Bibliometric Analysis of Adsorption Literatures: Contribution from Pakistan (1991-2017)

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Summary: In present work, adsorption related research contribution of Pakistani researchers from 1991 to 2017 have been analyzed by bibliometric methods. In total, 1,737 articles were selected through Science Citation Index Expanded (Web of Science) and statistical analysis of selected publications was conducted on the basis of four indicators such as total number of citations since publication to the end of the recent year, the number of citation of an article in recent year only, the total number of citations for an article in its publication year, and the total number of citations per year. A sharp increase in research output was observed after year 2000 which may be credited to reforms of Higher Education Commission in Pakistan. Though Pakistani researchers produced fewer review papers as compared to original research articles, reviews received three fold more citations. Almost 95% adsorption related articles from Pakistan have been published in low impact factor journals. Multidisciplinary chemistry journals published most of adsorption related Pakistani articles with maximum publications (10%) in Journal of the Chemical Society of Pakistan. Among various research institutes, University of Peshawar, Pakistan ranked first on the basis of total number of articles, first author articles, and corresponding author articles. Six most highly cited publications belonged to Pakistan Council of Scientific and Industrial Research (PCSIR). Number of international collaborative publications increased since 1991 to 2017 and resulted in their ratio being higher as compared to single institutional or nationally collaborative publications. The main focus of adsorption related literature from Pakistan since 1991 to 2017 was removal of metallic or dye contaminants from water and/or industrial effluents.

Keywords: Adsorption, Bibliometric, Pakistan, SCI-EXPANDED, Y-index.

Introduction

Chemical and biological water pollution is considered as one of the major environmental concerns locally and globally [1,2]. Discharge of untreated/semi-treated industrial and domestic effluents with high level of organic pollutants, non-biodegradable heavy metals and anthropogenic microorganisms etc. is not only a serious threat for human health but it is also affecting aquatic lives thereby disturbing whole ecosystem [3]. This problem is severe in developing countries where due to lack of financial resources and weak political will, high cost industrial and domestic effluent treatments projects are not top priority [4]. Therefore it is important for developing countries like Pakistan to explore and adopt cost effective methods for water and wastewater treatments. taAdsorption is considered as one of the best choices as compared to other alternatives owing to its cost effectiveness, simplicity, energy efficiency and reusability of exhausted adsorbents [5,6]. Besides water and wastewater treatment, adsorption technology has widespread applications in variety of industrial and domestic processes such as bulk separations, gas and liquids processing, catalytic reactions etc. [7,8]. Some other applications of adsorptions are purification of air and liquid fuels, recovery of precious metals, gas storage in porous adsorbents and odour control [9-11].

Scientists and researchers seem quite keen to explore different naturally occurring and synthetic adsorbents for their applications in pollution control, catalytic reactions and purification of industrially important chemicals etc. [12]. They are finding new interpretations of phenomenon involved in sorption mechanism, adsorbate solution chemistry, sorption equilibria, dynamics and adsorbent regenerations. Development and application of new simulation tools for adsorption data is another area of interest [13-15]. Being low cost separation process, adsorption technology can be quite suitable for developing countries with limiting resources. Probably, scientists from Pakistan also understand and appreciate importance of adsorption processes which is evident from appreciable volume of adsorption related literature from Pakistan.

It is almost impossible for interested fraternity to comprehend research patterns in a specified field at macro (international and national) and meso (institutional) levels using traditional review methods [16]. Bibliometric analyses can be helpful in generalizing and assessing research output of a country or institution using quantitative as well as qualitative

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bibliometric indicators e.g. Research productivity can be inferred from publication counts while number of citations, national and international collaborations and content analyses suggest quality and spread of research products [17]. Application of mathematical and statistical models on publication characteristics, such as authorship, quality of the journal, sources, subjects, geographical origins, and citations also provides insight into quality of research in a particular area of interest [18].

The principle objective of this study is to provide an introductory survey of adsorption literature from Pakistan. It is expected that this bibliometric analysis will provide valuable evidence for assessing trends and quality of research produced by Pakistani researchers in the field of adsorption. This study may also be useful in identifying important yet neglected adsorption related research themes for future directions.

Methodology

The data relevant to present study were derived from the SCI-EXPANDED (online version), in Clarivate Analytics (formerly known as the Thomson Reuters and the Institute for Scientific Information) Web of Science (updated on September 26, 2018). Only those publications were considered which were published in years ranging from 1991 to 2017 and contained the terms "adsorption", "sorption", and "biosorption" in title, abstract, authors' keywords, and *KeyWords Plus* Pakistan was also searched in terms of address. Usually front page of article contains bibliographical data i.e. title, abstract, authors with their affiliations and keywords therefore only documents with searching keywords in "front page" included title, abstract, and author keywords were further analyzed [19]. All records were downloaded and recorded along with year wise frequency of citations for each publication into spreadsheet software, and manipulated them using Microsoft Excel 2016 [20,21]

Four indicators such as the total number of citations from Web of Science Core Collection since publication to the end of recent year (TC_{year}) [22]; the number of citation of an article in recent year (the last year) only (C_{year}) [23] the total number of citations for an article in its publication year (C_0) [24] and the total number of citations per year ($TCPY = TC_{year}$/year) [25] were used to characterize the articles. Publications from United Kingdom (UK) contain all the articles originated from England, Scotland, Northern Ireland, and Wales. As per SCI-EXPANDED database, we considered reprint author as corresponding author [23]. In single author articles, the author was taken as first as well as corresponding author [23]. For multi author publications with unspecified contribution of authors, first author was considered as the corresponding author [26]. Assessment of contribution from different institutions was based on affiliation of at the minimum one author.

Results and Discussion

Document Type and Language

In total 1,793 documents were found within eight document types indexed in the Clarivate Analytics Web of Science. Table 1 shows that the most common document type was the research article (97%) followed by review papers (2.5%). Review had the highest citations per publication ($CPP_{2017} = TC_{2017}/TP$) with 38, followed by proceedings papers (CPP_{2017} = 14) and articles (12). However, average number of authors for reviews, proceedings papers, and articles was found similar. Reviews in adsorption research in Pakistan received three-fold more citations than articles (Fig. 1). It has been reported earlier that reviews are more frequently cited as compared to articles [27]. Proceedings papers also had higher CPP_{2017} than the articles. Similar results were found in drinking water research in Africa [18]. It should also be noticed that documents could be classified in two or more document types in Web of Science, for instance a highly cited document entitled "Biosorption of lead, copper and zinc ions on loofa sponge immobilized biomass of Phanerochaete chrysosporium" [28] was document types of "article" and "proceedings paper", thus the sum of percentages was higher than 100%.

Table-1: Characteristics of document type.

Document type	*TP**	%	TC_{2017}	CPP_{2017}	*AU*	*APP*
Article	**1,737**	**97**	**21,152**	**12**	**7,574**	**4.4**
Review	**44**	**2.5**	**1,693**	**38**	**215**	**4.9**
Proceedings paper	**23**	**1.3**	**325**	**14**	**97**	**4.2**
Meeting abstract	**4**	**0.22**	**5**	**1.3**	**16**	**4.0**
Correction	**3**	**0.17**	**0**	**0**	**10**	**3.3**
Letter	**3**	**0.17**	**9**	**3.0**	**6**	**2.0**
Editorial material	**1**	**0.056**	**0**	**0**	**4**	**4.0**
Note	**1**	**0.056**	**5**	**5.0**	**2**	**2.0**

TP: number of publications; TC_{2017}: the total number of citations from Web of Science Core Collection since publication to the end of 2017; CPP_{2017}: number of citations (TC_{2017}) per publication (*TP*); *AU*: number of authors; *APP* (*AU*/*TP*): number of authors (*AU*) per publication (*TP*)

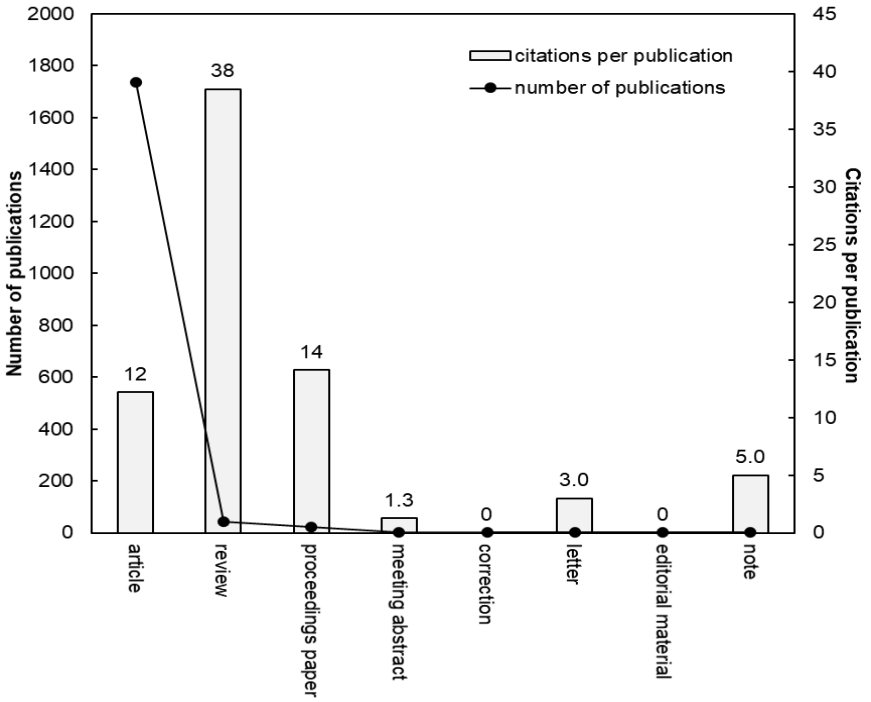

Fig. 1: Relationship between type of publication and citations per publication.

Only the 1,737 articles were selected for further analysis on the basis of containing whole research ideas and results [29]. All in all, English was the language of choice for communicating scientific data. Only one non-English article was published in Chinese and there is no any citations for this article (TC_{2017} = 0).

Publication Output

In recent years, Ho and co-workers proposed a relationship between articles and their citations per publication (CPP_{2017} = TC_{year}/TP) by years [30,31]. Fig. 2 shows the mentioned relationship which indicates that a sharp increase in the number of articles were found after 2000 which may be credited to reforms of Higher Education Commission (HEC) Pakistan with a vision of improving research output in Pakistan and its continuous investment in development and up gradation of research institutes [32,33]. In 2001, 16 adsorption articles were published resulting in highest CPP_{2017} of 42, which can be attributed to the highly cited article entitled "Removal of Pb(II) from aqueous/acidic solutions by using bentonite as an adsorbent" [34] by Naseem and Tahir from Pakistan Environmental Protection Agency with TC_{2017} = 302. The use of TC_{2017} for determination of CPP_{2017} is preferred as compared with the citation index from Web of Science Core Collection because they are consistent and ensure repeatability [35]. A total of the 1,737 Pakistan adsorption articles were published in SCI-EXPANDED between 1991 and 2017. The mean value of TC_{2017} was 12 with 303 as the maximal value.

Web of Science Category and Journal

Journal Citation Reports (JCR) indexed 8,996 journals with citation references across 182 Web of Science categories in SCI-EXPANDED in 2017. In order to know development among research fields, a relationship between the number of articles in categories and publication years was reported [29]. The Pakistan adsorption articles were published by 434 journals among the 85 Web of Science categories in SCI-EXPANDED. Category of multidisciplinary chemistry had the highest total articles (444 articles; 26% of 1,737 articles) followed by chemical engineering (414 articles; 24% of 1,737 articles), environmental sciences (268 articles; 15% of 1,737 articles), physical chemistry (217 articles; 12% of 1,737 articles), water resources (178 articles; 10% of 1,737 articles), and environmental engineering (153 articles; 8.8% of 1,737 articles). Fig. 3 shows trends of four new active categories in 2017. Multidisciplinary chemistry (444 articles, rank 1st), chemical engineering (414 articles, rank 2nd), environmental sciences (268 articles, 3rd), and water resources (178 articles, rank 4th) are new fields of Pakistan adsorption research.

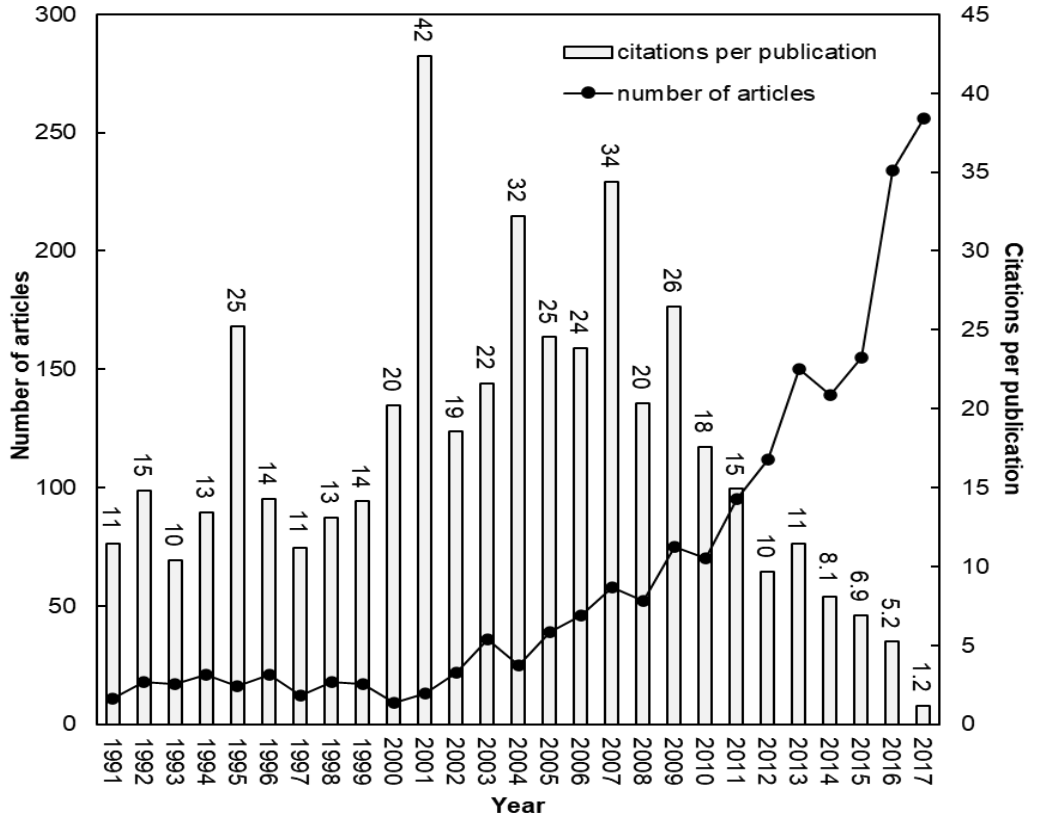

Fig. 2: Number of Pakistan adsorption articles and citations per publication by years.

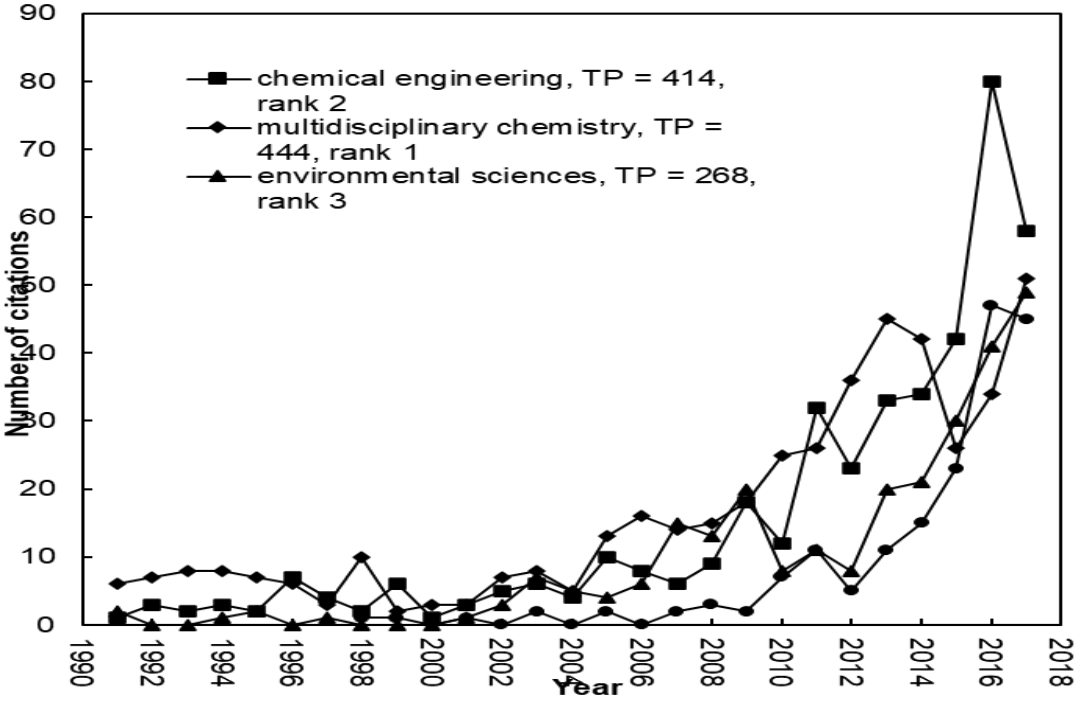

Fig. 3: Trends of four new active Web of Science categories.

Table-2: Characteristics of top ten journals.

Journal	*TP* (%)	IF_{2017}	Web of Science category
Journal of the Chemical Society of Pakistan	189 (13)	0.276	multidisciplinary chemistry
Journal of Hazardous Materials	50 (3.5)	4.836	environmental engineering civil engineering environmental sciences
Desalination and Water Treatment	46 (3.2)	1.272	chemical engineering water resources
Separation Science and Technology	45 (3.1)	1.083	multidisciplinary chemistry chemical engineering
Asian Journal of Chemistry*	38 (2.6)	N/A	multidisciplinary chemistry
Pakistan Journal of Botany	32 (2.2)	0.658	plant sciences
Radiochimica Acta	29 (2.0)	1.100	inorganic and nuclear chemistry nuclear science and technology
Adsorption Science & Technology	28 (1.9)	0.633	applied chemistry physical chemistry chemical engineering
Journal of Radioanalytical and Nuclear Chemistry	27 (1.9)	0.983	analytical chemistry inorganic and nuclear chemistry nuclear science and technology
Chemical Engineering Journal	26 (1.8)	5.310	environmental engineering chemical engineering

TP: Total number of articles; N/A: not available; *: *Asian Journal of Chemistry* is not listed in SCI-EXPANDED after 2014

The *Journal of the Chemical Society of Pakistan* published the most Pakistan adsorption articles with 176 articles (10% of 1,773 articles), followed by *Desalination and Water Treatment* with 113 articles, while their impact factors (IF_{2017}) were 0.276 and 1.383 respectively (Table-2). Article with the highest C_{2017} and *TCPY* was published in *Journal of American Chemical Society* [36]. It had the highest impact factor (IF_{2017} = 14.357) which published Pakistan adsorption articles [36]. Article with the highest TC_{2017} of 303 was published in *Chemosphere* [37].

Publication Performances: Countries

International research collaboration is defined as the share of articles published together with at least one author from another country anywhere in the world [38]. Policy makers in developing countries encourage international collaborations as it can provide access to facilities and resources of technologically advanced countries [39]. Individual and institutional interests and individual's migration and mobility tendencies also contribute in internationally collaborative studies [40]. Usually internationally co-authored papers receive more citations as compared to nationally co-authored as well as single-institution papers [41]. According to a study conducted by Sarwar and Hassan in 2015 Pakistan's international collaborations are more than world's average collaborations for years 2000-2011 [32].

In total, 623 Pakistan adsorption articles (38% of 1,773 articles) resulted from international collaborations with 56 countries. The collaborative partners of the articles revealed that 10% of 1,737 Pakistan adsorption articles resulted from collaborations with institutions in China, followed by the Saudi Arabia (82 articles; 4.7% of 1737 articles), the UK (75 articles; 4.3% of 1737 articles), Malaysia (69 articles; 4.0% of 1737 articles), and USA (53 articles; 3.1% of 1737 articles) (Fig. 4). According to a survey conducted on research output of Pakistan in Science and Technology in 2001-2010, internationally co-authored publications resulting from collaborative linkages with US, the UK, Germany, and China were on top of the list of 45 collaborative countries [42]. Hence adsorption related articles followed the similar trend of producing publications in collaboration with traditional research collaborators. Although articles co-signed by authors from Pakistan and Malaysia appeared after 2005, it soon became 5th top collaborator in adsorption articles.

In Fig. 4 it can be seen that until 2001, the adsorption related internationally co-authored publications resulted majorly with contribution of authors from China, the UK, and USA. From 2001-2010 the number of internationally collaborated publications increased with collaborating authors from variety of countries. After 2010 number of internationally co-authored publications increased dramatically. This trend is not surprising and can be related to global international collaboration on rise from 25% in 2001 to 35% in 2013 [43]. Overall Pakistan's international collaboration has also been found to show similar trend [44].

Publication Performances: Institutions

Of the 1,737 Pakistan adsorption articles, 623 (36% of 1,737 articles) were single-institute articles and 1,114 (64% of 1,737 articles) were resulted from inter-institutional collaborations. Inter-institutional collaborations can further be classified into national and international collaborations. Till

2017, 457 (26% of 1,737) adsorption related articles resulted from national level inter-institutional collaborations while international collaborations produced 657 (38 % of 1,737) articles. Indicators such as total number of articles, *TP*, first author articles, *FP*, and corresponding author articles, *RP*, have been presented to evaluate publication performance [45]. Table 3 shows the top 10 institutions for Pakistan adsorption articles in the SCI-EXPANDED. University of Peshawar took the first position in terms of indicators of *TP*, *FP*, and *RP*. During the period 1991–2017, University of Peshawar published 12% of the analyzed Pakistan adsorption articles, 8.9% of the first author articles, and 8.4% of the corresponding author articles. Similarly, Quaid I Azam University, University of Punjab, University of Agriculture Faisalabad, Pakistan Institute of Nuclear Science and Technology published 12%, 11%, 11%, and 8.9% of 1,737 Pakistan adsorption articles respectively.

Different disciplines and different countries have their own collaborative characteristics. A ratio of single institution papers : nationally co-authored papers : internationally coauthored papers (S : N : I) might be helpful in describing publication characteristics of country and institutions [46,47]. Pakistan ratio of S : N : I is 36 : 26 : 38 in the Web of Science indicated that Pakistan's adsorption related research had more internationally collaborations publications as compared to single institution and national collaborations. This trend is quite encouraging because researchers from a developing country i.e. Pakistan with limited research resources seem keen to excel by resource and/or expertise sharing with technologically advanced countries. A survey conducted by National Scientific Board in 2016 reported that from 2001 to 2013 the worldwide internationally collaborative Science and Engineering papers increased from less than one-quarter to 32% [48].

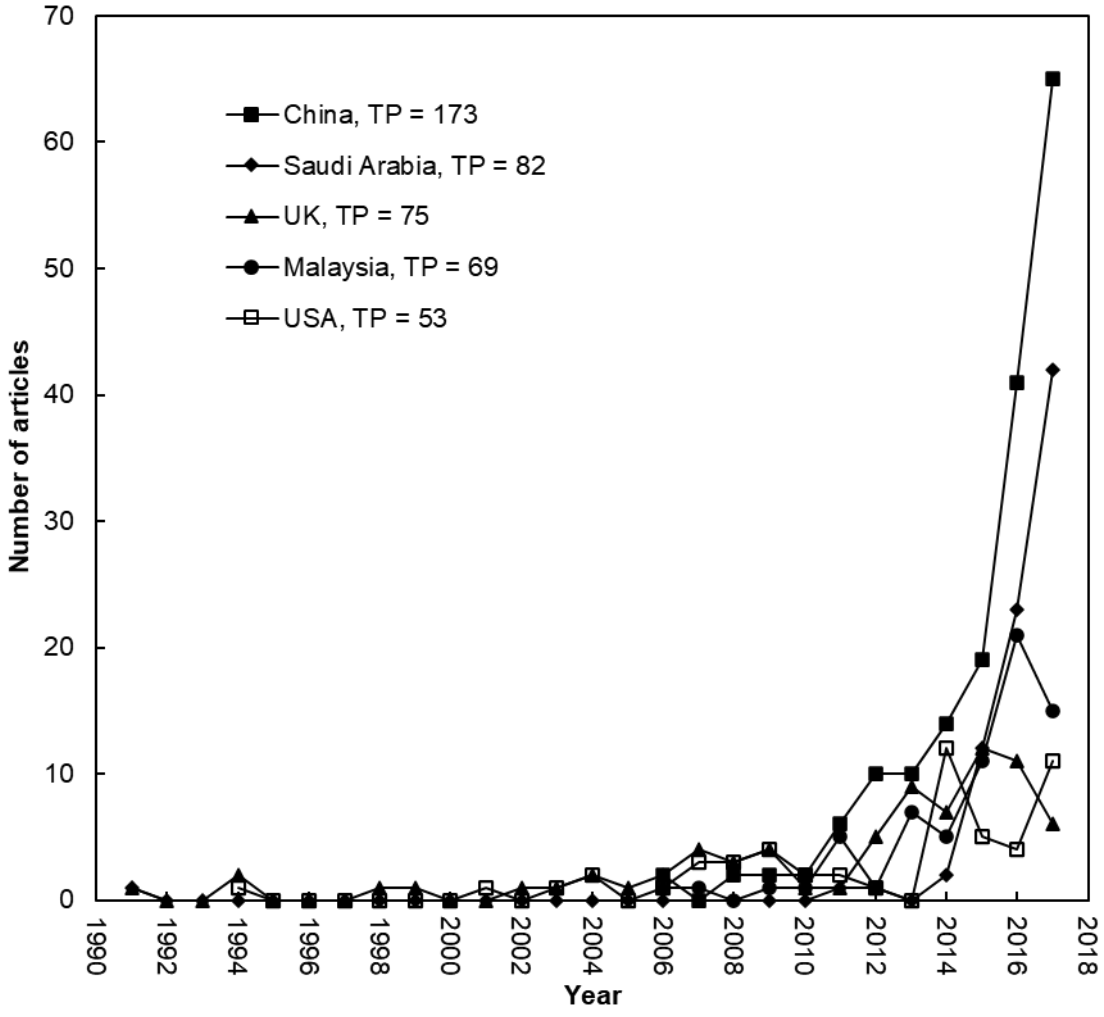

Fig. 4: Comparison of the growth trends of the top five collaborative countries.

Table-3: The top 10 institutions for Pakistan adsorption articles in the Science Citation Index Expanded (*TP* ≥ 50).

Institute	*TP*	*CPP*	*TPR* (%)	*FPR* (%)	*RPR* (%)	%*SI* (*SI*)	%*NC* (*NC*)	%*IC* (*IC*)
University of Peshawar	**216**	**11**	**1 (12)**	**1 (8.9)**	**1 (8.4)**	**46 (100)**	**29 (62)**	**25 (54)**
Quaid I Azam University	**207**	**12**	**2 (12)**	**5 (5.1)**	**5 (5.1)**	**16 (34)**	**43 (88)**	**41 (85)**
University of Punjab	**190**	**16**	**3 (11)**	**4 (6.7)**	**4 (7.0)**	**36 (69)**	**39 (75)**	**24 (46)**
University of Agriculture Faisalabad	**185**	**18**	**4 (11)**	**2 (7.8)**	**3 (7.4)**	**39 (72)**	**37 (69)**	**24 (44)**
Pakistan Institute of Nuclear Science and Technology	**154**	**14**	**5 (8.9)**	**3 (7.7)**	**2 (7.7)**	**51 (78)**	**46 (71)**	**3.2 (5)**
COMSATS Institute of Information Technology	**140**	**8.8**	**6 (8.1)**	**7 (2.9)**	**7 (3.0)**	**2.9 (4)**	**29 (40)**	**69 (96)**
University of Sindh	**110**	**17**	**7 (6.3)**	**6 (4.9)**	**6 (4.8)**	**41 (45)**	**26 (29)**	**33 (36)**
University of Karachi	**65**	**6.0**	**8 (3.7)**	**8 (2.6)**	**8 (2.7)**	**55 (36)**	**29 (19)**	**15 (10)**
Bahauddin Zakariya University	**60**	**11**	**9 (3.5)**	**9 (2.0)**	**9 (1.9)**	**18 (11)**	**48 (29)**	**33 (20)**
University of Malakand	**50**	**3.3**	**10 (2.9)**	**10 (1.6)**	**9 (1.9)**	**16 (8)**	**54 (27)**	**30 (15)**

TP: total number of articles; CPP: citations per publication; TPR (%): rank of total number of articles and percentage; FPR (%): rank of first author articles and percentage in all Pakistan adsorption articles with first author information in SCI-EXPANDED; RPR (%): rank of corresponding author articles and percentage in all Pakistan adsorption articles with corresponding author information in SCI-EXPANDED; %SI (SI): percentage in TP in an institute and single institute articles; %NC (NC): percentage in TP in an institute and nationally collaborative articles; %IC (IC): percentage in TP in an institute and number of internationally collaborative articles

University of Peshawar stands first in producing adsorption based publications with a total of 216 publications and S : N : I as 46 : 29 : 25. Interestingly among top ten Pakistani institutes generating adsorption related literature, three institutes namely Quid-e-Azam University, Pakistan institute of Nuclear Science and Technology, and COMSATS institute of Information Technology are situated in the same city i.e. Islamabad but exhibit very different collaborative trends. COMSATS institute of Information Technology with S : N : I of 2.9 : 29 : 69 is the only institute in the top ten list which has more than 65% publications resulted from international collaboration. Pakistan institute of Nuclear Science and Technology is more inclined to work independently as 51% of its total adsorption related publications came from research conducted exclusively by their own researchers while Quid-e-Azam University published more nationally collaborative work as compared to single institution and International multi-institution publications. University of Malakand with S : N : I of 16 : 54 : 30 is the only university with its more than 50% publications from nationally collaborated research.

Publication Characteristics of the Contributors with the Y-index

Ho firstly proposed the *Y*-index which is related to the numbers of first author publications (*FP*) and corresponding author publications (*RP*) [23,52]. The Y-index combines two parameters (*j*, *h*), to assess both the publication potential and characteristics of the contribution as a single index. The *Y*-index has been applied to examine the publication characteristics in different disciplines [23,26,49,50]. The *Y*-index is defined as [51,52]

$$j = FP + RP \qquad (1)$$

$$h = \tan^{-1}\left(\frac{RP}{FP}\right) \qquad (2)$$

where, *j* is publication potential, which is a constant related to publication quantity, and *h* is publication characteristics, which can describe the proportion of *RP* to *FP*. The greater *j*, the more the contribution of the first author and corresponding author publications. Different values of *h* stand for different proportions of corresponding author publications from first author publications. $h > 0.7854$ means more corresponding author publications; $h = 0.7854$ means the same quantity of first author publications and corresponding author publications; and $h < 0.7854$ means more first author publications. When $h = 0$, j = number of first author publications and $h = \pi/2$, j = number of corresponding author publications.

In total, 1,705 Pakistan adsorption articles with both first and corresponding authors in Web of Science were analyzed by using the *Y*-index. Fig. 5 shows distribution of the *Y*-index (*j*, *h*) of the top 16 authors with $j \geq 24$. *j* is a publication intensity constant: an author with a high *j* has more articles as the first or corresponding author, and takes the leadership role in more articles. S. Mustafa from University of Peshawar has the most adsorption articles and he has the highest *j* of 89 in Fig. 5. Next are H.N. Bhatti ($j = 71$), M. Iqbal ($j = 55$), S.M. Hasany ($j = 54$), and R. Rehman ($j = 53$). S. Mustafa also published the most first author articles (43) with *Y*-index (89, 0.8191), followed distantly by H.N. Bhatti (71, 1.309), M. Iqbal with 20 first author articles (55, 1.052), S.M. Hasany with 25 first author articles (54, 0.8593), R. Rehman with 26 first author articles (53, 0.8043), R. Qadeer with 25 first author articles (51, 0.8050), M.M. Saeed with 24 first author articles (48, 0.7854). Again H.N. Bhatti from University of Agriculture, Faisalabad published the most corresponding author articles with 56, followed

by S. Mustafa with 46 and *Y*-index (89, 0.8191), M. Iqbal with 35 (55, 1.052), and S.M. Hasany with 29 (54, 0.8593). In addition, F.K Bangash (24, 0.7854) and A. Khan (24, 0.5404) had the same value of *j*. It is clear from Fig. 5, that these authors located on the same curve (*j* = 24), means they have the same publication potential but different publication characteristics. H.N. Bhatti (*h* = 1.309) has higher ratio of corresponding author articles to first author articles while A. Khan (*h* = 0.5404), N. Khalid (*h* = 0.9995), A. Rehman (*h* = 0.6435), and J. Shah (*h* = 0.7509) have lower one. Similarly, M.M. Saeed (48, 0.7854), M. Afzal (26, 0.7854), F.K. Bangash (24, 0.7854) had the same value of *h*. Fig. 5 shows that all these authors located on the straight line (*h* = 0.7854), means they have the same publication characteristics but different publication potential. M.M. Saeed (*j* = 48) has higher publications while M. Afzal (*j* = 26), F.K. Bangash (*j* = 24) have lower one. A possible bias may occur when calculating the *Y*-index in that authors are sometimes listed in alphabetical order by some authors [35]. In such case the first author may not be the major contributor to an article. Another bias in analysis of authorship might occur when different authors have the same name or authors used different names over time in their articles. Another potential confounder arises when an author moves from one affiliation to another.

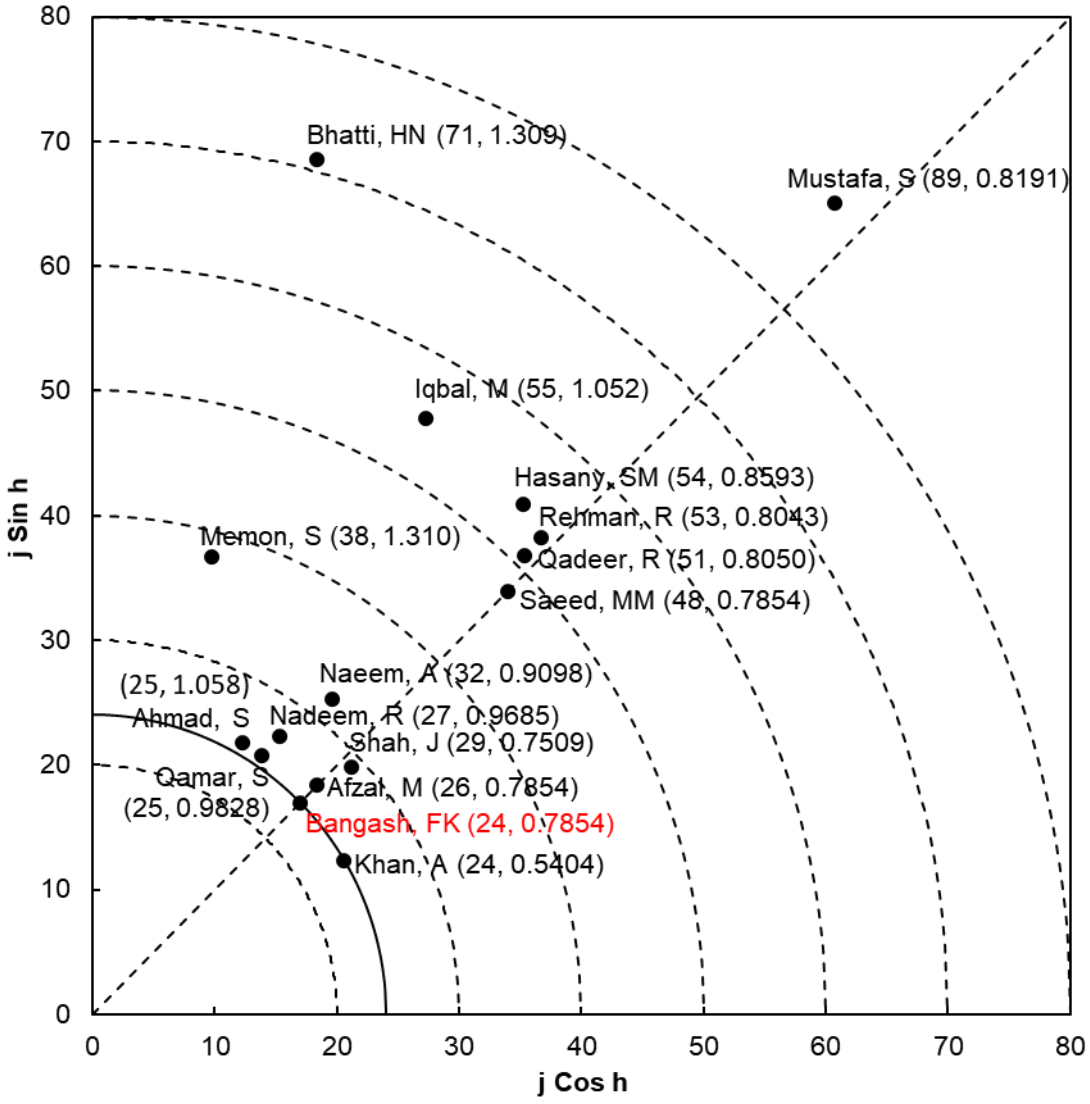

Fig. 5. Top 16 authors with *Y*-index (*j* ≥ 24).

Table-4: Top 10 most cited Pakistan adsorption articles.

Rank (TC_{2017})	Rank (C_0)	Rank (C_{2017})	Rank (*TCPY*)	Article information
1 (303)	375 (0)	2 (40)	4 (25)	Tahir, S.S. and Rauf, N. (2006), Removal of a cationic dye from aqueous solutions by adsorption onto bentonite clay. Chemosphere, 63 (11), 1842-1848. [37] [51]
1 (303)	103 (2)	18 (25)	6 (23)	Saeed, A. Iqbal, M. and Akhtar, M.W. (2005), Removal and recovery of lead(II) from single and multimetal (Cd, Cu, Ni, Zn) solutions by crop milling waste (black gram husk). Journal of Hazardous Materials, 117 (1), 65-73. [54] [56]
3 (302)	375 (0)	7 (35)	16 (18)	Naseem, R. and Tahir, S.S. (2001), Removal of Pb(II) from aqueous/acidic solutions by using bentonite as an adsorbent. Water Research, 35 (16), 3982-3986. [34] [33]
4 (254)	375 (0)	12 (31)	13 (20)	Saeed, A., Akhter, M.W. and Iqbal, M. (2005), Removal and recovery of heavy metals from aqueous solution using papaya wood as a new biosorbent. Separation and Purification Technology, 45 (1), 25-31. [56] [57]
5 (246)	103 (2)	2 (40)	3 (27)	Iqbal, M., Saeed, A. and Zafar, S.I. (2009), FTIR spectrophotometry, kinetics and adsorption isotherms modeling, ion exchange, and EDX analysis for understanding the mechanism of Cd^{2+} and Pb^{2+} removal by mango peel waste. Journal of Hazardous Materials, 164 (1), 161-171. [57] [55]
6 (231)	375 (0)	146 (7)	20 (17)	Liu, G.D., Wang, J., Kim, J., Jan, M.R. and Collins, G.E. (2004), Electrochemical coding for multiplexed immunoassays of proteins. Analytical Chemistry, 76 (23), 7126-7130. [58] [58]
7 (226)	103 (2)	4 (37)	10 (21)	Iqbal, M.J. and Ashiq, M.N. (2007), Adsorption of dyes from aqueous solutions on activated charcoal. Journal of Hazardous Materials, 139 (1), 57-66. [59] [68]
8 (222)	172 (1)	82 (11)	60 (10)	Khan, S.A., Riaz-ur-Rehman, and Khan, M.A. (1995), Adsorption of chromium (III), chromium (VI) and silver (I) on bentonite. Waste Management, 15 (4), 271-282. [60] [62]
9 (193)	375 (0)	175 (6)	74 (8.8)	Hasany, S.M. and Chaudhary, M.H. (1996), Sorption potential of Haro river sand for the removal of antimony from acidic aqueous solution. Applied Radiation and Isotopes, 47 (4), 467-471. [61] [61]
10 (183)	375 (0)	123 (8)	39 (12)	Tahir, S.S. and Rauf, N. (2003), Thermodynamic studies of Ni (II) adsorption onto bentonite from aqueous solution. Journal of Chemical Thermodynamics, 35 (12), 2003-2009. [55] [54]

TC2017: the total number of citations from its date of publication to the end of 2017 from Web of Science Core Collection; C0: the total number of citations in its publication year; C2017: the total number of citations in 2017; TCPY: TC2017/year.

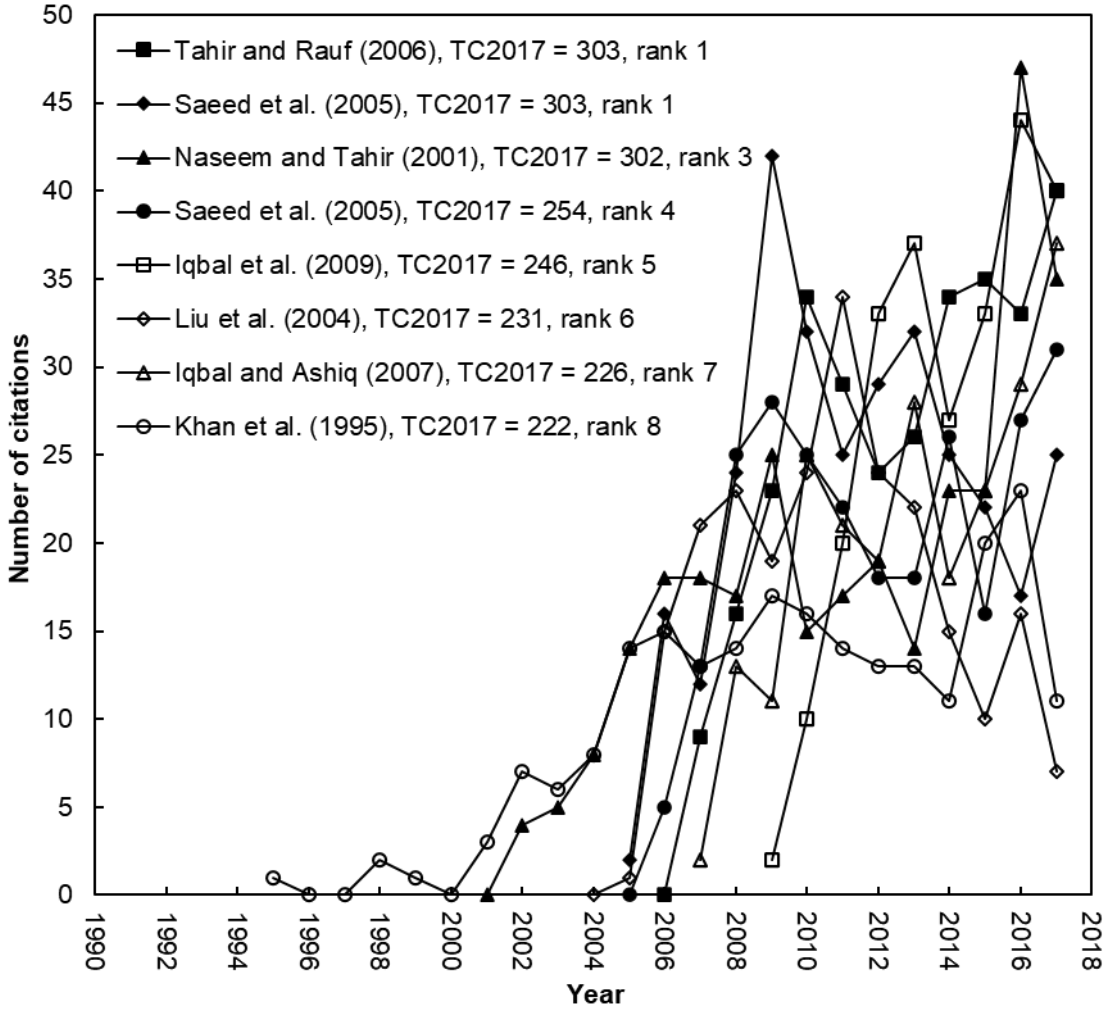

Fig. 6. The citation histories of the top eight most cited articles ($TC_{2017} \geq 222$)

The Most Cited Articles

In order to have total citations as scientific data which can be repeated and checked, the total number of citations from Web of Science Core Collection since publication to the end of recent year (TC_{year}) was proposed by Ho and co-workers [22,53]. Number of citations in publication year (C_0) and average number of citations per year ($TCPY = TC_{2017}$/year) were compared. Furthermore, C_{2017} was also applied for impact of most cited articles. In 2017, 795 articles, 46% of 1,737 Pakistan adsorption articles, had no any citations and 85% articles had less than 5 citations ($C_{2017} < 5$). In publication year, 1,363 articles, 78% of 1,737 Pakistan adsorption articles, had no any citations ($C_0 = 0$). Twenty percent of Pakistan adsorption articles had $TC_{2017} = 0$. Table 4 lists the 10 most cited articles with $TC_{2017} \geq 180$ from Web of Science Core Collection. There is no relation between the top ten articles in TC_{2017} and C_0 respectively. Four of the top ten articles as per TC_{2017} can be found in top ten articles ranked by C_{2017}, *TCPY*, and TC_{2017}. The article entitled "Removal of a cationic dye from aqueous solutions by adsorption onto bentonite clay" [37] by S.S. Tahir and N. Rauf from Pakistan Council of Scientific and Industrial Research published in *Chemosphere* had the highest TC_{2017} of 303. This is also second most impact in 2017 with C_{2017} of 40 and fourth by *TCPY* of 25. The most impact article in 2017, with C_{2017} of 75, was "Hollow cobalt-based bimetallic sulfide polyhedra for efficient all-pH-value electrochemical and photocatalytic hydrogen evolution" authored by Zhen-Feng Huang, Jiajia Song, Ke Li, Muhammad Tahir et al., published in *Journal of American Chemical Society* in 2016 [36]. The same publication also had the highest *TCPY* of 48. This article also ranked third in $C_0 = 21$. An article entitled "Biopolymers composites with peanut hull waste biomass and application for Crystal Violet adsorption" [62] by authors from University of Agriculture Faisalabad and University of Lahore in Pakistan had the highest C_0 of 27. The Pakistan Council of Scientific and Industrial Research (PCSIR) Islamabad published two articles with TC_{2017} values of ≥ 180. Both articles were authored by S.S. Tahir and Naseem Rauf [37,55]. The same authors produced another of top ten articles using affiliation of Pakistan Environmental Protection Agency, Islamabad [34]. M. Iqbal and Asma Saeed published three of top ten articles using affiliations of Pakistan Council of Scientific and Industrial Research (PCSIR) Islamabad [54,56,57]. As PCSIR Islamabad and PCSIR Lahore are actually branches of same government owned research organization and altogether six of top ten articles with TC_{2017} value of > 180 belonged to authors affiliated with PCSIR. Only one internationally co-authored article entitled "Electrochemical coding for multiplexed immunoassays of proteins" with international collaboration between Department of Chemistry and Biochemistry in New Mexico State University and Department of Chemistry at University of Peshawar in Pakistan could make its place in top ten articles as per TC_{2017} [58]. Highly cited articles can be published in earlier [63] and also found soon after publication [49]. Fig. 6 shows the relationship between citations and time for the highly cited articles ($C_{2017} \geq 222$). Out of eight most cited articles only two published before year 2000 but their citations frequency was low [60,61]. Right after the year 2002, the article citations amplified at a fast pace. The noticeable cause for increased citation rate may be due radical change in the scenario of higher education and growth of information technology for the improvement of research culture in Pakistan. Facilitation of universities and degree awarding institutes by HEC, Pakistan in the form of easy access to digital library and Ph.D. level scholarships for study in technologically advanced countries are the considerable reasons for increased visibility of the articles [62,63].

Research Focuses

In last decade, Ho and co-workers proposed the distribution of words in article titles, abstract, author keywords, and *KeyWords Plus* to evaluate trends in research topics [20,66]. Furthermore, "word cluster analysis" was successfully applied to find the research hotspots of specific topics [67]. Article title, author keywords, and *KeyWords Plus* of selected publications for present study were analyzed in order to determine focus of Pakistani scholars (Table 5). The words such as removal, adsorption, sorption, biosorption, and bioremediation, adsorbent ranked first as per their appearance in the title, author keywords, and *KeyWords Plus*. The second most frequently used set of words comprised of aqueous, water, waste-water, solution, and etc. suggests medium of adsorption. Most frequent adsorbates studied by Pakistan researchers were found to be arsenic; heavy metals for example, cadmium, copper, chromium, lead, zinc, and dyes for example, methylene blue solutions. Therefore, few studies papers on organic pollutant removal by moringa oleifera pods, catalytic ozonation, natural zeolite incinerator ash, and etc. Also few studies mentioned use of nanoparticles as adsorbents, most frequently studied adsorbents remained biomass, soils and carbon/activated carbon/activated charcoal. The most studied phenomenon was kinetics followed by adsorbent characterization, equilibrium and thermodynamics. In short, Pakistani researchers remained consistent studying removal of heavy metals and/or dyes from aqueous solutions by using biomass, soils or activated carbon.

Table-5: Classification of words in article title, author keywords, and keyword plus.

Class	Words	Title	Author Keywords	*KeyWords Plus*
Adsorption process	**removal, adsorption, sorption, biosorption, and bioremediation**	**778 (54%)**	**502 (47%)**	**1,299 (85%)**
Adsorption medium	**solution, solutions, aqueous, water, wastewater**	**688 (48%)**	**---**	**597 (44%)**
Adsorbate	**metal, ions, heavy metals, heavy metal ions, cadmium, copper, chromium, lead, Pb, hexachromium, zinc, arsenic**	**361 (25%)**	**179 (17%)**	**493 (36%)**
	dye, dyes, blue, methylene blue	**162 (11%)**	**13 (1.2%)**	**50 (3.7%)**
Adsorbent	**modified, activated, synthesis**	**166 (12%)**	**32 (3.0%)**	**121 (8.8%)**
	biomass, rice, husk	**161 (11%)**	**----**	**117 (8.6%)**
	carbon, Activated carbon, activated charcoal	**73 (5.0%)**	**32 (3.0%)**	**172 (13%)**
	soil, soils	**93 (6.5%)**		
	goethite	**--**	**----**	**30 (2.2%)**
	nanoparticles	**----**	**----**	**30 (2.2%)**
Phenomenon	**kinetic, kinetics**	**124 (8.6%)**	**129 (12%)**	**108 (7.9%)**
	effect	**99 (6.8%)**	**---**	**-----**
	characterization, FTIR	**57 (3.9%)**	**40 (3.8%)**	**---**
	equilibrium, isotherms, isotherm, adsorption isotherm, Langmuir isotherm, sorption isotherms	**55 (3.8%)**	**141 (13%)**	**152 (11%)**
	Langmuir, Freundlich			
	thermodynamic, thermodynamic parameters	**49 (3.4%)**	**104 (9.8%)**	**……**

Limitations

All the inferences in the study have been derived from data extracted from the SCI-EXPANDED (online version), in Clarivate Analytics Web of Science (updated on September 26, 2018). Publications indexed in other databases such as Scopus and Google Scholar etc. have not been included in the study. Author name disambiguation arising from using inconsistent spellings, use of full name and sometimes just initials can also be a reason of errors in the study. Only those indicators which are related to citation counts have been used to determine quality of research. However total number of views and downloads might also indicate worth of the Pakistani research publications.

Conclusion

In this study few significant findings were obtained about adsorption literature from Pakistan. Though Pakistani scientists were found more active in publishing original research articles, their reviews received more citations. The adsorption related publications increased dramatically after 2000. International as well as local collaborative research resulted in 64% of total publications. Various international and local collaborations were also found successful in publishing adsorption-based articles in last 15 years. Usually low impact factor journals published adsorption articles originating from Pakistan with Journal of chemical Society of Pakistan with highest number of publications. Pakistan Council of Scientific and Industrial Research (PCSIR) stood on top in terms of quality publications as it produced six of top ten highly cited articles (60% of 10 highly cited articles >183 total citation) whereas University of Peshawar ranked first on the basis of total number of articles, first author articles, and corresponding author articles. Analysis of words in title, author keywords, and *KeyWords Plus* indicated that with few exceptions focus of adsorption related research publications from Pakistan remained consistent in terms of choice of adsorbate, adsorbent and studied parameters. It may be recommended that Pakistani researchers should broaden choice of their research topics and devise their research questions based on novel applications of adsorptions phenomenon such as energy storage, catalytic activities, improvement of industrial processes etc. Take catalytic activities for example, TiO_2 nanocomposites, SAPO-34 Catalysts, and etc. were the useful catalytic for adsorption process. Though this study provided indications about quality of adsorption based literature generated from Pakistan, content analysis of these publications may also be helpful in providing more insight into their trends and worth.

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