeness	Cannot be computed	
Betweenness	0.13	0.00019

Ranking of authors based on scientometrics and social network measures: Application of scientometrics and social network measures to the dataset of AU identified the 15 prolific, central, and influence authors (Table 3). The italic and bold fonts represent the presence of authors in multiple measures.

Based on the research publications as the unit of analysis, Sanjeevaraj, C. identified as the most productive authors of AU with 198 publications. He also occupied the central position of the network with a higher normalized degree of centrality (0.51) and collaborated with others showing that most prolific authors seemed to collaborate more frequently (Pravdic, Oluic-Vukovic 1986). He also secured the maximum h-index (Aksnes, 2003), the first bibliometric measure to combine productivity and impact. The suggestion that the h-index favors the authors with long careers since they have more publications (Bornmann & Daniel, 2009) was verified because Sanjeevaraj, C and Rajendran, S. those having longer careers obtained a higher h-index (Figure 1). The author's productivity increased by the number of collaborators, resulting in proportionately high-impact articles. A correlation coefficient test was undertaken and revealed that there were positive correlations between the number of publications and number of collaborators (0.95) and h-index (0.87) (Table 4). Following Sanjeeviraja, C., Pandian, S. K. has published 187 articles in 14 years (Figure 1), whose comparatively low career period is reflected in his h-index (31) (Figure 1).

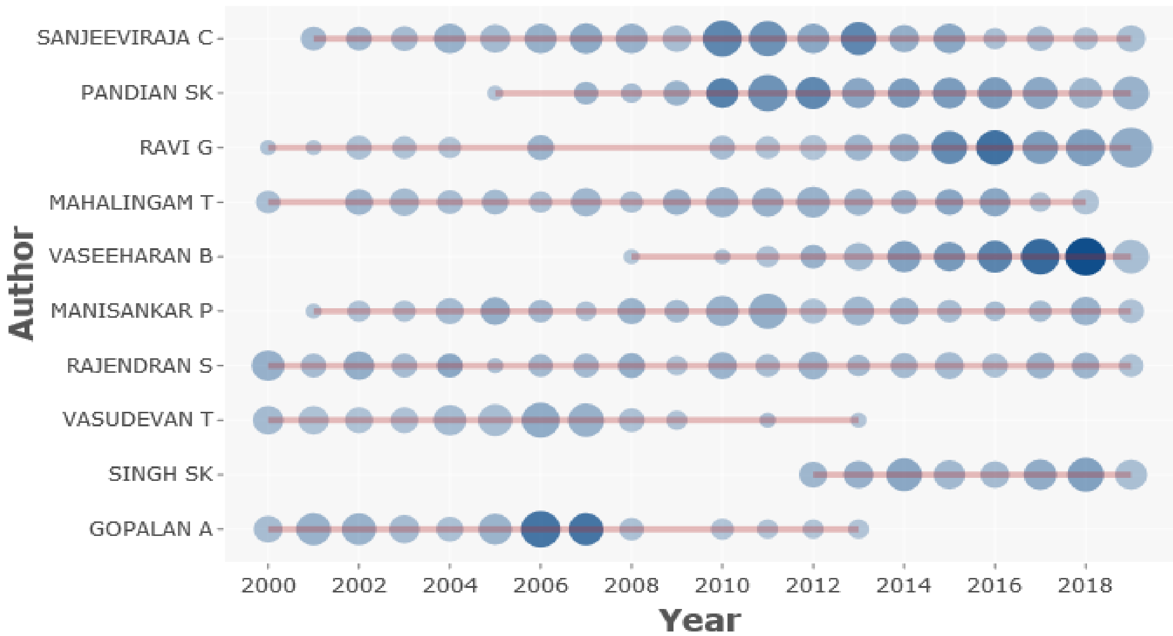

Figure 1: Timeline for the Ten Most Productive Authors Of AU

Nevertheless, he secured second in node betweenness (0.1318), followed by Manisankar R (0.1318). The top authors of betweenness are identified as intermediaries or the technical gatekeepers who connect and strengthen the collaboration between the sub-network or group of authors. Freemen closeness centrality was applied to the dataset to explore the influential authors of AU. It revealed that Manishankar, P. (0.339), Ravi, G. (0.322), and Pandian, S.K. (0.321) occupied the first three places. This measure also identified 22 influential authors who shared the top 15 places. These authors are central nodes in the whole network to scatter research ideas across the network more quickly. The centrality measures recognized 15 authors as core authors of the AU and secured different ranks in each measure.

Table 3
Ranking of authors based on scientometrics and social network measures

Rank	Publications	nDegree Centrality	Node Betweenness	Free Closeness	H-Index
1	*Sanjeeviraja C (198)*	*Sanjeeviraja C (0.51)*	*Manisankar P (0.1318)*	*Manisankar P (0.339)*	*Sanjeeviraja C (36)*
2	*Pandian SK (167)*	*Ravi G (0.45)*	*Pandian SK (0.1267)*	*Ravi G (0.322)*	*Rajendran S (34)*
3	*Ravi G (159)*	*Vaseeharan B (0.45)*	*Ravi G (0.1039)*	*Pandian SK (0.321)*	*Pandian SK (31)*
4	*Mahalingam T (130)*	*Pandian SK (0.38)*	*Sanjeeviraja C (0.091)*	*Prabhu NM (0.320)*	*Mahalingam T (29)*
5	*Vaseeharan B (129)*	*Mahalingam T (0.34)*	*Singh Sk (0.087)*	*Sanjeeviraja C (0.314)*	Gopalan A (28)
6	*Manisankar P (123)*	*Jayachandran M (0.26)*	*Vaseeharan B (0.0819)*	*Singh SK (0.313)* *Vaseeharan B (0.313)*	*Jayachandran M (27)*
7	*Rajendran S (117)*	*Singh Sk (0.25)*	*Jeyakanthan J (0.068)*	*Rajendran S (0.312)*	*Manisankar P (25)*
8	Vasudevan T (110)	*Manisankar P (0,24)*	*Rajendran S (0.0602)*	Mahalingam T (0.309) Palanisamy S (0.309)	Vaseeharan B (25)
9	*Singh SK (100)*	Govindarajan M (0.23)	Vasudevan T (0.054)	Vasudevan T (0.308)	*Ravi G (23)*
10	Gopalan A (91)	Vasudevan T (0.23)	Mahalingam T (0.0507)	Jeyakanthan J (0.306) Murugan R (0.306)	Vasudevan T (22)
11	Jayachandran M (90)	Alharbi NS (0.22)	Balamurugan K (0.0423)	Balamurugan K (0.305) Manikandan R (0.305) Prakash S (0.305)	Sekar C (20)
12	Balamurugan K (76)	Benelli G (0.22)	Prabhu NM (0.0421)	Sekar C (0.304) Devi KP (0.304)	Kalaignan GP (20)
13	Kalaignan GP (71)	Rajendran S (0.21)	Devi KP (0.0419)	Jayachandran M (0.303)	Devi KP (18)
14	Devi KP (65)	Kadaikunnan S (0.20)	Sekar C (0.0402)	Ramasamy P (0.300)	Sankaranarayanan K (17)
15	Sekar C (59)	Devi KP (0.20)	Jayachandran M (0.0309)	Selvam S (0.298) Ganesan V (0.298)	Sivakumar R (17)

A correlation coefficient test was conducted to study the relationship between scientometrics and social network measures (Table 4). The basic scientometrics measure, publication count, positively correlated with normalized degree centrality (n degree - 0.95), node betweenness (0.86), and other impact measure h-index (0.87). As the number of collaborators increases, it automatically increases the non-redundant paths and creates some new shortest paths between nodes in the network. Consequently, it establishes a positive correlation between degree and betweenness centrality. A positive correlation was found (0.63) between impact measure h-index and betweenness centrality.

Table 4
Correlation between centrality and scientometrics measures

Correlation Coefficient	nDegree	F. Closeness	BC	h-index	NP
nDegree	1				
F. Closeness	0.31	1			
BC	0.81	0.22	1		
h-index	0.87	0.36	0.63	1	
NP	0.95	0.28	0.86	0.87	1

*Correlation is significant at the 0.05 level. (In all cases)

Frequency distribution of centrality measures for co-authorship network: Figure 2 shows the frequency distribution of centrality measures for co-authorship network. The frequency of degree centrality following a power-law distribution (r^2 = 0.90) fits at $y=3937.8x^{4.318}$. It exhibits a scale-free nature where 98.9% of authors have secured less than 0.2 degree centrality, whereas 0.096% of authors have more than 0.5 degree centrality. Betweenness centrality follows the polynomial curve order by two fits at $y=154.45x^2-1457.8x+3277.9$ (r^2=0.95), and closeness centrality is driven by the normal curve.

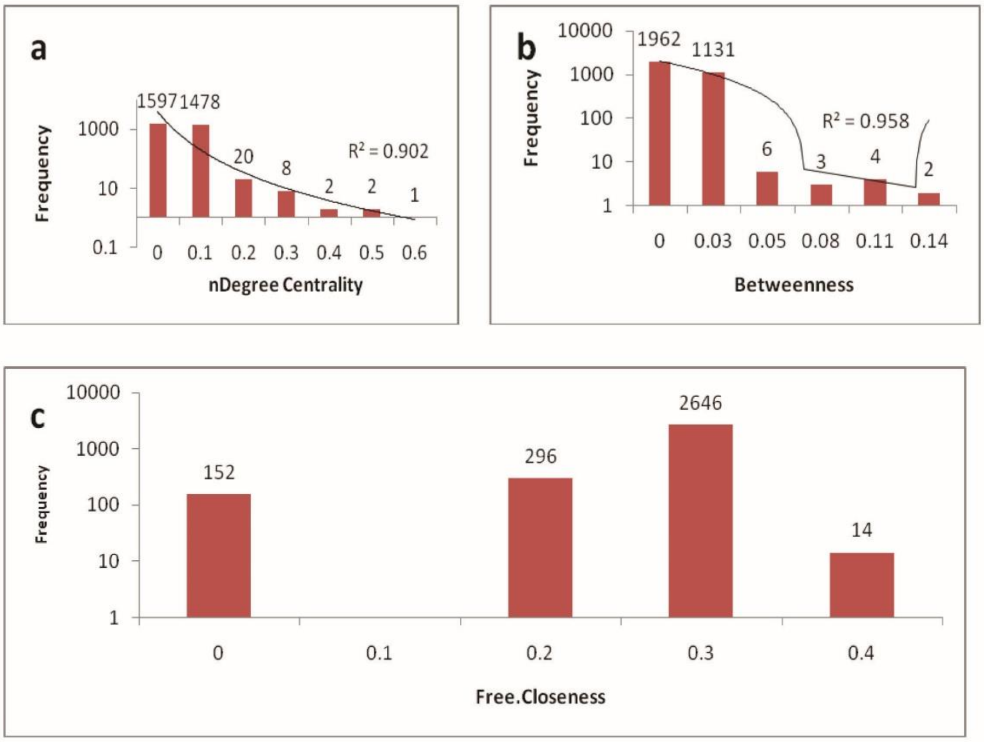

Figure 2: Frequency Distribution of Centrality Measures: a) Degree Centrality, b) Betweenness, and c) Closeness Centrality

International scientific collaboration network of AU: AU researchers published 88.4% of articles in collaboration with scholars from 57 countries. 76.4 % of articles were published in collaboration with a single country, and the remaining 23.6 % were the results of multilateral collaboration. An international scientific collaboration network has been constructed to analyze the international collaborative pattern of AU. Each node represents the country in the network, and the lines or links between nodes express their collaboration. The node's size is determined by the degree, and the value of lines determines the collaborative strength between countries. The clustering algorithms "components" used in this network revealed a single component, and there was no disconnection between nodes (Figure 3). Thus, collaborators of AU also collaborated with themselves. AU's most preferred collaborative country is South Korea, with collaborative strength of 241, followed by Taiwan (collaborative strength 138 and Saudi Arabia (collaborative strength 91). Iran has published 9 articles with AU members and ranked in 29, and Italy has published 16 articles with AU members and ranked 28. Even though South Korea has published a maximum of 76 articles with AU members, but collaborated with other scholars from 20 countries also. The countries Ireland, Eritrea, Libya, Egypt, Finland, Bangladesh, Wales, and Scotland have been collaborating with AU members alone, so the sizes of the nodes appear very small (Figure 3).

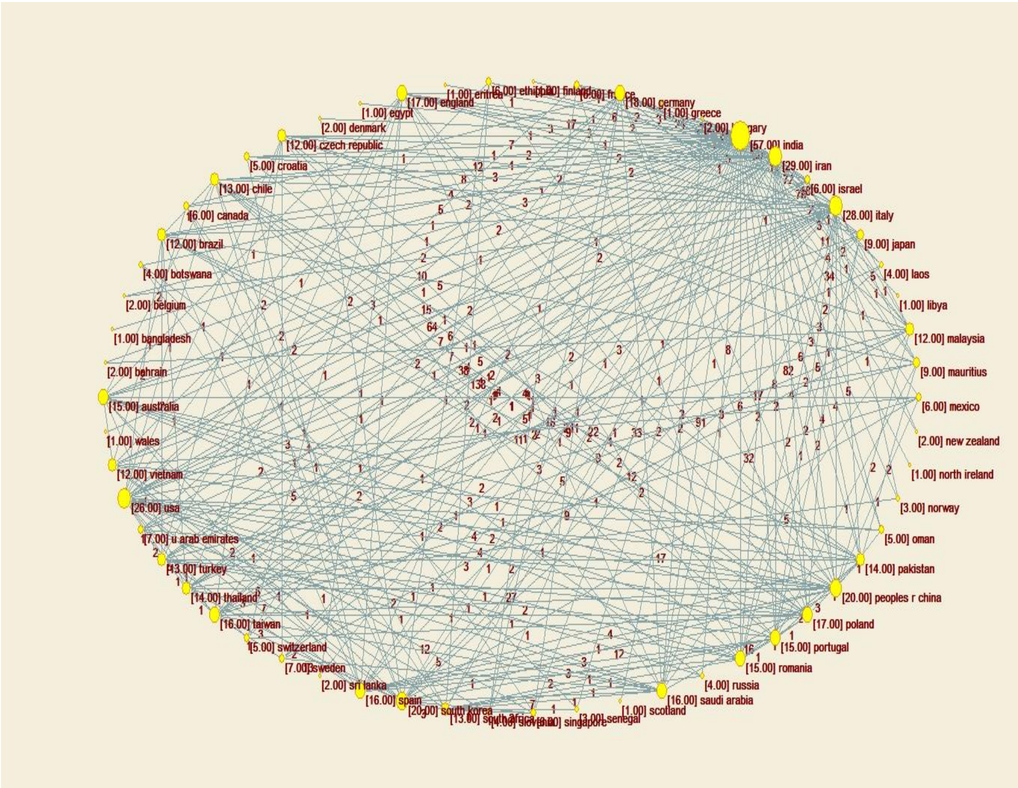

Figure 3: International Scientific Collaboration Network of AU (This network figure was drawn in the original circular layout of Pajek)

Intellectual structure of AU: Citation network analysis: Citations are the most commonly used measure to evaluate the research productivity of an author, article, organization, and journal. There are enormous scientometrics measures, such as h-index, impact factor, immediacy index, available to assess the importance of scientific productivity and identify the research specialties in a field or organization. "Citation analysis, therefore, may spot the articles that influence the research for some time and link them into a research tradition that is the backbone of a specialty" (Nishavathi & Jeyshankar, 2020). In a citation network analysis, each node represents knowledge (article, citation), and edges linking this knowledge represent the flow of knowledge. Unlike collaborative networks, the flow of knowledge has a direction from one node to another which indicates the previous relevant articles or their citations and enhances new intellectual knowledge. Hence, the citation network is acyclic, citing only previous articles known as the direct network. The dataset transformed into the citation network does not include the globally cited document in the Web of Science database. The network constitutes 1,926 cited documents denoted by the first author's name, the title of the journal, and the year of publication. The network is sparse due to low density (0.001) and consists of 92 research specialties. The largest component has 79% of the cited documents (Table 2).

Application of centrality measures to citation network analysis: Citation network analysis is a directed network. The degree of centrality is calculated for both in and out-degree. In-degree implies cited document, and out-degree represents citing the document. The most intellectual ideas will receive more citations. Hence, in-degree centrality is used to find the most cited documents in the citation network analysis. This study identified the top 10 most important documents by citation counts (Table 5). The maximum citation count was 37, and the normalized in-degree was 0.067, respectively, for the document Thenmozhi, R. & Pandian, S. K., 2009, Fems. Immunol. Med. Mic. Among the most cited 10 documents, 60% were published by the Department of Biotechnology, the Department of Industrial Chemistry (20%), and the Department of Bio-Informatics (20%). The most cited documents were outcomes of collaborative research. The values of LCS and normalized in-degree vary because it excludes self-citation ties and adds edge weight while calculating the nIndegree centrality. The maximum normalized out-degree is 0.0332 obtained by the document Srinivasan, 2016, V193, P592. It also secured a higher nIndegree (0.0332) than the documents Rajendran, V. & Gopalan, A. 2000, Electrochem. Soc and Musthafa, 2010, Chemotherapy, but due to its low citation count (13), it could not occupy any place in the most cited documents (Table 5). Application of the eigenvector centrality to the dataset explored a different array of most cited documents (Table 6). The document Nithya, C & Pandian, S.K., 2010, Res. Microbiol. was placed in 3rd position (Table 5) escalated to first place (Table 6), despite lower LCS. Four new documents become parts of the important or core document list (Table 6) because the eigenvector considers the number of inward links and the degree of all adjacent nodes in the network. Substantively, it considers only inward citation; however, both inward and outward relevant citations are essential to determine the core documents. A new advanced centrality method, “Hub and Authority” considers both inward and outward citations applied to the dataset and obtained the most influential and authoritative documents of AU (Table 7).

Table 5

Most cited document of AU: Citation count and in-degree

Rank	Most Cited Document	LCS	GCS	nIndegree
1	Thenmozhi & Pandian, SK 2009, FemsImmunol Med Mic	37	97	0.067
2	Bakkiyaraj & Pandian, SK 2010, Biofouling	31	72	0.055
3	Nithya & Pandian, SK 2010, Res Microbiol	26	61	0.052
4	Rajendran & Gopalan, A 2000, J ElectrochemSoc	25	67	0.023
5	Selvaraj & Singh, SK 2012, Med Chem Res	22	24	0.037
6	Padmavathi & Pandian, SK 2014, Biofouling	21	49	0.037

Rank	Most Cited Document	LCS	GCS	nIndegree
7	Musthafa & Veera Ravi, A 2010, Chemotherapy	20	82	0.019
8	Tripathi & Singh, SK 2014, MolBiosyst	20	27	0.033
9	Nithya & Pandian, SK 2011, Biofouling	19	55	0.037
10	Packiavathy & Veera Ravi, A 2013, Appl Micro boil Biot	19	60	0.037

Local citation score (LCS) and Global citation score (GCS): The documents ranked in the hub are influenced by the authoritative documents. Consequently, knowledge linkages are driven from those influential to authoritative documents that ventured new insights. The document Musthafa, 2011, V36, P55 ranked 7th in the citation count (Table 5) has not been found in the eigenvector ranking (Table 6) but has appeared 10th in hub scores and 9th in the authority scores (Table 7). Similarly, recent document Devi, 2018, V120, P166 has not been found in the citation count and eigenvector ranking but ranked 9th in hub scores. The document Srinivasan, 2016, V193, P592 has not ranked either in citation count or eigenvector ranking lists (both in Tables 5 & 6) but is listed 10th in the authority score (Table 7). Comparing the documents in hub and authority scores revealed that Thenmozhi, 2009, V57, P284 is the authoritative document rather influential.

Table 6
Most cited documents: Eigenvector Value

Rank	Most Cited Documents	Eigenvector value
1	Nithya & Pandian, SK 2010, V161, P293	0.328
2	Bakkiyaraj & Pandian, SK 2010, V26, P711	0.327
3	Thenmozhi & Pandian, SK 2009, V57, P284	0.317
4	Nithya & Pandian, SK 2011, V27, P519	0.252
5	Padmavathi & Pandian, SK 2014, V30, P1111	0.237
6	Packiavathy & Veera Ravi, A 2013, V97, P10177	0.226
7	Srinivasan & Veera Ravi, A 2016, V193, P592	0.219
8	Bakkiyaraj & Pandian, SK 2012, V22, P3089	0.218
9	Santhakumari & Veera Ravi, A 2016, V28, P313	0.190
10	Packiavathy & Veera Ravi, A 2012, V45, P85	0.183

Documents are identified in hub and authority scores (Bakkiyaraj, 2010, V26, P711; Nithya, 2011, V27, P519; Packiavathy, 2012, V45, P85) (Table 7). These are the most influential and authoritative documents published by AU.

Table 7
The 10 most authoritative documents: Hub and authority scores

Rank	Documents	Hub Scores	Documents	Authority Scores
1	Bakkiyaraj, & Pandian, SK 2010, V26, P711	0.3260	Thenmozhi & Pandian, SK 2009, V57, P284	0.5340
2	Nithya & Pandian, SK 2011, V27, P519	0.3160	Nithya & Pandian, SK 2010, V161, P293	0.4640
3	Packiavathy, & & Pandian, SK 2012, V45, P85	0.2670	Bakkiyaraj, Pandian, SK 2010, V26, P711	0.3840
4	Packiavathy, I & Pandian, SK 2013, V97, P10177	0.2660	Musthafa, & AVR 2010, V56, P333	0.2560
5	Bakkiyaraj & Pandian, SK 2012, V22, P3089	0.2540	Nithya & Pandian, SK 2011, V27, P519	0.1870
6	Santhakumari, & Veera Ravi, A 2016, V28, P313	0.2260	Padmavathi & Pandian, SK 2014, V30, P1111	0.1530
7	Padmavathi, & Pandian, SK 2014, V30, P1111	0.2200	Packiavathy& Pandian, SK 2013, V97, P10177 & Nithya, SKP 2010, V192, P843	0.1450
8	Nithya & Pandian, SK 2010, V161, P293	0.2160	Packiavathy & Pandian, SK 2012, V45, P85	0.1390
9	Devi, KP 2018, V120, P166	0.2040	Bakkiyaraj & Pandian, SK 2012, V22, P3089	0.1380
10	Musthafa & Veera Ravi, A 2011, V36, P55	0.2000	Srinivasan & Veera Ravi, A 2016, V193, P592 & Musthafa, Veera Ravi, A 2011, V36, P55	0.1240

The nIndegree and out-degree distribution fit with the power-law distribution (nIndegree $r^2 = 0.98$; out-degree $r^2 = 0.94$), which follows a scale-free network where few documents are cited by a large number of documents and a large number of documents left un-cited and vice versa (Figure 4).

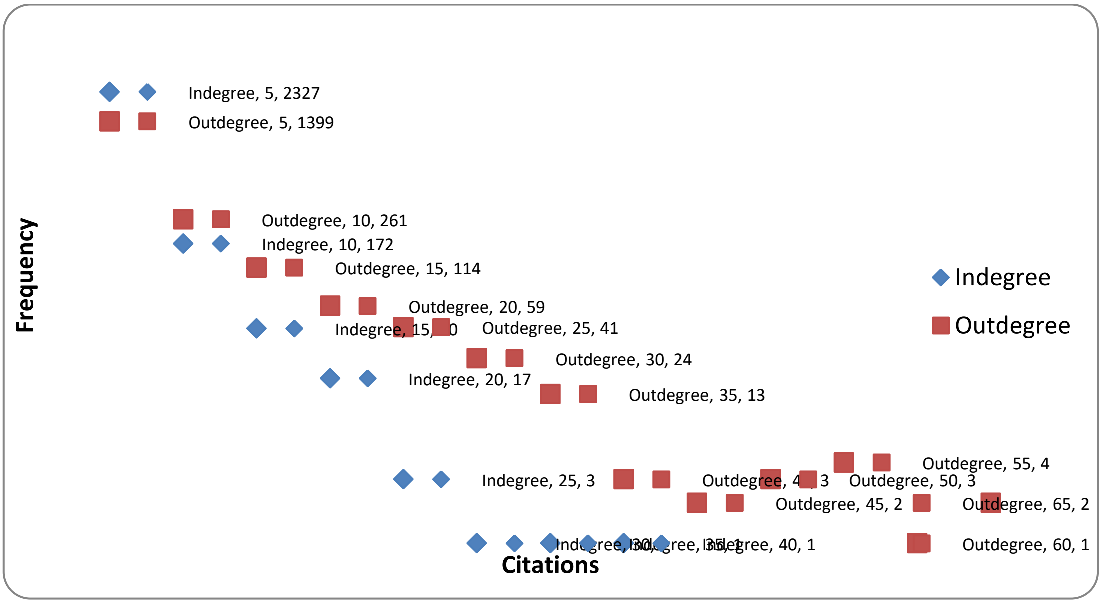

Figure 4: Distribution of In- and Out- Degrees of Citation Network Analysis

Main Path Analysis: Search path Count Method: In a citation network, the *main path* is the path from a source vertex to a sink vertex with the highest traversal weights on its arcs. "The main path analysis calculates the extent to which a particular citation or article is needed for linking articles, called the traversal count or traversal weight of a citation or article" (de Nooy, 2018). The main path is extracted from the citation network (v-1926), and the Search Path Count (SPC) command is used to compute the traversal weight. Application of SPC to the citation network disclosed that 88.9 % of lines have a traversal weight of lesser than 0.28, whereas the remaining 11.1% of lines have greater than 0.28. The maximum traversal weight was secured by the document Thenmozhi, 2009, V57, P284 (0. 806), followed by Nithya, 2010, V161, P293 (0.403) and Srinivasan, 2017, V110, P232 (0.3747). They are essential citations from where the biotechnological research originated and influenced others to add new insights to the field (Figure 5). It is noteworthy that the high traversal weight documents are ranked in all centrality measures (Tables 5, 6 & 7). The disconnected components are listed separately at the bottom of Figure 5.

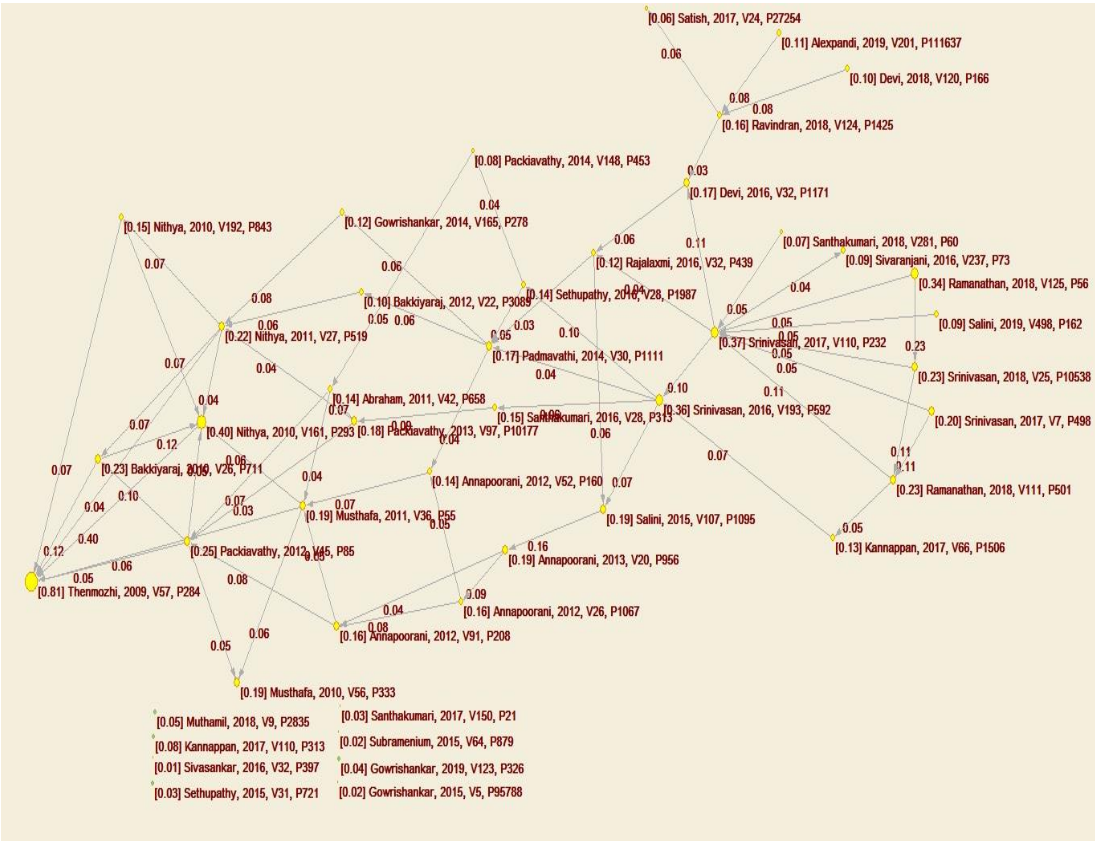

Figure 5: Main Path in the Citation Network

Three fields plot analysis: The most preferred and cited journals of the most productive authors: Journals are the carrier of intellectual information intended to scatter the research findings across the globe. Analyzing the journals for their impact, subject coverage, and productivity will help the institution regarding subscription policies. In addition to the above, for an institution, it is essential to know about the source usage of its academician, researchers, and professionals. Hence the dataset has been analyzed with three field plots in R programming. The center field represents the ten most productive authors of the AU, the left field represents sources of preferred journals, and the right field denotes cited or referred journals. The ten most productive authors cited 65.4 % of articles from the top 15 referenced sources and published 61.3% in the top 15 preferred journals (Figure 6). The most productive author, Sanjeeviraj, C., Department of Physics, has referenced 1,635 articles from the most referenced journals and published 31.3% of articles in the most preferred journals. Pandiyan, S. K., Department of Bio-Technology ranked 2nd referenced 139 journals and published 3.6% of articles in the most preferred journals. Singh, S. K., Department of Bio-Informatic Science (9th rank) published 17% of the articles in the most preferred journals. However, Rajendran, S. (7th rank), Department of Industrial Chemistry (1,480 referenced articles) contributed 36.7% of articles to the most preferred journals. Similarly, Gopalan, A., Department of Industrial Chemistry (10th rank) contributed 43.9% of articles to the most preferred journals (Figure 6).

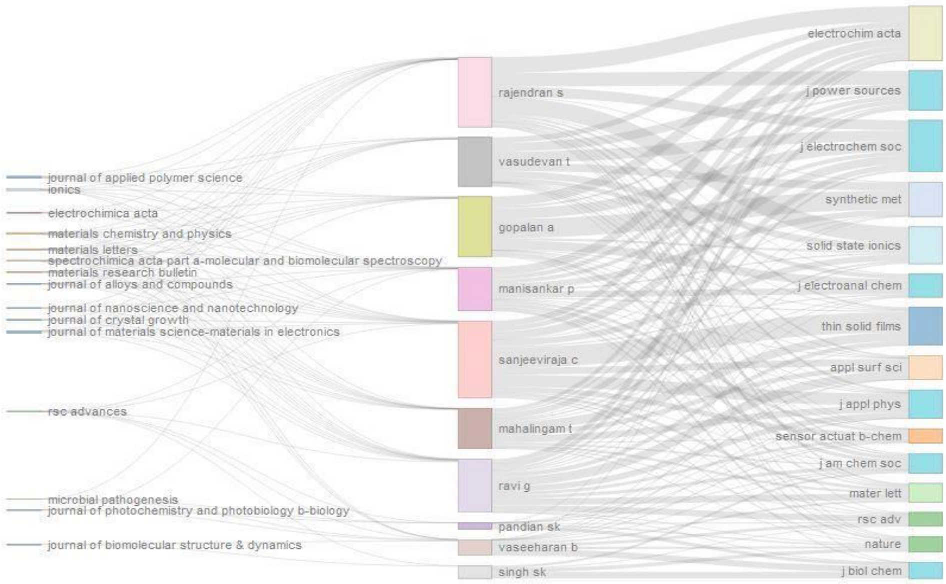

Figure 6: Most Preferred and Cited Journals by Ten Most Productive Authors of AU

The journals Electrochimica Acta and Rsc Advances have been two of the most cited and preferred journals by the most productive authors. Namely, 63.8% of the articles had been referenced, and 60 % were published in the journal Electrochimica Acta; 40% had been referenced, and 50% were published in the journal Rsc Advances by the most productive authors (Figure 7). Totally 12 journals shared the top ten list of preferred journals. Journal of Biomolecular Structure & Dynamics, Journal of Nanoscience & Nanotechnology, and Spectrochimica Acta Part A-Molecular and Biomolecular Spectroscopy have shared the sixth position in the ten most preferred journals (Figure 7).

The top ten productive authors have published 20% of the articles in the Zone 1 core journals, comprising 26. AU has published 362 single article**s** in 52.5% of journals.

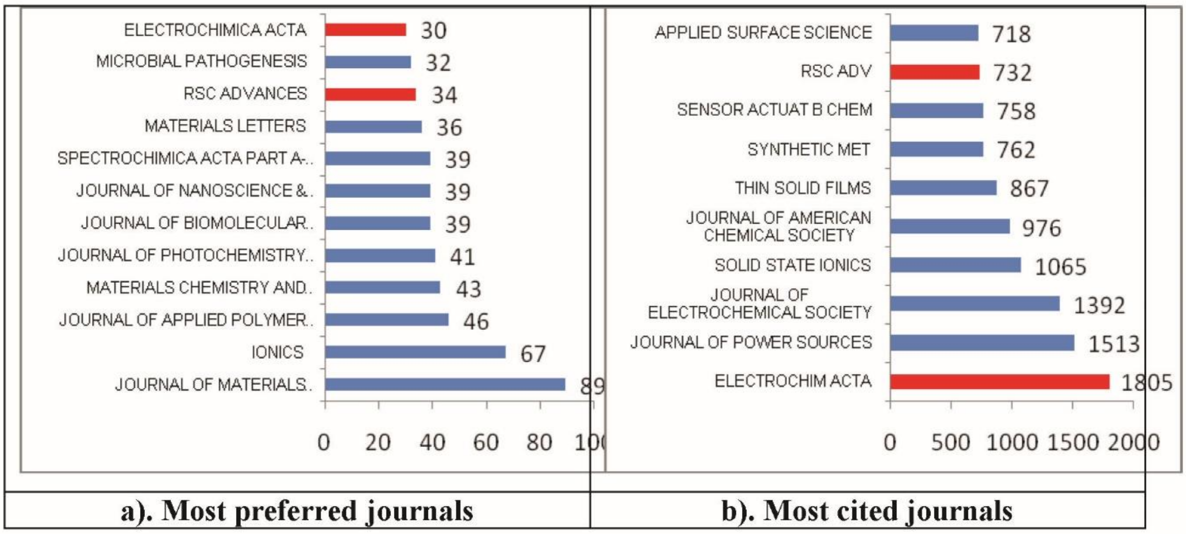

Figure 7: The Top Ten Most Preferred and Cited Journals

Discussion

An attempt has been made in this study to evaluate the research productivity of AU by applying scientometric and social network measures. The overall productivity of AU is 2,686, with an average of 76.7 publications since its inception, as reflected in the WoS database. This study is limited to 2,652 publications covering 2000-2019, and its productivity has increased to 128 publications per year. Application of scientometrics to the co-authorship of AU delves into the statistical characteristic of attributes, but centrality measures elucidate the relationship between the authors, which helps find the most productive, influential authors and their social interactions. This article also mapped the international scientific collaboration of AU.

It is noteworthy that AU is situated in a semi-urban area of Tamil Nadu, India, but its degree of collaboration was 0.99, which is higher than other famous research institutions in India such as CECRI (0.98) (32), CTCRI (0.87) (Pillai & Priyalakshmi, 2013), and IIT, Kharagpur (0.96) (Bid, 2016). Particularly as high as 88.41% of the articles were produced through international collaborative works, and the remaining 11.04% of them have domestically collaborated. As specified by (Lemarchand, 2012), the availability of infrastructure facilities, high connectivity, and visibility in the scientific network increases the productivity of an individual and provides the chance to increase collaborative links in hot topics of the national scientific network have resulted in domestic collaboration. AU has preferred to collaborate with the Asian continent than others. On the contrary, IIT Kharagpur tends to collaborate with developed countries like the USA (1,109 articles) and German (550 articles) (Bid, 2016). Thus, authorities of the AU should motivate their researchers to exchange their skills, expertise, and knowledge with other international scholars and support international scientific programs in that "highly cited articles are authored by a large number of scientists, often involving international collaboration" (Aksnes, 2003). The scientific productivities of the most prolific authors have been increased than those of 10 years from 2009 to 2018 (Jeyshankar & Nishavathi, 2019), but Sanjeevaraja, C. was still recognized as the most prolific author of AU. There were not many differences in the rank of the top 10 most prolific authors and their centrality measures compared to those of 10 years of 2009-

2018 (Jeyshankar & Nishavathi, 2019). It shows consistency in the research productivity of authors of AU. As Nundulall and Dorasamy (2012) indicated, any "academic staff need to be developed in terms of the skills and competencies required of researchers", in a competitive age of emphasizing a combination of teaching and research at the universities. In this regard, AU can invite those prolific authors to be mentors for other scholars to promote their university research capacity.

The frequency distribution of all degree centrality follows a power-law distribution (r^2=0.90), which is corroborated with r^2=0.91 at $p\ (k) = 1.1788k^{-2.1514}$ (Yan & Ding, 2009; Zervas Tsitmidelli, Sampson, Chen & Kinshuk., 2014). This finding is consistent with other studies also (Newman, 2001). In the studies, the correlation coefficient between the number of citations and centrality was analyzed and suggested using centrality measures as supplementary indicators for assessing the scientific recognition of authors. In addition, this study attempted to correlate the centrality measures with the productivity and h-index of authors. It is evidenced that there is a positive correlation between productivity, degree of centrality, and betweenness measures. Also, a positive correlation was found between the impact measure h-index and betweenness centrality (0.63).

The citation network analyses divulge the hub and authorities of the AU and found the main path of the most cited publications that constitute the Bio-Technology Department's mainstream development. Notably, 99 % of the ten most-cited documents result from intra-institutional collaboration and exhibit the student-faculty relationship in the authorship pattern. Even though Sanjeeviraja, C., Department of Physics has identified as a highly productive author, the highly cited document was Thenmozhi, R., 2009, Fems. Immunol. Med. Mic. from the Department of Biotechnology. It might be because the Pajek software used in this study considers the first author only, and Sanjeeviraja, C. has published his entire articles (198) in collaboration with others, many of whom he is not the first author. The three-field plot disclosed that the highly productive authors preferred to publish in the core journals (Zone 1 of Bradford's Laws of Scattering) referenced in their citations. It also revealed that 11% of articles published by AU were being un-cited at a global level.

Conclusion

This study focused mainly on two networks, co-authorship, and citation, to identify, analyze and visualize the research communities in AU, which can be helpful in research management and strategic planning at the university. In addition, the authorities may create research avenues for international collaboration with developed countries to minimize the research economies and maximize international visibility and research impacts. Students and faculty exchange programs with developed countries will also foster international collaboration. Further research on the conceptual network of the AU, its comparison with other networks, and temporal network analysis would reveal more insights into the productivity of AU. There was insufficient literature on academic universities as a unit of study in the social network aspect. This study attempted to bridge the gap in the literature, and the methodology used in this study can aid other organizations to identify and promote collaborative research within each university and enhance its collaboration among the universities.

The construction of citation networks and deploying network measures to the citation literature of AU unveil the research specialties, cohesive departmental research, and the backbone of research traditions to strengthen their research activities. Furthermore, a co-authorship network evinces the global visibility of research findings and positive effects on international research initiatives. Besides, the network measures deployed in this article may also be used as criteria to evaluate any university's research performance and potential in terms of excellence in research, innovation in economies, and internationalization of research literature. As Jin and Rousseau (2004) indicated, “simple quantitative evaluations focusing on numbers stimulate the growth of publications, but have little effect on the quality of research. Hence new approaches and regulations for research evaluation are nowadays being introduced”. We expect this article can add a small idea for the approaches.

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