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# Research status of the periodic table: a bibliometric analysis

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**Abstract**
In this paper, we present a bibliometric analysis of the Periodic Table. We have conducted a comprehensive analysis of Scopus based database using the keyword "Mendeleev Periodic Table". Our findings suggest that the Periodic Table is an influential topic in the field of Inorganic as well as Organic Chemistry. Areas for future research could include on expanding our analysis to include other bibliometric indicators to gain a more comprehensive understanding of the impact of the Periodic Table in the chemistry-based scientific investigations and even in the field of astrochemistry, which explores chemical processes in space, is intricately linked to fundamental chemistry. In this context, the quote of Carl Sagan is relevant where he eloquently expressed an inherent connection between chemistry and astrophysics: "The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars." In the ongoing study we have presented a ground level investigation of the conjecture of Sagan via Periodic Table based on bibliometric analysis whereas in the next level our aim is to present the stellar connection of it through Hertzsprung-Russel diagram as well as cluster of stars. The Periodic Table holistically serves as a foundational platform for understanding chemical elements both on the Earth and in celestial bodies. The present investigation fundamentally identifies the main working field of research and lays the groundwork for potential connections to astrochemical studies.

**Keywords** Periodic table · Bibliometric analysis · Chemistry · Astrochemistry

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## Introduction

Bibliometrics is the use of statistical methods to analyse books, articles and other publications, especially in scientific contents. Bibliometric methods are frequently used in the field of library and information science as a tool for finding the impact of publications using statistics. It involves collecting data, processing it and analysing from bibliographic database like Scopus, Web of Science or Google Scholar. In a way we can say that bibliometric analysis can be used to explore and analyse large volume of scientific data, unpack the evolutionary nuances of specific field and shed light on emerging areas in that field. There are several tools available for conducting analysis on bibliometric (as can be seen in the later part of this manuscript Sect. Methodology).

Therefore, other than library science (Bhavnani and Wilson 2009; Coombs and Peters 2017; Cabezas-Clavijo et al. 2021) and business as well as administrative management (Evans and Fischer 1993; Schaufeli et al. 1996; Maslach 1998; Leiter and Maslach 2001; Schaufeli et al. 2002; Sharma 2002; Kumar et al. 2013; Wang et al. 2019; Bakera et al. 2020) nowadays there is a growing trend to exploit this effective tool in the other field also, e.g. ecology and evolutionary biology (Brown et al. 2018; Claireaux et al. 2018; Pesendorfer et al. 2019), psychology (Figueredo et al. 2006; Griskevicius et al. 2011; Sacco and Osipowicz 2012; Del Giudice 2014), anthropology (Kaplan et al. 2000), public health (Wells et al. 2017), criminology (Dunkel and Beaver 2013), accountancy (Leiby and Madsen 2017), economics (Zeng and Yang 2023) and so on. Recently a successful application of bibliometrics has been noted in the biological system (Nettle and Frankenhuis 2019) where the authors used a bibliometric analysis of an interdisciplinary research area in the context of the evolution of life-history theory.

Motivated by the above mentioned works based on the bibliometric analysis we are now presenting here a study in the purview of basic science, especially in the field of chemistry. However, at this juncture we would like to recall the comment by the famous astrophysicist Carl Sagan who relates the basic chemistry to the astrophysics in the following unique manner: “The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of starstuff” (Sagan 2002). Therefore, for the time being we start the present bibliometric study from the Periodic Table as our initial platform which we shall connect later on with the astrochemistry as well as cosmochemistry.

This investigation thus fundamentally identifies the main working field of research dynamics and indicates the overall directional trend for the future research. As per the best of our knowledge, there is no such study having bibliometric analysis on the Periodic Table available in the literature as the stepping stone towards the astrochemical arena. Therefore, the following queries will be served as the pathways for the present study by using bibliometric analysis: (1) What is the current publication trend in the field of the Periodic Table? (2) Who are the most influential authors and relevant journals in this field of the Periodic Table? (3) Which are the most productive countries and institutions involved in the Periodic Table? (4) Who are the most prolific authors and what is the author collaborating trend in the Periodic Table? (5) Which are the most influential works in this field of the Periodic Table?

The outline of the present work is as follows: in the Sect. An overview of the periodic table we have provided background of the Periodic Table. Section Methodology is a precursor of the methodology we have adopted in the investigation. In Sect. Results and findings we have dealt with the results and findings

on different features of the bibliometric analysis in the research field of the Mendeleev Periodic Table, e.g. Country production (Sect. Country production), Core sources by Bradford's Law (Sect. Core sources by Bradford's law), Author's local impact by h-Index (Sect. Author's local impact by H-index), Author's production (Sect. Author's production), Annual scientific production (Sect. Annual scientific production), Most global cited documents (Sect. Most global cited documents), Co-occurrence network (Sect. Co-occurrence network), Most relevant authors and countries (Sect. Most relevant authors and countries). Section Discussions is dealt with discussion on pros and cons of bibliometric analysis whereas in Section Conclusion we have made a few concluding remarks along with some future scopes of the present study.

## An overview of the periodic table

Dmitri Ivanovich Mendeleev, a Russian chemist was the most important donor to the early evolution of the periodic table. In 1869, after the spurning of Newland's Octave Law came into focus of the Periodic Table (Mendeleev and Moseley 2014). In this, he intentionally ordered elements based on atomic weight (not atomic mass) and observed that chemical properties repeat periodically. Mendeléev's genius lay in leaving gaps for undiscovered elements, predicting their existence based on the periodic pattern and thus the table allowed for the inclusion of new elements without disrupting existing groups.

During Mendeleev's work, only 63 elements were investigated. However, one can take a presentist account to explore that there were actually 60 elements, as three of those taken by Mendeleev were later on discovered to be mixtures (Leal et al. 2022). After studying the properties of elements, he found that the properties of elements were related to atomic mass in a periodic way. He arranged the elements in such a pattern that elements with same properties come under same vertical column of the table. Mendeleev among chemical properties used formulae of hydrides and oxides as a basic criterion for classification. He took 63 cards and wrote property of one element on each card. He makes a group of elements with similar properties and pinned it on the wall. He observed that elements were arranged in order of increasing atomic mass and elements with similar properties had periodic occurrence.

He articulated a periodic law based on his observations entitled "The properties of elements are the periodic function of their atomic masses" (Mendeleev and Moseley 2014). In his description of periodic table of 1871, he left gaps in which unknown elements would find their place in periodic table, believed by him. One of the demerits of this table is that increase in atomic mass was not regular while going from one element to other. Hence the number of elements yet to be discovered was not predictable. There are several good review papers available in the literature on the genesis of the Periodic Table (Rawson 1974; Kak 2004; Leal et al. 2022).

In summary, the Periodic Table represents a collaborative achievement, shaped by scientific insights, historical context and global cooperation. Mendeléev's work was pivotal, but other chemists like Lothar Meyer, John Newlands and later on several others also have contributed significantly. The periodic table evolved through a gradual process of discovery, with various researchers independently recognizing patterns in chemical properties.

## Methodology

It involves in two main procedures: performance analysis and science mapping analysis. The performance analysis investigates the activity indicators of publications, emphasizing the most significant contributions of research constituents to a given research field (Bota-Avram 2023). On the other hand, science mapping analysis identifies and analyzes the scientific performance of articles, authors, institutions, countries and journals based on the number of citations, reveals the trends of the field studied through the analysis of keywords, identifies and clusters scientific gaps from most recent publications (deOliveira et al. 2019).

It is a quantitative method that evaluates the inter-relationships and impacts of authors, institution, publications, and countries in a specific area. It is a kind of review method based on computer aided scientific review. It uses mathematical and statistical tools to identify significant authors or studies and relationship between them.

The study screened research paper keywords to identify important publications on Mendeleev periodic table. This study examined research papers on Mendeleev periodic table listed in the Scopus indexed journals because of its wider coverage of quality journals and its credibility of research information, rigorous indexing and large number of citations (Bergman 2012). We used 'Mendeleev periodic table' as a keyword while screening the Scopus database. We comprehensively analysed all these papers by using bibliometric techniques and literature to examine the research papers on Mendeleev periodic table listed in the Scopus index. A bibliometric study is an analytical approach that uses the empirical and quantitative values to explain the distribution dynamics of research papers within a particular topic and a given period (Almind and Ingwersen 1997; Persson et al. 2009).

In this paper we set our limit of searching database to document type related to article and journal, language to English and subject area specified to chemistry, physics and astronomy and chemical engineering. We have selected only Q1 and Q2 based database in this paper.

In the last two decades, bibliometric techniques have become a common method used in science and research. Many areas of research use bibliometric methods for three reasons: expanding their area of operation, assessing the influence of a research group or determining the effect of a specific study (Pilkington and Meredith 2009). Therefore, they have become one of "the few truly interdisciplinary areas of research that can be extended to almost all fields of science that can be identified" (Glänzel 2003).

## Results and findings

### Country production

In Fig. 1, a graph has been drawn in which a plot between country production of articles over time period from 1959 to 2021 is discussed. Under this graph, we can infer from the data that USA has highest number of production of articles in the last year from 2015 to 2021. Unfortunately, Kazakhstan has no publication from 1959 to 2018. In the early years, i.e., from 1959 till 2003 there is no article publication by the scientists of Belgium, Brazil and China though later on they started publishing articles.

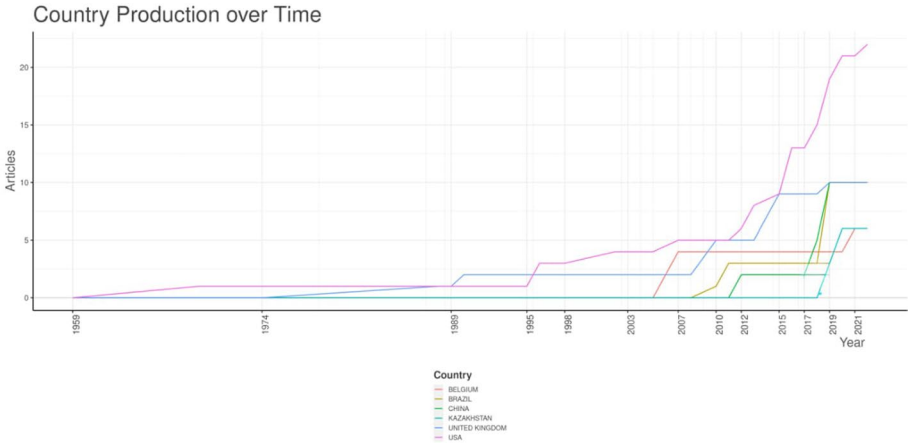


**Fig. 1** Country production over time

## Core sources by Bradford's law

The Bradford Law can be defined as pattern that estimates the exponentially diminishing returns of searching for references in Science journals. This pattern was first described by Samuel C. Bradford in 1934 (Bradford 1934; Black 2004; Yatsko 2012). This law is also known as Bradford's law of scattering or Bradford's distribution as it describes to show the articles of a particular subject that are scattered through the mass of periodicals as has been described: "there are a few very productive periodicals, a larger number of more moderate producers, and a still larger number of constantly diminishing productivity" (Vickery 1948; Hjørland et al. 2005). Here a graph is plotted against number of articles and source rank of articles using Bradford's law (vide Fig. 2). It can be noted from the plot that the journal 'Foundation of Chemistry' has the highest number of articles among others and 'Crystallography Reports' has the least numbers.

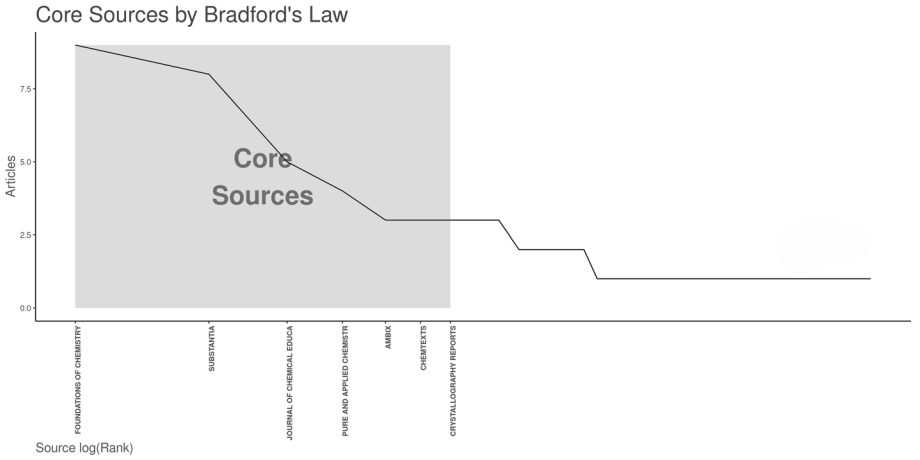


**Fig. 2** Core sources by Bradford's Law

### Author's local impact by H-index

The *H*-index is an author-level matrix that measures both the productivity and citation impact of a publication (Hirsch 2005). Basically *H*-index can be attributed as a amazing tool for determining author's relative work impact by determining author's cited publication. From Fig. 3, it can be found out that Novaro has a *H*-index measure which is 2.0 based on the calculation technique.

### Author's production

It calculates and plots the author production in terms of number of publications over the time. There is a tool in bibliometrix package for *R* which plots number of publication of authors over period of time. This tool takes input of bibliographic data and returns a list containing two data frames.

The first data frame consists of author's name and their publication count over time, while the second frame consists of publication count of each author.This tool can be used to know the productivity of author's in field of interest. Figure 4 indicates that the author O. Novaro has the highest production over time period of 1989 to 2008.

### Annual scientific production

A plot is drafted between number of articles and year time period ranging from 1959 to 2021. The peak is seen at year 2019 which gives the idea of the highest number of articles in that particular year. A sudden rise in articles from 2017 to 2019 is observed. This plot of annual scientific production depicts the era production of articles on Mendeleev Periodic Table. In the early year's scientific production is very less which rises after 2017 (Fig. 5).

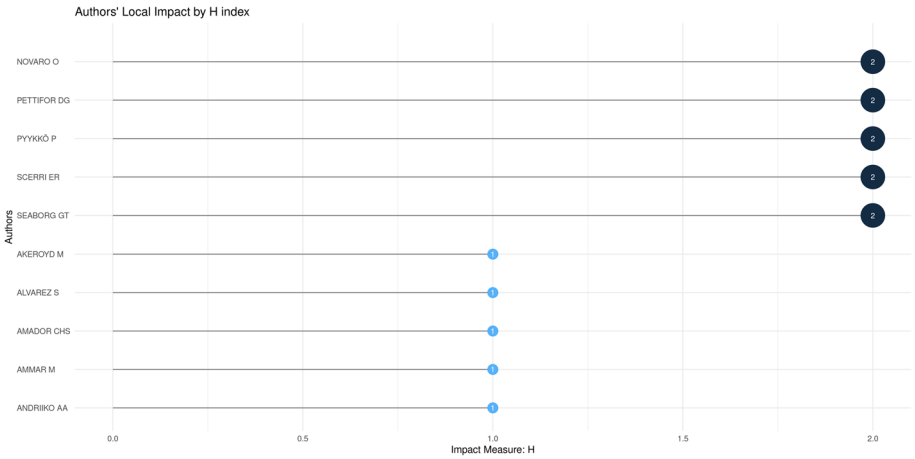


**Fig. 3** Author's local impact by H-Index

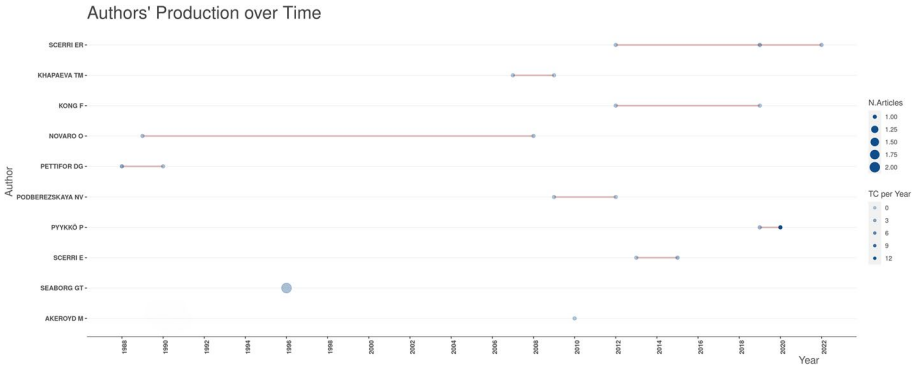


**Fig. 4** Author's production over the time

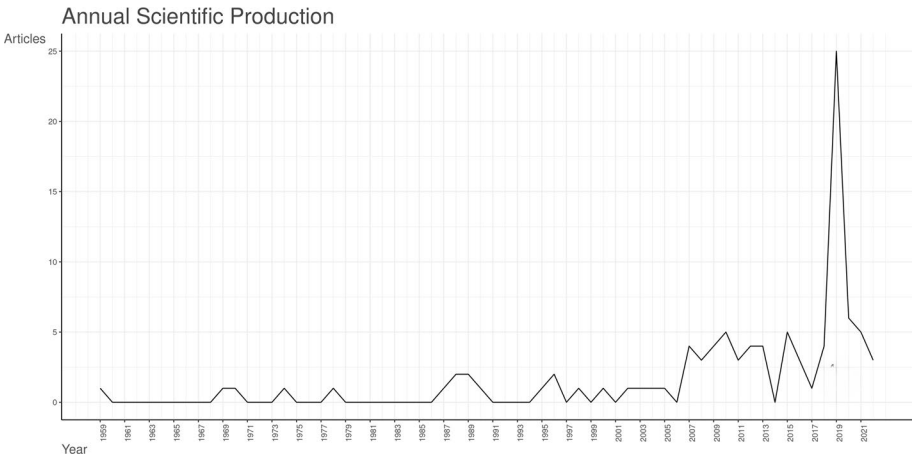


**Fig. 5** Annual scientific production

## Most global cited documents

According to a bibliometrix analysis based on the number of publications, keywords and citations in Mendeleev's Periodic Table, the most globally cited document with 156 citations was the paper entitled "Electron affinities of the heavy elements" by R.J. Zollweg in 1969 (Zollweg 1969). On the other hand, the least cited document is "Superheavy elements in D I Mendeleev's periodic table" by Y.T. Oganessian and S.N. Dmitriev in 2009 with only 22 citations (Oganessian and Dmitriev 2009). This feature is very obvious as over time the paper by Zollweg received much citation in comparison to the work by Oganessian and Dmitriev (Fig. 6).

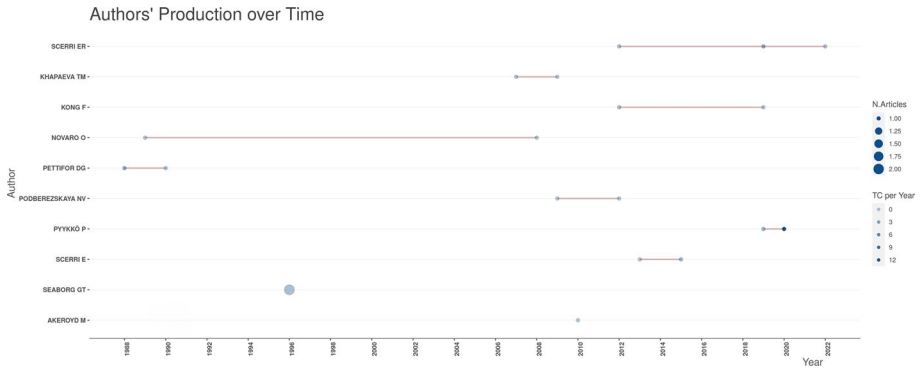


**Fig. 6** Most global cited documents over the time

## Co-occurrence network

Co-occurrence network sometime referred as semantic network. It can be attributed as an useful tool to analyse the big data and large text by identifying the main themes and topics, or even mapping an entire research field. The method of constructing co-occurrence networks includes identifying keywords in the text, calculating the frequencies of co-occurrence and analysing the networks. Map represents the connection of various keywords to each other with lines. These lines signify the co-occurrence of keywords with each other in different papers in the considered data set collected from Scopus database. It is to be distinctively noted here that 'Periodic Table' is the main keyword which in turn related to atoms, molecules, chemical elements, bonds, electrons and so on which are co-related to each other (Fig. 7).

## Most relevant authors and countries

In the Fig. 8, authors are placed in an order according to decrease in the number of documents. E.R. Scerri is the most relevant author with three documents based on the

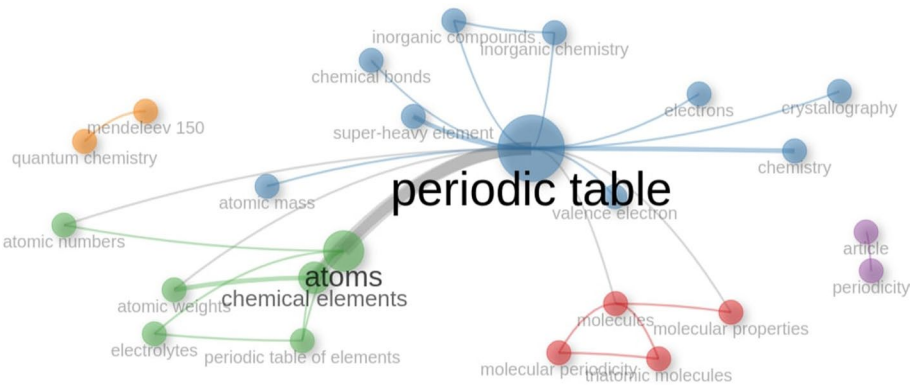


**Fig. 7** Co-occurrence network over the time

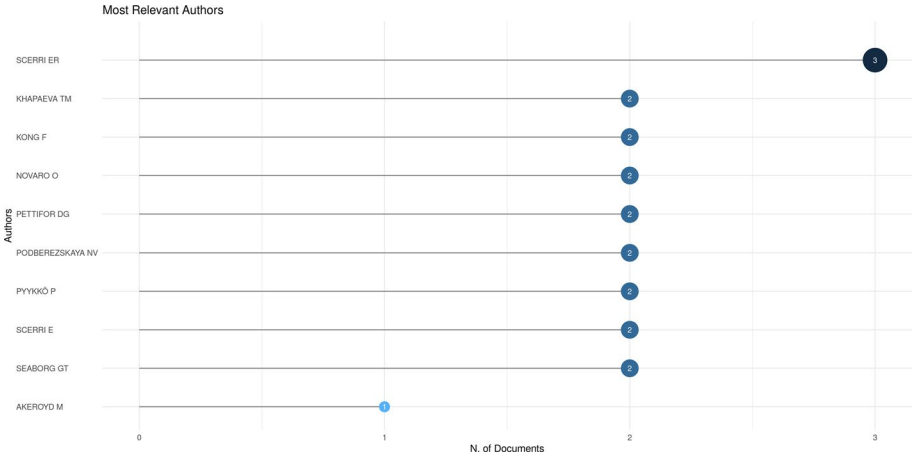


**Fig. 8** Most relevant authors over the time

data set collected from Scopus database whereas in the bottom of the figure there is an entry with the name M. Akeroyd.

On the other hand, the database collected from Scopus and analysed with the bibliometrix tool provides the most corresponding author's countries on the basis of their publication on Mendeleev's periodic table (Fig. 9). Countries can publish their data in two ways: single country publication and in a collaboration with different countries as multiple country publication. USA has the highest number of publications as single country publication among others countries. Italy has only multiple country publication collaboration. China, Brazil and Kazakhstan all three countries have both the of publications, i.e., single country publication and multiple country publication.

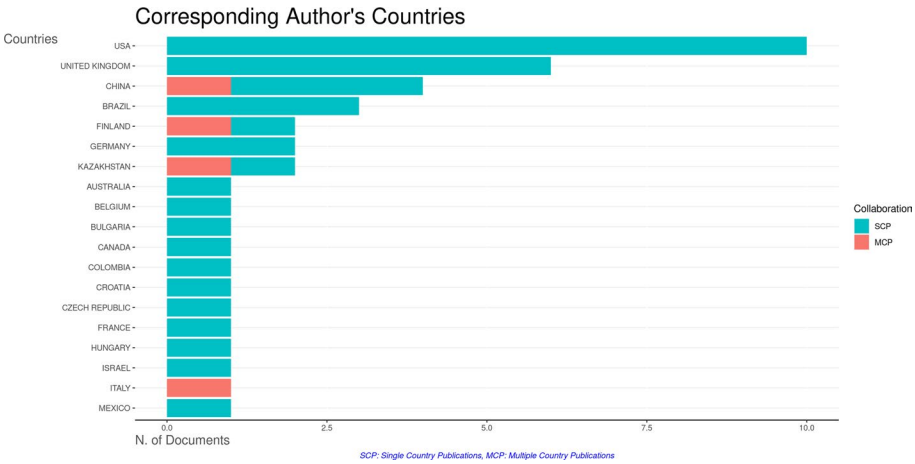


**Fig. 9** Most relevant countries over the time

## Discussions

So far we have shown different interesting features of bibliometric analysis which are really informative for getting at a glance a global scenario of the Periodic Table as proposed initially by Mendeleev. However, there are several issues as well as pros and cons of this type of data analytic system. At this jucture it is to mention clearly that we could not always able to include all the authors and their prominent publications in our specific choice for bibliometric analysis due to lack of facility on computational part. Basically, the accuracy of bibliometric data heavily relies on the sources and databases used. Some databases might not capture publications comprehensively and thus leading to serious gaps. Bibliometric analyses are based on specific tools, such as BiblioShiny and VosViewer, but they don't always capture the full richness of a researcher's career. We would like to discuss all these in the following points:

(i) We have mentioned in our methodology part of the article that out of several hundred thousand papers on Mendeleev Periodic Table published in different kinds of journals (viz. Q1, Q2, Q3, Q4) as well as from different books and conference proceedings and articles but we have considered mainly Q1 journals along with Q2 journals also. So, some of the authors, as for example Scerri is not appearing frequently even though he has several dozens of publications on the Mendeleev Periodic Table having citations specifically in 2019 altogether as high as 1014! To furnish this information and fillup the gap, in a substantive way other than technical analysis, we have cited a few relevant research papers published in Q1 and Q2 journals (Scerri 1991a, b, 1998, 2008, 2009; Shawn et al. 2016; Scerri 2019a, b, 2020, 2021, 2022).

(ii) In this connection we would also like to mention 83 articles which are on the periodic table and closely related topics. The vast majority of these articles, as evident from Fig. 4, have been published by O. Navaro (from 1989 to 2008) and ER Scerri (from 2012 to 2023) dealing with the philosophical nature of the elements of the periodic table. But our methodology did not allow us to pick up in detail all these varied themes as well as varied journals other than Q1 and Q2 only.

(iii) In our article, from the Fig. 8, it appears that we have listed two distinct authors, i.e. E. Scerri and E.R. Scerri! However, after investigation we have come to know they are the same very same person. The use of different initials might have led to the confusion as there is no way for the executing bibliometric software to detect this apparent difference! However, eventually it is assured that they both represent one person with a remarkable expertise in the field of chemistry and the periodic table.

(iv) Another point which is a more general in its nature that, since our study purports to document the amount of work carried out on the Periodic Table, would it not be worth widening our search to include books on the subject and considering their level of citation. In this context the one book entitled with "The Periodic Table: Its Story and Its Significance" having citations 1000 citations from 2019 could not possible to put in our list of entries. However, our study is focused on the scientific papers only that have contributed to the development and understanding of the periodic table, rather than the books that have explained or explored it. We understand that books are a valuable source of information and inspiration. But to restrict number of entries in the 'Testing Ground' as otherwise the data analytic study becomes cumbersome, time consuming and the created plots become extremely hazy to include as well as present in a legible manner! Therefore, we have chosen to limit our search mostly to

peer-reviewed publications with Q1 and Q2 categories that have been cited by other researchers in the field.

(v) One can notice that the peak in publication for the year 2019 was due to the 150th anniversary of the publication of Mendeleev's first periodic table of 1869. There should have a mention of this event in any relevant documentation of Periodic Table. However, our study was not focused on the historical or cultural aspects of the periodic table, but rather on the hardcore quantitative analysis of the scientific papers that have contributed to the development and understanding of the periodic table over time. Therefore, we could not include any mention of this event in our article, as it was not relevant to our research question and substantive scope.

## Conclusion

This study represents the bibliometric analysis of various studies published on the Periodic Table. We have selected Q1 and Q2 from the Scopus database. This study focused on the year wise trends of publication of the Periodic Table. It identifies the most global cited documents, most relevant authors and most relevant author's countries and authors productivity over time that are prominently involved in its research. In addition to, this study presents co-occurrence network analysis, annual scientific production and author's impact by *H*-index.

Some of the salient features of the present investigations are as follows:

(i) These analyses give a direction to researchers venturing into the area of the Periodic Table by providing information on journals, authors, collaborators and countries that are prominent in this domain as well as co-occurrence network used in the research.

(ii) From the data we analysed we can infer that USA is the country that has the highest publication over time. One can observe from the relevant plot (vide Fig. 3) that Novaro is the highest productive author of time period 1989 to 2008. Also, it is evident that the year 2019 has the highest annual scientific publication in the Periodic Table.

(iii) The most globally cited document in the field of the Periodic Table is "Electron affinity of heavy elements" with 156 citations published in the "Journal of Chemical Physics". E.R. Scerri is the most relevant author of the time with the highest number of documents on periodic table. USA can be awarded as the most relevant country in term of publication. Results of annual scientific production and the most cited document have collected increasing interest in the field. It is important for the future researchers to explore the ideas that are needed to identify the research gap. The analysis of relevant author's and countries indicates global interest in this domain.

(iv) Research can be attributed more powerful and impacting effect when it gives a global result. Such studies enable research students as well as scientists to collaborate with experts who are working globally. These results are valuable for finding research journals, articles and other issues present in the domain of periodic table in that time span which in turn will be beneficial for the coming generation to find out possible outcomes in the field of research.

In connection to the scope for future study we would like to state here that in this paper, we only included the data which is based on Scopus database of the Periodic Table

containing Q1 and Q2 factor so the paper which are not indexed in Scopus are not included in research. Therefore, (a) the future researcher can collect more amount of data from other sources such as Web of Science and Google Scholar, (b) more comprehensive research can be carried out by focusing on different network diagrams that are not studied out here, and (c) a diversified study can be done by extending the time span of database selection where the data set can be studied comprehensively by including different network. Furthermore, one can study the astrochemistry problems based on the present structure where micro-chemical elements can be connected to the macro-objects under the periphery of cosmological realm. This aspect may be considered in one of our future projects on the astrochemistry research which we have started here via the Periodic Table.

We can summarise that bibliometric analysis is an influential tool to explore publishing trends and their relationship between communicated work. Furthermore, it helps in recognizing the most influential researches as well as researcher in the field as evident in the present study of the Periodic Table.

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**Data availibility** A comprehensive data archive is available as open source in the Internet.

**Code availability** Not applicable.

## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** Not applicable.

**Consent to participate** Not applicable.

**Consent for publication** Yes.

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