International Journal of Information Science and Management
Vol. 20, No. 2, 2022, 127-143
https://dorl.net/dor/20.1001.1.20088302.2022.20.2.8.3

Original Research

Scientific Productivity of Leading Countries

B Elango
Assistant Prof., Department of Library and Information Science, Rajagiri College of Social Sciences, Kerala, India. elangokb@yahoo.com
ORCID iD: https://orcid.org/0000-0002-8938-0155

Dong-Geun Oh
Professor, Department of Library and Information Science, Keimyung University, Korea, Republic of.
Corresponding Author: odroot@kmu.ac.kr
ORCID iD: https://orcid.org/0000-0002-3620-9901

Received: 19 February 2021
Accepted: 07 December 2021

Abstract

The main aim of this study is to analyze and compare the scientific productivity of major countries. The related data are collected from Scopus through the open-access portal www.scimagojr.com. Data has been collected on the number of documents and their rank for the top countries. Bibliometric indicators such as Compound Annual Growth Rate (CAGR) and Activity Index (AI) have been used along with a simple percentage. Further, Pearson correlation has been used to compare the rankings. Twenty-four countries have at least 1% of global scientific output in 2018, and all these top countries also ranked in Nature Index 2019 except Indonesia and Malaysia. The top two countries, the United States and China, produced more than 600,000 documents in 2018, with others following distantly. The majority of the top countries are grouped under upper-middle and high income. Fifty percent of the top countries are from Europe. Tremendous improvement in terms of global rank from 1998 to 2018 has been observed for Iran, Indonesia, and Malaysia. All the top countries focus on different disciplines.

Keywords: Bibliometrics, Scientometrics, Scientific Output, Publication Share, Activity Index.

Introduction

Countries show their power in the natural resources and the scientific output, which is the benchmark for measuring the quality and quantity of research carried out. Research funding plays an important role in scientific publishing (Wang, Liu, Ding & Wang, 2012), and a country's scientific performance is based upon that country's policy on research funding and thrust areas. McAllister & Wagner (1981) found a strong relationship between R&D expenditures and the number of papers. According to World Bank data, only two countries (Israel and Korea) spent more than 4% of GDP on research and development in 2018 (OECD, 2020). South Korea is ranked ninth among these two countries, and Israel ranked sixteenth in the Nature Index of 2019 (Nature Index, 2019).

Similarly, South Korea was ranked ninth in science and engineering articles in 2018. Further, only India and Iran achieved more than 10% annual growth in 2018 over 2008 in science and engineering articles (White, 2019). The income level of the countries also has a major role in scientific productivity. For example, high-income countries contributed more than 50% of world science and engineering articles in 2018 (ibid). A country's scientific status needs to be assessed, which is important for the governments and relevant stakeholders to understand scientific priorities and funding (King, 2004).

With this background, this study tries to make a quantitative analysis and compare the scientific productivity among the top countries in detail from various aspects such as the number of documents produced and their rank, global publication share in various disciplines, the growth rate of publications, and activity profile. The following questions were the focus of this research:

1. What are the most prolific countries?
2. What are the publication share and growth of the prolific countries?
3. Is there any correlation between the publications/documents rank and the ranks of Nature Index or GDP or population?
4. Has the country's subject/discipline priority shifted in any way?

Literature Review

Only a few studies have been undertaken to explore the national performances in global scientific research: May (1997) compared the scientific outputs of countries from a range of perspectives. He discovered that the top 15 countries accounted for over 82% of papers published worldwide in science, engineering, and medicine. The top seven countries, in particular, belonged to the G7 group. Rousseau and Rousseau (1998) assessed the efficiency and effectiveness of the R&D effort of European countries. They used GDP, active population, and R&D expenditure as inputs and publications and patents as outputs. According to them, investing more money into science would increase the number of papers. To measure the quantity and quality of science in different countries, King (2004) analyzed the published research papers and reviews and their citations based on the data from the Thomson ISI (now Clarivate) for the ten years, 1993-2002. According to him, the group of 31 countries accounted for more than 98% of the world's highly cited papers. Gaillard (2010) attempted to measure the research and development in developing countries using available R&D statistics, focusing on trends and concentrations, the relative share of Highly Qualified Skills abroad, R&D expenditure, the impact factor, and the relative importance of international collaboration. Gonzalez-Brambila, Reyes-Gonzalez, Veloso & Perez-Angón (2016) analyzed the scientific productivity of nine developing nations, and the findings reveal that these countries are closing the gap in science, with R&D investments and scientific impact expanding at more than double the rate that of the developed world. Chasapi, Promponas & Ouzounis (2020) attempted to quantify bioinformatics publication output among countries using the number of publications and citations and the h-index obtained from the Web of Science. They discovered that wealthy countries produce most of the field's output. In a recent study, Elango, Oh and Rajendran (2021) performed a quantitative analysis and compared the scientific productivity between India and Korea, focusing on the ranking, the number of publications and its global share, the growth of publications, international collaboration pattern, publication quality, and open-access pattern. They found that from 1998 to 2018, the rankings of these two countries have improved and maintained an annual growth rate of 10% during the period 1998-2018.

Materials and Methods

This study used the Scopus database because it includes more journals and articles than Web of Science (Falagas, Pitsouni, Malietzis & Pappas 2008). The SCImago Journal & Country

Rank is an open-access portal that offers publication indicators on the journals and countries derived from the Scopus database. The indicators retrieved from this database can assess and analyze the research results. Nowadays, the SCImago database is also being used to analyze scientific productivity (Medina 2015; Zacca-González, Chinchilla-Rodríguez, Vargas-Quesada & de Moya-Anegón, 2015; Chinchilla-Rodrıguez, Arencibia-Jorge, de Moya-Anegón & Corera-Álvarez, 2015; Daneshmand, Forouzandeh, Azadi & Cheraghzadeh Dezfuli, 2015; Elango 2019a).

SJR database[1] is used to collect the publication data, and all the document types and sources are considered for this study. Countries having at least 1% of global publication shares in 2018 are taken for this study. Out of 224 countries that published at least one paper in 2018, the top 24 countries (10%) were produced more than 30000 publications: this reflects the Shockley model of productivity (Shockley, 1957), in which a small number of countries produce the most. We have taken 2018 as a base year because about 5% of the rise has been observed in global science and engineering research output in the year 2018 (Makri 2018). Publication performances of top countries have been compared in ten years, i.e., 1998, 2008, and 2018 (Siddiqi, Stoppani, Anadon & Narayanamurti, 2016; Hinrichs, Debus & Grundmann, 2019). Data on the number of documents and rank was imported into MS-Excel for further analyses. The database was accessed during June 2020 (http://www.scimagojr.com).

In order to analyze and compare the scientific productivity of top countries, the following indicators were used.

Compound Annual Growth Rate

Compound Annual Growth Rate (CAGR) is used to measure growth over a period of time, and it is obtained with the following formula (Elango, 2019b):

$$CAGR = \left(\frac{Ending\ Value}{Beginning\ Value}\right)^{\frac{1}{n-1}} - 1$$

Where, n = number of years, calculated value has been multiplied by 100.

Activity Index

Activity Index (AI) characterizes a country's relative research effort devoted to a given discipline. Originally, it was suggested by Frame (1977) and elaborated by various researchers (Schubert & Braun 1986).

$$AI = \frac{I_i/I_o}{W_i/W_o}$$

Where,

I_i = country’s output in a discipline

I_o = country’s total output

W_i = world output in a discipline

W_o = world total output

Now, it is being used in a variety of formats. For example, Relative Activity Index (Nishy, Salini, Mini & Vishnumaya, 2014), Thematic Specialization Index (Zacca-González et al. 2014), Publication Activity Index (Moed, 2006), Transformative Activity Index (Guan and Ma, 2004), Research Priority Index (Sangam, Arali, Patil & Megeri, 2013).

In this study, the Activity Index of a country is calculated as:

$$AI = \frac{World\ share\ of\ a\ Country\ in\ a\ discipline}{World\ share\ of\ a\ Country\ in\ all\ disciplines}$$

AI = 1 indicates that a country's research effort in a specific discipline is equal to the world average; AI > 1 indicates it is greater than the average; and AI < 1 indicates lower than the average.

Further, Pearson correlation has been used to compare the rankings of the number of documents with that of Nature Index, Population and GDP of top 24 countries.

Results

Ranking of Publication of Top Countries

Global ranking and the number of documents of the top 24 countries in 2018 are shown in Table 1. Only eleven countries out of the top twenty-four countries have publication numbers of more than 100,000 in 2018, and there is a shortage of below 2,000 documents for Spain. In particular, the top three countries, the United States, China, and United Kingdom, have more than 200,000 publications in the year 2018, while Germany and India follow with nearly 200,000. On the other hand, other countries follow distantly with below 200,000 documents. In terms of the number of documents, the top 24 countries can be classified into three categories: high productivity with more than 500,000 documents (the United States and China), medium productivity with documents between 100,000 and 500,000 (nine countries), and low productivity with documents of less than 100,000 (thirteen countries). These top 24 countries may be called scientifically wealthier nations in the world.

Table 1
Global rank and documents of top countries in 2018 comparing population and GDP

Country	No. of Documents (2018)	Documents Rank (2018)	Nature Index Rank (2019)	Population Rank (2018)	GDP Rank (2018)	Classification by income	Region
United States	699,393	1	1	3	1	HI	North America
China	605,616	2	2	1	2	UMI	Asia
United Kingdom	216,528	3	4	21	6	HI	Europe
Germany	184,756	4	3	17	4	HI	Europe
India	179,049	5	15	2	7	LMI	Asia
Japan	135,548	6	5	11	3	HI	Asia
France	124,315	7	6	22	6	HI	Europe
Italy	123,042	8	11	23	8	HI	Europe
Canada	113,652	9	7	39	10	HI	North America
Australia	106,637	10	9	55	13	HI	Australia
Russia	103,781	11	16	9	11	UMI	Europe
Spain	98,110	12	10	30	14	HI	Europe
South Korea	86,834	13	13	28	12	HI	Asia
Brazil	83,839	14	22	6	9	UMI	South America

Country	No. of Documents (2018)	Documents Rank (2018)	Nature Index Rank (2019)	Population Rank (2018)	GDP Rank (2018)	Classification by income	Region
Netherlands	64,016	15	12	68	17	HI	Europe
Iran	59,911	16	38	19	27	UMI	Asia
Poland	51,181	17	24	38	21	HI	Europe
Switzerland	49,448	18	8	100	20	HI	Europe
Turkey	45,691	19	36	18	19	UMI	Europe
Sweden	44,178	20	14	91	22	HI	Europe
Taiwan	36,814	21	23	56	21	HI	Asia
Belgium	35,858	22	19	79	23	HI	Europe
Indonesia	34,496	23	66	4	16	LMI	Asia
Malaysia	34,227	24	50	44	36	UMI	Asia

Nature Index: https://www.natureindex.com/annual-tables/2019/country/all (2019 ranking is based on the publications in the 82 high-quality science journals from 1 January 2018 to 31 December 2018)

Statistics on population: https://en.wikipedia.org/wiki/List_of_countries_by_population_(United_Nations)

GDP: https://databank.worldbank.org

Classification of the country (as of July 2018): www.worldbank.org (HI – High Income, UMI – Upper Middle Income, LMI – Lower Middle Income)

Note: Since Taiwan is not ranked in GDP by World Bank, the related rank has been taken from that country's GDP information (https://countryeconomy.com/gdp). For Nature Index ranking, the related rank positions of the 24 countries have been taken from the actual publication count.

Pearson correlation analysis has been employed to compare the number of documents, Nature Index, Population, and GDP. Because ranking the countries/institutions helps to identify countries/institutions that have performed well in quantity/quality (Jazayeri, Alavi & Rahimi-Movaghar, 2012). This analysis has been done with SPSS Version 28 and provided in Table 2, which shows that the document ranking is very strongly associated with GDP rank (.894 at 0.01 level), and with Nature Index ranks (.770 at 0.01 level); and is strongly associated with the population ranks (.546 at 0.01 level). Interestingly, Nature Index rank has even no significant correlation with Population rank. In addition, GDP has strong correlations with Nature Index ranks (.664) and population ranks (.572), respectively, at 0.01 levels. According to Kozak (2009), the correlation value between 0.50 and 0.70 is strong, and more than 0.70 is very strong. Similarly, Lin, Hu & Hou (2018) found that a country's GDP is significantly correlated with its scientific output.

Table 2
Correlation matrix of rankings

Variables	Documents Rank 2018	Nature Index Rank 2019	Population Rank 2018	GDP Rank 2018
Documents Rank 2018	1			
Nature Index Rank 2019	.770**	1		
Population Rank 2018	.546**	-.074	1	
GDP Rank 2018	.892**	.664**	.572**	1
** Significant at 0.01 and		* 0.05 levels of Pearson correlation.		

The top 8 countries in terms of the number of documents also ranked among the top eight in GDP, and the remaining countries have little fluctuations among the ranks. Interestingly, Brazil is not included in the top 10 countries of documents but ranked ninth in GDP. Among the top 24 countries in terms of the number of documents, only two countries were grouped under lower middle income, while others were under upper middle income (n = 6) and high income (n = 16). It clearly shows that a country's income level has played an important role in scientific activity. It also evidences that there is no considerable research productivity in low-income countries. Twelve countries (50%) are from Europe, one-third of the countries (33.3%) are from Asia, two countries (the United States and Canada) are from North America, and two from others (Brazil from South America and Australia).

Global Publication Share and Rank of Top Countries

Table 3 shows the global publication share and rank changes of top countries in ten-year intervals, from 1998 to 2008, and 2018. The United States is the leader in the world in terms of the number of documents. However, there was a decline in the global publication share from 1998 to 2018. Following the United States, the United Kingdom, Germany, and Italy also maintain their ranks at 3, 4, and 8, respectively, in the reference periods analyzed. In terms of global publication share, there was a decline for the United Kingdom and Germany, while almost a ten percent increase for Italy. Among the top 24 countries, nine countries (China, India, Australia, South Korea, Brazil, Iran, Turkey, Indonesia, and Malaysia) improved their ranks from 1998 to 2018 as well as their global publication shares have also been increased. It can be noted that there is a tremendous improvement in terms of global rank from 1998 to 2018 for Iran (from 51 to 16), Indonesia (from 63 to 23), and Malaysia (from 49 to 24). There was a slip in the global publication rank for some countries such as Japan, France, Canada, Russia, Spain, Netherlands, Sweden, and Belgium.

Table 3

Global publication shares and related ranks of top countries

Country	Global Publication Share			Global Rank		
	1998	2008	2018	1998	2008	2018
United States	29.04	24.31	21.92	1	1	1
China	3.46	11.73	18.98	6	2	2
United Kingdom	8.01	7.01	6.79	3	3	3
Germany	7.00	6.19	5.79	4	4	4
India	1.88	2.72	5.61	13	10	5
Japan	7.92	5.53	4.25	2	5	6
France	5.00	4.38	3.90	5	6	7
Italy	3.36	3.54	3.86	8	8	8
Canada	3.47	3.69	3.56	7	7	9
Australia	2.26	2.64	3.34	11	11	10
Russia	2.82	1.7	3.25	9	15	11
Spain	2.3	2.81	3.08	10	9	12
South Korea	1.16	2.31	2.72	16	12	13
Brazil	1.04	1.92	2.63	19	14	14
Netherlands	2	1.97	2.01	12	13	15
Iran	0.1	0.91	1.88	51	22	16
Poland	1.07	1.33	1.6	17	18	17
Switzerland	1.39	1.43	1.55	15	17	18
Turkey	0.55	1.19	1.43	26	20	19
Sweden	1.55	1.22	1.38	14	19	20
Taiwan	1.01	1.57	1.15	20	16	21
Belgium	1.07	1.08	1.13	18	21	22
Indonesia	0.05	0.07	1.08	63	64	23
Malaysia	0.1	0.36	1.07	49	41	24

Publication Growth

The growth of scientific production has been calculated and provided in Table 4: there is no common pattern among the top countries. Out of 24 countries, only six countries (China, India, Iran, Turkey, Indonesia, and Malaysia) achieved more than 10% growth from 1998 to 2018. Among the top countries, India maintained the 10% growth in both ten-year periods; India, Russia, Sweden, and Indonesia have higher growths in recent ten-year periods from 1998-2008 to 2008-2018, while there is a dip in growth for other countries.

Table 4

Publication growth of top countries

Country	CAGR (in %)			Change in CAGR from I to II
	1998-2008 I	2008-2018 II	1998-2018 III	
United States	4.25	2.39	3.31	-
China	19.96	8.60	14.14	-
United Kingdom	4.97	3.04	4.00	-
Germany	4.83	2.75	3.78	-
India	10.13	10.96	10.55	+
Japan	2.36	0.62	1.49	-
France	4.71	2.20	3.44	-
Italy	6.67	4.27	5.46	-
Canada	6.76	3.16	4.95	-
Australia	7.90	6.17	7.03	-
Russia	0.88	10.23	5.45	+
Spain	8.26	4.46	6.34	-

Country	CAGR (in %)			Change in CAGR from I to II
	1998-2008 I	2008-2018 II	1998-2018 III	
South Korea	13.75	5.23	9.41	-
Brazil	12.82	6.73	9.74	-
Netherlands	5.98	3.74	4.86	-
Iran	32.23	11.66	21.51	-
Poland	8.46	5.30	6.87	-
Switzerland	6.36	4.29	5.32	-
Turkey	14.64	5.56	10.01	-
Sweden	3.59	4.98	4.28	+
Taiwan	11.01	0.44	5.59	-
Belgium	6.28	3.83	5.05	-
Indonesia	9.89	35.36	21.96	+
Malaysia	20.61	15.21	17.88	-

Global publication share of top countries in various disciplines

According to supplementary Table S1, there is no common pattern in the publication activity in various disciplines among the top countries, and there is a decreasing trend in the global publication share in all the disciplines from 1998 to 2018 for the United States, whereas an increasing trend for China, Italy, South Korea, Brazil, Iran, Poland, Turkey, Indonesia, and Malaysia. A moderate increase has been observed in a few disciplines (ex. neuroscience, psychology) for the United Kingdom while decreasing and fluctuating trends in other disciplines. Germany has a considerable increase in social science disciplines and dentistry and multidisciplinary. In the case of India, there is an increasing trend in all the disciplines except veterinary science, which shows a slight decrease. In the case of Japan, there is an increasing trend in the social sciences and nursing while a declining trend in other disciplines.

Similarly, France and the Netherlands have experienced growth in the global share in social sciences, nursing, and dentistry for France, neuroscience, earth, and energy for the Netherlands. Canada shows an increasing trend in health sciences, neuroscience, business, and social science. Australia has experienced strong growth in all the disciplines from 1998 to 2018, with some fluctuation in dentistry, veterinary science, agricultural, arts & science, decision science, and energy. In the case of Russia, there is a fluctuating trend in all the disciplines except dentistry, energy, and psychology. In the case of Spain, there is a mixed pattern: for example, there is strong growth in almost two-thirds of disciplines covering all the four broad domains. However, Switzerland is losing its global publication shares in the life sciences. Sweden has more shares in the social sciences. Taiwan shows a fluctuating trend in all disciplines except dentistry. Belgium has experienced strong growth in physical sciences and social sciences.

To interpret the global publication share of top countries, symbol coding has been used (see Table 5): ← means there is a decrease in global publication share from 1998 to 2018; → means there is an increase in global publication share from 1998 to 2018; ~ means there is a fluctuation from 1998 to 2018.

Table 5
Matrix of global publication share

Country	AAH	ABS	BGM	BMA	CHE	CHM	CSC	DEN	DES	EEF	ENE	ENG	ENV	EPS	HEP	IAM	MAT	MED	MTH	MUL	NEU	NUR	PHA	PSY	PTP	SOS	VET
United States	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	~	↑	↑	↑	~	↑	↑	↑	↑	↑
China	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
United Kingdom	~	↑	↑	~	↑	↑	↑	↑	↑	~	~	↑	↑	↑	↑	↑	↑	↑	↑	↓	↓	~	↑	↓	↑	↑	↑
Germany	↑	↑	↑	↓	↑	↑	↑	↓	↑	↓	↑	↑	↑	↑	~	↑	↑	↑	↑	↓	↓	↓	↑	↓	↑	↓	↑
India	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↑
Japan	↑	↑	↑	↓	↑	↑	↑	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↓	↑	~	↑	↑	↑	↓	↑
France	↓	↑	↑	↓	↑	↑	↑	↓	↑	↓	↑	↑	↑	↑	~	↑	↑	↑	↑	↓	↑	↓	↑	↓	↑	↓	↑
Italy	↑	↓	↓	↑	↓	↑	↓	↓	↑	↑	↑	↑	↑	↑	↓	↓	↑	↓	↑	↑	↓	↓	↑	↑	↑	↑	↓
Canada	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	~	↑	↓	↑	↑	↓	~	↓	↓	↓	~	↑	↑	↓	↑
Australia	~	~	↓	↓	↓	↓	↓	~	~	~	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	~
Russia	~	~	~	~	~	~	~	↓	~	↓	~	~	~	~	~	~	~	~	~	~	~	↓	~	↓	~	~	~
Spain	↓	~	~	↓	~	↑	~	~	~	↓	↓	~	↓	↓	↓	~	~	↓	~	↓	↓	↓	~	↓	↑	↓	↓
South Korea	↓	↓	↓	↓	↓	↓	~	↓	~	↓	↓	~	↓	↓	↓	~	↓	↓	~	↓	↓	↓	~	↓	↓	↓	↓
Brazil	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Netherlands	↓	↑	↑	↓	↑	↑	↑	~	↑	↑	↓	↑	↑	↓	~	↑	↑	↓	↑	↓	↑	↓	↑	↓	~	↓	↑
Iran	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↑	↓	↓	↓	↓	↓	↓	↓
Poland	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	~
Switzerland	↓	↓	~	↓	~	~	~	↓	↓	↓	~	~	↓	↓	↓	~	↓	↓	↓	↓	↓	↓	↓	↓	~	↓	~
Turkey	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	~	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	~
Sweden	~	↓	↑	↓	↓	↓	~	~	↑	↓	~	~	~	↓	~	↑	~	~	~	↓	~	↓	~	↓	↑	↓	↓
Taiwan	~	~	~	~	~	~	~	↓	↑	~	~	~	~	↓	~	~	~	~	~	↓	~	~	~	~	~	~	~
Belgium	↓	↓	↑	↓	~	↑	↑	↓	↑	↓	~	~	~	~	↓	↓	~	↓	~	↓	↓	↓	~	↓	↑	↓	↑
Indonesia	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	~	↓	↓	↓	↓	↓	↓	~	↓	↓	↓	↓	~
Malaysia	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

Table 6 provides the information about the disciplines with the highest global publication share in ten-year intervals (1998, 2008, and 2018) for the top 24 countries: only three countries show their unique strengths in a specific discipline, namely the United States in psychology, Russia in physics & astronomy, and Turkey in dentistry. This result is consistent with earlier studies. For example, the United States was the top contributor in the field of psychology with almost 60% of total publications (Guilera, Barrios & Gómez-Benito, 2013), more than 16% of Russian publications were published in the field of physics and astronomy in the year 2016 (Moed, Markusova & Akoev, 2018), and Turkey was one of the ten most productive countries in the global dental publications (Yahya Asiri, Kruger & Tennant, 2020).

Some countries show changes in their comparative strengths with others from one discipline to another (see Table 6), such as China from engineering to material science, the United Kingdom from arts & humanities to psychology, Germany from physics & astronomy to neuroscience, India from veterinary to computer science, Japan from chemistry to physics and astronomy, France from physics & astronomy to earth & planetary sciences, Australia from agriculture to health professionals, Brazil from veterinary to dentistry, the Netherlands from immunology & microbiology to psychology, Iran from veterinary to dentistry, Sweden from dentistry to multidisciplinary, and Belgium from veterinary to psychology. On the other hand, some countries focused on the three different disciplines in those three years: South Korea (physics & astronomy, material science, chemical engineering), Poland (chemistry, veterinary and earth & planetary sciences), Indonesia (agriculture, dentistry, and earth & planetary sciences) and Malaysia (agriculture, multidisciplinary and business).

Table 6
Disciplines with the highest global publication share

Country	Discipline		
	1998	2008	2018
United States	PSY	PSY	PSY
China	ENE	ENG	MAT
United Kingdom	AAH	PSY	PSY
Germany	PHA	NEU	NEU
India	VET	VET	CSE
Japan	CHM	PHA	PHA
France	PHA	PHA	EPS
Italy	NEU	EPS	NEU
Canada	PSY	NEU	PSY
Australia	ABS	HEP	HEP
Russia	PHA	PHA	PHA
Spain	CHM	ABS	AAH
South Korea	PHA	MAT	CHE
Brazil	VET	DEN	DEN
Netherlands	IAM	PSY	PSY
Iran	VET	VET	DEN
Poland	CHM	VET	EPS
Switzerland	IAM	NEU	MUL
Turkey	DEN	DEN	DEN
Sweden	DEN	DEN	MUL

Country	Discipline		
	1998	2008	2018
Taiwan	DES	CSC	DES
Belgium	VET	VET	PSY
Indonesia	ABS	DEN	EPS
Malaysia	ABS	MUL	BMA

Activity profile of top countries in various disciplines

Activity index (AI) is computed and provided in supplementary Table S2. To interpret the pattern of publication activity of top countries, symbol coding has been used (see Table 7): ← means there is a decrease in AI from 1998 to 2018; → means there is an increase in AI from 1998 to 2018; ~ means there is a fluctuation from 1998 to 2018. ↑ means the relative research effort is higher than the world average in all those three years; ↓ means the relative research effort is lower than the world average in all those three years.

Table 7

Matrix of Activity Index

Country	AAH	ABS	BGM	BMA	CHE	CHM	CSC	DEN	DES	EEF	ENE	ENG	ENV	EPS	HEP	IAM	MAT	MED	MTH	MUL	NEU	NUR	PHA	PSY	PTP	SOS	VET
United States	~	←	↑	←	↓	↓	←	↓	←	↑	↓	↓	~	↑	↑	↑	↓	→	←	↑	↑	↑	↓	↑	~	↑	↓
China	↓	→	→	↓	↑	↑	↑	↓	→	↓	↑	↑	→	↑	↓	→	↑	↓	↑	←	↓	↓	↑	↓	→	↓	↓
United Kingdom	↑	←	↑	↑	↓	↓	↓	↑	~	↑	↓	↓	←	↑	↑	↑	↓	↑	↓	→	↑	↑	↓	↑	←	↑	↑
Germany	↓	↓	↑	↓	←	↑	↓	↓	↓	→	↓	↓	↓	↑	↓	↑	←	→	↑	→	↑	↓	↑	→	↓	↓	↓
India	↓	←	~	↓	↑	↑	→	→	→	↓	↑	→	↑	←	↓	~	↑	↓	→	←	↓	↓	↑	↓	↑	↓	↑
Japan	↓	↓	↑	↓	↑	↑	↓	↑	↓	↓	←	↑	↓	↓	↓	↑	↑	~	↓	→	↑	↓	↑	↓	↑	↓	↓
France	↓	↑	↑	↓	←	←	~	↓	~	↓	↓	↓	↓	↑	↓	↑	↑	→	↑	↓	↑	→	↑	↓	←	↓	↓
Italy	↓	↓	↑	↓	↓	←	↓	→	~	→	↓	↓	↓	↑	↓	↑	↓	↑	↑	↓	↑	↓	↑	→	↑	↓	↓
Canada	←	↑	↑	↓	←	↓	←	↓	←	←	←	↓	↑	↑	↑	↑	↓	→	←	↓	↑	→	↓	↑	↓	↑	↑
Australia	↑	↑	↑	↑	↓	↓	↓	↓	←	↑	↓	↓	↑	↑	↑	↑	↓	→	↓	→	↑	↑	↓	↑	↓	↑	~
Russia	↓	↓	↓	↓	↑	↑	↓	↓	↓	↓	↑	↑	↓	↑	↓	↓	↑	↓	↑	↓	↓	↓	↑	↓	↓	↓	↓
Spain	→	↑	↑	→	←	↑	↓	↓	←	→	↓	↓	↑	↑	↓	↑	↓	↑	←	→	→	→	←	→	←	→	↓
South Korea	↓	↓	↑	↓	↑	↑	↑	→	←	↓	↑	↑	↓	↓	→	↑	↑	→	↑	→	↓	→	↑	↓	↑	↓	↓
Brazil	↓	↑	~	↓	↓	←	↓	↑	↓	↓	←	↓	→	←	→	↑	↓	→	←	~	↑	→	←	↓	↑	→	√
Netherlands	→	←	↑	→	↓	↓	↓	←	←	↑	↓	↓	↑	↑	↑	↑	↓	↑	↓	→	↑	→	↓	↑	←	→	←
Iran	↓	↑	→	↓	↑	↑	←	→	←	↓	↑	↑	↑	↓	↓	→	↑	→	↑	~	↓	↓	↑	↓	↑	↓	↑
Poland	↓	↑	→	↓	↑	↑	↓	↓	↓	↓	→	→	↑	↑	↓	↓	↑	↓	↑	↓	↓	↓	↑	↓	~	↓	↑
Switzerland	↓	~	↑	↓	←	←	↓	→	↓	→	↓	↓	→	↑	→	↑	↓	↑	↓	↑	↑	↓	↑	→	↑	↓	↑
Turkey	↓	↑	↓	↓	←	↑	↓	↑	←	↓	←	↓	←	↓	→	↓	↓	↑	→	↓	~	↓	↓	↓	←	↓	↑
Sweden	↓	↑	↑	→	↓	↓	↓	↑	~	~	↓	↓	↑	→	↑	↑	↓	↑	↓	→	↑	→	~	→	←	→	↓
Taiwan	↓	↓	↓	→	↑	↑	↑	↓	↑	→	~	~	↓	↓	↓	↓	↑	↓	↑	→	↓	↓	↑	↓	↓	↓	↓
Belgium	→	↑	↑	↓	↓	↓	↓	→	←	↑	↓	↓	→	↓	↑	↑	↓	↑	←	→	↑	↓	←	→	↑	→	↑

Table 8 shows which countries' disciplines have more than or equal the world average of AI in all those three years: there is no common pattern. Of 27 broad disciplines, the United Kingdom and Australia have achieved more than the world average in 13 disciplines, followed by South Korea and Iran in 11 disciplines, and the United States, Japan, and Canada in 10 disciplines. On the other hand, Turkey has achieved more than the world average in 4 disciplines. Fourteen countries out of 24 countries have achieved more than the world average in chemistry and chemical engineering, followed by immunology and microbiology, physics and astronomy by 13 countries. It can be noted that only four countries (China, South Korea, Taiwan, and Malaysia) have achieved more than the world average in computer science.

Table 8
Disciplines with AI ≥ world average

Country	Disciplines
United States (10)	BGM, EEF, EPS, HEP, IAM, NEU, NUR, MUL, PSY, SOS
China (9)	CHE, CHM, CSC, EPS, ENE, ENG, MAT, MTH, PHA
United Kingdom (13)	AAH, BGM, DEN, EEF, EPS, HEP, IAM, MED, NEU, NUR, PSY, SOS, VET
Germany (7)	BGM, IAM, NEU, CHM, EPS, MTH, PHA
India (7)	CHE, CHM, ENE, ENV, PHA, PTP, VET
Japan (10)	BGM, CHE, CHM, DEN, ENG, IAM, MAT, NEU, PTP, PHA
France (8)	ABS, BGM, EPS, IAM, NEU, MAT, MTH, PHA
Italy (8)	BGM, EPS, IAM, MED, MTH, NEU, PTP, PHA
Canada (10)	ABS, BGM, EPS, ENV, HEP, IAM, NEU, PSY, SOS, VET
Australia (13)	AAH, ABS, BGM, BMA, EEF, EPS, ENV, HEP, IAM, NEU, NUR, PSY, SOS
Russia (8)	CHE, CHM, EPS, ENE, ENG, MAT, MTH, PHA
Spain (7)	ABS, BGM, CHM, EPS, ENV, IAM, MED
South Korea (11)	BGM, CHE, CHM, CSC, ENE, ENG, IAM, MAT, MTH, PHA, PTP
Brazil (6)	ABS, DEN, IAM, NEU, PTP, VET
Netherlands (8)	BGM, ENV, EEF, HEP, IAM, MED, NEU, PSY
Iran (11)	ABS, CHE, CHM, ENE, ENG, ENV, MAT, MTH, PHA, PTP, VET
Poland (9)	ABS, CHE, CHM, EPS, ENV, MAT, MTH, PHA, VET
Switzerland (9)	BGM, EPS, IAM, MED, MUL, NEU, PTP, PHA, VET
Turkey (4)	CHM, DEN, MED, VET
Sweden (8)	ABS, BGM, DEN, ENV, HEP, IAM, MED, NEU
Taiwan (7)	CHE, CHM, CSC, DES, MAT, MTH, PHA
Belgium (9)	ABS, BGM, EEF, HEP, IAM, MED, NEU, PTP, VET
Indonesia (9)	ABS, DES, EEF, EPS, ENE, ENV, PHA, SOS, VET
Malaysia (9)	ABS, CHE, CHM, CSC, EEF, ENE, ENV, MAT, MUL

Discussion

There are 24 countries that have published at least 1% of global publications in the year 2018, and most of the countries are also ranked in the Nature Index in 2018. It clearly denotes that as the number of scientific works increases, the quality of publications also increases. Earlier, the results of Sandström and van den Besselaar (2016) showed that there was a strong correlation between more papers and more high-impact papers. The majority of the top countries are classified under upper-middle and high-income groups. This means that a country’s income level can have a significant impact on scientific production. This finding is in line with that of Jaffe (2014), who discovered that a country’s scientific productivity is more closely related to its gross national income per capita. At the geographical level, half of the top countries are from Europe, while Asian and European countries have equal contributions in terms of global publication share. Similar kind of findings has been found in other various subjects including auditing (Buele & Guzman, 2021). A tremendous improvement has been observed in the global ranks for three countries (Iran, Indonesia, and Malaysia) from 1998 to 2018. Similar trends have been observed by various researchers (Akhondzadeh, 2017; Rochmyaningsih, 2019; Lewison, Kumar, Wong, Roe & Webber, 2016). Of the top 24 countries, only four countries (India, Russia, Sweden, and Indonesia) have achieved higher growth in the recent ten-year period than the previous one. Analysis of the highest global publication share by countries reveals that all the top 24 countries have comparative strengths in different disciplines respectively. However, analysis on the activity index shows that in some disciplines only a few countries have comparative strengths. For example, 14 countries out of 24 countries have achieved more than the world average in the subjects of Biochemistry, Genetics, and Molecular Biology, and 13 countries have achieved in Immunology and Microbiology.

This study has some limitations. First, the growth rate was determined using the Compound Annual Growth Rate, which takes only the initial and final values into account. Second, publications are being classified into several subject disciplines through journals in the Scopus database. As a result, the sum of the share of documents in various disciplines is not equal to the total number of documents produced by the countries.

Conclusion

In this study, a comparison of research (scientific) productivity of top countries has been conducted based on the data collected from Scopus through the open-access portal SCImago which yields interesting facts. The results of this study can be used to plan the national policy to support the research and/or research funds in each country because it shows the disciplines and research areas of the nation which has comparative strength or weakness.

Each country can also find good candidate partners to cooperate with each other at the national level to make international cooperative projects or programs to complement or support each other for mutual benefits. In this regard, the future study can focus both on some specific subject areas and on any specific country or country to support those kinds of cooperative and collaborative programs and to assist related policy development in any country. This kind of study can be used as basic and essential data for those who work in the related areas, because most countries have tried to encourage and support research productivity which is one of the critical key factors for national competitiveness, regardless of their economic levels.

References

Akhondzadeh S. (2017). Research in Iran: An overview. *Avicenna Journal of Medical Biotechnology*, 9(2), 1.

Buele, I. & Guzman, A. V. (2021). Auditing: An analysis of scientific production in Scopus. *Open Science Journal*, 6(3), 1-10.

Chasapi, A., Promponas, V. J. & Ouzounis, C. A. (2020). The bioinformatics wealth of nations. *Bioinformatics*, 36(9), 2963-2965. https://doi.org/10.1093/bioinformatics/btaa132

Chinchilla-Rodrıguez, Z.C., Arencibia-Jorge, R., de Moya-Anegón, F. & Corera-Álvarez, E. (2015). Some patterns of Cuban scientific publication in Scopus: The current situation and challenges. *Scientometrics*, 103(3), 779-794. https://doi.org/10.1007/s11192-015-1568-8

Chinchilla-Rodríguez, Z., Zacca-González, G., Vargas-Quesada, B., & Moya-Anegón, F. (2015). Latin American scientific output in Public Health: combined analysis using bibliometric, socioeconomic and health indicators. *Scientometrics*, 102(1), 609-628. https://doi.org/10.1007/s11192-014-1349-9

Daneshmand, A.R., Forouzandeh, H., Azadi, M & Cheraghzadeh Dezfuli, S. (2015). A bibliometric analysis of hematological research productivity among five Islamic countries during 1996 to 2013 (a 17-years period). *Iranian Journal Of Blood And Cancer*, 7(2), 67-74. Retrieved from https://ijbc.ir/article-1-585-fa.pdf

Elango, B. (2019a). A bibliometric analysis of literature on engineering research among BRIC countries. *Collection and Curation*, 38(1), 9-14. https://doi.org/10.1108/CC-05-2017-0017

Elango, B. (2019b). Calculation errors in bibliometrics: the case of CAGR, *COLLNET Journal of Scientometrics and Information Management*, 13(2), 331-337. https://doi.org/10.1080/09737766.2019.1694397

Elango, B., Oh, D.G. & Rajendran, P. (2021). Assessment of scientific productivity by India and South Korea. *DESIDOC Journal of Library & Information Technology*, 41(3), 190-198. https://doi.org/10.14429/djlit.41.03.16558

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A. & Pappas, G. (2008). Comparison of PubMed, Scopus, web of science, and Google scholar: strengths and weaknesses, *The FASEB Journal*, 22(2), 338-342. https://doi.org/10.1096/fj.07-9492lsf

Frame, J.D. (1977). Mainstream research in Latin America and the Caribbean, *Interciencia*, 2(3), 143-148.

Gaillard, J. (2010). Measuring research and development in developing countries: main characteristics and implications for the Frascati manual. *Science, Technology and Society*, 15(1), 77-111. https://doi.org/10.1177/097172180901500104

Gonzalez-Brambila, C. N., Reyes-Gonzalez, L., Veloso, F. & Perez-Angón, M. A. (2016). The scientific impact of developing nations. *PLoS One*, 11(3), e0151328. https://doi.org/10.1371/journal.pone.0151328

Guan, J. & Ma, N. (2004). A comparative study of research performance in computer science. *Scientometrics*, 61(3), 339–359. https://doi.org/10.1023/B:SCIE.0000045114.85737.1b

Guilera, G., Barrios, M. & Gómez-Benito, J. (2013). Meta-analysis in psychology: A bibliometric study. *Scientometrics*, 94(3): 943-954. https://doi.org/10.1007/s11192-012-0761-2

Hinrichs, D. L., Debus, E. S. & Grundmann, R. T. (2019). Surgical publication activity in the English literature over a 10-year interval. *BJS Open*, 3(5), 696-703. https://doi.org/10.1002/bjs5.50172

Jazayeri, S. B., Alavi, A. & Rahimi-Movaghar, V. (2012). Situation of medical sciences in 50 top countries from 1996 to 2010-based on quality and quantity of publications. *Acta Medica Iranica*, 50(4), 273-278. Retrieved from https://acta.tums.ac.ir/index.php/acta/article/view/3896/3871

Jaffe, K. (2014). The Relevance of Science in Development: Scientific Development Favors Economic Prosperity, but Not Necessarily through its Effect on Technological Knowledge in Middle Income Countries. In Economic Behavior, Game Theory, and Technology in Emerging Markets (pp. 1-17). IGI Global.

King, D. A. (2004). The scientific impact of nations. *Nature*, 430(6997): 311-316. Retrieved from http://personalpages.to.infn.it/~cassardo/pensieri/documenti/King-Impact-of%20-Nations_Nature_430.pdf

Kozak, M. (2009). What is strong correlation? *Teaching Statistics*, 31(3), 85-86. https://doi.org/10.1111/j.1467-9639.2009.00387.x

Lewison, G., Kumar, S., Wong, C. Y., Roe, P. & Webber, R. (2016). The contribution of ethnic groups to Malaysian scientific output, 1982–2014, and the effects of the new economic policy. *Scientometrics*, 109(3), 1877-1893. https://doi.org/10.1007/s11192-016-2139-3

Lin, G., Hu, Z., & Hou, H. (2018). Research preferences of the G20 countries: A bibliometrics and visualization analysis. *Current Science*, 115(8), 1477-1485. Retrieved from https://www.jstor.org/stable/26978439

Makri, A. (2018). Pakistan and Egypt had highest rises in research output in 2018. *Nature*. https://doi.org/10.1038/d41586-018-07841-9

May, R. M. (1997). The scientific wealth of nations. *Science*, 275(5301): 793-796. https://doi.org/10.1126/science.275.5301.793

McAllister, P. R. & Wagner, D. A. (1981). Relationship between R&D expenditures and publication output for US colleges and universities. *Research in Higher Education*, 15(1): 3-30. https://doi.org/10.1007/BF00976546

Medina, F. (2015). The output of researchers in Morocco compared to some North African countries from 1996 to 2012, and its relationship to governmental major decisions on higher education and scientific research, *Scientometrics*, 105(1), 367-384. https://doi.org/10.1007/s11192-015-1701-8

Moed, H. F. (2006). Bibliometric rankings of world universities, CWTS Report 2006-01. Leiden: Centre for Science and Technology Studies (CWTS). Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.152.5099&rep=rep1&type=pdf

Moed, H. F., Markusova, V. & Akoev, M. (2018). Trends in Russian research output indexed in Scopus and Web of Science. *Scientometrics*, 116(2): 1153-1180. https://doi.org/10.1007/s11192-018-2769-8

Nature Index (2019). 2019 tables: Countries/territories. Retrieved from https://www.natureindex.com/annual-tables/2019/country/all

Nishy, P., Salini, C. P., Mini, S. & Vishnumaya, R. S. (2014). A bibliometric evaluation of organic chemistry research in India. *Annals of Library & Information Studies*, 61(4), 332-342. Retrieved from file:///C:/Users/drghane/AppData/Local/Temp/A_bibliometric_evaluation_of_organic_che.pdf

OECD (2020). *Gross domestic spending on R&D*. Retrieved from https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm

Rochmyaningsih, D. (2019). *How to shine in Indonesian science? Game the system*. Retrieved from https://www.science.org/content/article/how-shine-indonesian-science-game-system.

Rousseau, S. & Rousseau, R. (1998). The scientific wealth of European nations: Taking effectiveness into account. *Scientometrics*, 42(1), 75-87. https://doi.org/10.1007/bf02465013

Sandström, U. & van den Besselaar, P. (2016). Quantity and/or quality? The importance of publishing many papers. PLoS One, 11(11), e0166149. https://doi.org/10.1371/journal.pone.0166149

Sangam, S. L., Arali, U., Patil, C. G. & Megeri, M. N. (2013). Scientometrics analysis of Genetics Literature. *COLLNET Journal of Scientometrics and Information Management*, 7(2),173-190. https://doi.org/10.1080/09737766.2013.832901

Schubert, A. & Braun, T. (1986). Relative indicators and relational charts for comparative assessment of publication output and citation impact. *Scientometrics*, 9(5-6), 281-291. https://doi.org/10.1007/BF02017249

Shockley, W. (1957). On the statistics of individual variations of productivity in research laboratories. *Proceedings of the IRE*, 45(3), 279-290. https://doi.org/10.1109/JRPROC.1957.278364

Siddiqi, A., Stoppani, J., Anadon, L. D. & Narayanamurti, V. (2016). Scientific wealth in Middle East and North Africa: Productivity, indigeneity, and specialty in 1981–2013. *PloS one*, 11(11), e0164500. https://doi.org/10.1371/journal.pone.0164500

Wang, X., Liu, D., Ding, K. & Wang, X. (2012). Science funding and research output: a study on 10 countries. S*cientometrics*, 91(2): 591-599. https://doi.org/10.1007/s11192-011-0576-6

White, K. (2019). Publications Output: US Trends and International Comparisons. Science & Engineering Indicators 2020. NSB-2020-6. *National Science Foundation*. Retrieved from https://ncses.nsf.gov/pubs/nsb20206/publication-output-by-region-country-or-economy

Yahya Asiri, F., Kruger, E. & Tennant, M. (2020). Global Dental Publications in PubMed Databases between 2009 and 2019: A Bibliometric Analysis. *Molecules*, 25(20), 4747. https://doi.org/10.3390/molecules25204747

Zacca-González, G., Chinchilla-Rodríguez, Z., Vargas-Quesada, B. & de Moya-Anegón, F. (2014). Bibliometric analysis of regional Latin America's scientific output in public health through SCImago journal & country rank. *BMC Public Health*, 14, 632. https://doi.org/10.1186/1471-2458-14-632