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RESEARCH ARTICLE

Evaluating the Effectiveness of Author-Count Based Metrics in Measuring Scientific Contributions

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ABSTRACT The assessment and evaluation of the academic influence of the researcher is a challenging task. This task allows the scientific community to make valuable decisions, such as identifying leading experts in a specific field, nominating candidates for scientific awards, awarding scholarships/grants, promoting researchers, and selecting tenure positions. Scientists have proposed various varied and multifaceted metrics to determine the most influential researchers. These metrics are the citation count, total number of publications, hybrid approaches, h-index, and variants of the h-index. Contemporary research in this domain shows that there is no universally accepted yardstick available for determining the finest parameter to recognize the most influential researcher within a particular domain. Moreover, to recognize the potential metric, some researchers have conducted evaluation surveys. In these evaluation surveys, the researchers utilized a limited number of indices on a small and imbalanced dataset as well as on fictional case scenarios, which makes it challenging to determine the significance and influence of each metric over the others. The present study computed fourteen distinct metrics based on the author-count. Our aim is to determine the potential metrics. For experimental purposes, we collected 1050 researchers' data from the mathematics domain. For the benchmark dataset, we have collected the awardee's data of the last three decades of four different societies of mathematics domain. To evaluate these metrics, we first computed the Spearman correlations among the obtained values of these metrics to assess their similarities and differences. The results showed a high degree of correlation among these metrics. However, some metrics represent weak correlations, signifying that their rankings are highly dissimilar to those of the other metrics. Furthermore, the position of award winners is checked in the top 10, 50, and 100 return records based on a ranked list of each metric. The potential value of each metric such as the hf metric, indicates that 60% of the awardees in the top 10% of the ranked list are associated with this, whereas the potential value of fractional g metric is linked with 49% of the awardees in the top 100% of the ranked list. In addition, it is further scrutinized that most of the award winners lie in a top position belonging to IMS, LMS, and AMS society return by fractional g-index, gf index, and gm index, which indicates that there is some relationship between these societies and metrics.

INDEX TERMS Author assessment parameters, AMS, H index, IMU, LMS, NASL, researcher ranking.

I. INTRODUCTION

Researchers' ranking has become a highly visible and influential issue in the scientific community. According to

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Jiang et al. [1], ranking can be useful for selecting highly successful scientists across various fields. It also provides valuable information for policymakers to make informed decisions about allocating research funding, tenured positions, promotions, and nominations for scientific awards [2]. A comprehensive ranking system will also assist conference organizers in selecting keynote speakers [3]. The implementation of a fair ranking system for professors could enable students to make informed decisions about choosing a supervisor for their research projects and peruse their doctoral studies [3], [4]. The ability to objectively and systematically evaluate researchers is essential for the advancement of scientific knowledge and the promotion of scientific excellence [5], [6]. Thus, there is a long literary history of researchers' rankings [7], [8] [9]. The scientific literature provides a plethora of parameters for assessing the value of scientists' contributions.

Numerous techniques have been developed to rank authors based on their educational abilities and scholarly achievements [10] within the scientific community. Raheel et al. [11], stated that each ranking technique employed to evaluate researchers follows its own criteria. For example, some approaches for ranking researchers involve several quantitative indicators, such as the number of publications, citations [12], [13] [14], [15], and co-authors [16], [17], as well as qualitative factors, such as peer review and expert evaluation [18], [19] [20]. These standards are used to evaluate the scholarly output and productivity of researchers and may include both qualitative and quantitative measures.

Subsequently, attention has shifted towards the development of indices and ranking systems aimed at assessing the influence and productivity of researchers [21]. The purpose of these indicators is to measure the quantity of research output and to quantify the quality of publications authored by researchers [22], [23]. However, it is widely acknowledged that these measures are limited in their ability to capture the full scope of a researcher's contributions [24], [25].

In 2005, Hirsch introduced a novel metric for gauging the significance of researchers, known as the h-index, which has since become one of the most popular and successful measures for scholars contribution [26]. He argues that the h-index serves as a reliable indicator of whether an author will win a prestigious honor, such as the Nobel Prize or membership in the National Academy. This statistic provides a quantitative assessment of the productivity and influence of a researcher's work, considering both the number of publications and citations received by the researcher. The scientific community has recognized several h-index limitations. Such as, h-index fails to consider the citations received by the top h-core publications when comparing two researchers that have the same h-index but different highly cited publications. To overcome this limitation g index [27] was proposed that resolves the issue by considering the citation of top h core publications of a researcher. Although the g index resolves the issue but it has further limitations that a small number of highly cited papers will result in a higher g-index compared to a larger number of moderately cited papers. To limit the weaknesses of h-index and g-index, a new index was proposed to measure researcher's significance called Hg index [28]. Several new metrics have been proposed such as, a-index [29] contemporary h-index [30] f-index [31] q2-index [32] and Hx -index [33] and DS-index [34] etc.

In a recent suvery, Bihari et al. [35] stated that, more than 80 metrics have been proposed for ranking researchers. They have classified these metrics into seven types based on the following attributes:

- The complement of the h-index
- Authors count-based parameters
- Parameters based on publication age
- Combinations of two or more indices
- Based on extra citation counts
- Based on total number of publications counts
- Several other variants.

The scientific community does not agree on the best method to rank researchers despite the plethora of available ranking parameters [11]. One of the causes is that each ranking parameter has its own benefits and drawbacks, making it challenging to determine the most accurate parameter.

Previous studies attempted to evaluate rankings using a specific index. Whenever a new technique is proposed, it is developed using hypothetical or imaginary scenarios, or based on several datasets. Furthermore, as these techniques rely on and are evaluated using various types of datasets, it is challenging to discern and comprehend the significance of each technique individually. However, such studies have limitations, and further research is needed to evaluate these ranking metrics using a large dataset. By examining extensive datasets for analysis, a more better understanding of the strengths and limitations of each ranking metric can be achieved. Current state-of-the-art ranking researchers lack an empirical evaluation of metrics. Therefore, there is a need to measure and evaluate the author count-based metrics using a single domain dataset.

To overcome these limitations, we conducted a study that evaluated the effectiveness of metrics based on the total number of authors [35] for ranking researchers in the field of mathematics using a large dataset of researchers.

The proposed study has a paramount concern of presenting the scientific community best performing potential metrics. For evaluation purposes, our study utilized a large dataset that included 525 awardees researchers and an equal number of non-awardee researchers, spanning a period of three decades from 1990 to 2023. This dataset includes information about authors from the field of mathematics, allowing us to gain insights into trends and patterns over time. The main objective of this study is to determine the potential metrics for ranking researchers in the field of mathematics. To achieve this purpose, this study aimed to provide specific research questions deemed essential in identifying the most effective ranking criterion.

RQ1.Which type of correlation exists among the author count-based metrics?

RQ2. Which metrics have the strongest influence in determining the presence of international award winners among top-ranked authors lists?

RQ3. Which prestigious mathematical awarding societies for the nomination of awardees have any common association with these metrics?

We have evaluated Hi index, hf index, gf index, gF index, hi-index, Hm index, k norm index, w norm index, gm index, pure h-index, fractional h-index, fractional g-index, hi norm index and normalized hi index on a large dataset within the field of mathematics. The calculation method and a brief introduction of all these metrics are discussed in the third section of the manuscript.

Award-providing societies in the field of mathematics are considered benchmarks for the assessment of specified metrics. The most prestigious mathematical awarding organizations included the American Mathematical Society (AMS), International Mathematical Union (IMU), London Mathematical Society (LMS), and Norwegian Academy of Science and Letters, which were employed as benchmarks in our analysis.

In this study, we aim to investigate the role of author count-based metrics on the dataset of researchers of the mathematics domain. It is important to note that this study does not involve making predictions about awards. This research only examines the performance of each metric. This study introduces several novel contributions to the field of scientometrics that have not been addressed in the existing literature to the best of our knowledge. These contributions are: We have employed an extensive array of parameters based on author count, encompassing a large range of factors. Also to mitigate bias, we meticulously gathered a dataset that includes an equal number of awardees and non-awardees researchers.

The overall key contribution of this study are:

- We have created a dataset in the field of mathematics comprising a total of 1050 researchers, including both Awardees researchers and Non-Awardees researchers of the last three eras.
- We have extracted the metadata of the authors from Google Scholar, including their publication, citation information and coauthors etc.
- Implementing all the Author count-based metrics using Python language.
- Finding the Correlation between these metrics and evaluating all these parameters on the data set for finding potential metrics.
- Presenting the analysis in the form of results and finding the best-performing metrics in this domain.

The remaining paper is divided into the following section. In the Literature Review section, a brief description of the ranking factors is provided. The Methodology section describes the research methodology for assessing metrics and also introduce the data collection method. In the Result and Discussion section, the results of our research have been presented. The Conclusion section summarizes the main findings and their implications. Finally, the future work section suggests some future studies.

II. LITERATURE REVIEW

Over the past few decades, the evaluation of the influence and significance of certain scholars and research groups has become increasingly significant [36]. Knowledge of the scientific influence of a researcher is often essential in a variety of circumstances [3], such as determining the most successful researchers and their work, which can lead to significant funding opportunities, collaborations, and professional recognition [37]. It also helps students identify an appropriate supervisor for their doctoral research, select recipients of awards within the scientific community, and identify qualified peer reviewers for journals and conferences [38]. In addition, measuring the significance of scientific research can also help policymakers and funding agencies make informed decisions about which research projects to invest in, leading to a more efficient use of resources and more significant contributions to scientific knowledge [39], [40], [41].

Research by a single author can be judged and rated using a wide range of evaluation criteria. Scholars have been ranked based on a variety of parameters, such as the number of publications, number of citations [17], co-authorship [12], [42], use of hybrid methods, h-index and also some variants of h index. It has been said that the number of publications a researcher produces serves as a gauge of the quality of their work [43]. The use of this measurement does not accurately reflect the researcher's scientific influence or the significance of their work. This simply indicates the quantity of research produced.

Cameron et al. [44] stated that researchers with numerous publications are often considered highly productive. However, using the number of publications as the only factor to evaluate a researcher's performance is insufficient. This is because some researchers publish their work in substandard journals or conferences, which may not accurately demonstrate the significance or importance of their research. In addition, a researcher's high citation count can be viewed as a measure of their recognition and influence in the academic world, which does not necessarily mean that their work is of high quality and consistent. Therefore, using citations as the sole criterion for evaluating a researcher's contributions may not provide a complete picture of their influence on the field [39]. Smolinsky and Lercher [45] also stated that it is critical to consider the technique and context of citation analysis when evaluating the influence and significance of the research rather than simply relying on the number of citations received [46].Liu and Cheng in [47] stated that authors with a large network of co-authors are the most capable researchers. However, there are many studies with single authors, which does not mean that they do not contribute to the scientific community.

Hirsch suggested the h-index as a method to gauge the significance of researchers. According to Hirsch, the h-index has several advantages over bibliometric indices [48]. Some of these are: it does not require any data processing and is easy to calculate; the output is a singular numerical value that integrates both the quality and quantity of the academic researchers' published works; and the h-index can additionally serve the purpose of quantifying the scientific influence of academic journals. The proposed metric for evaluating research performance has been swiftly adopted by the scientific community.

However, it is affected by certain limitations that have been recognized and tackled by Hirsch himself and other experts in the field [49]. Schreiber in [50] stated that due to the varying citation practices observed across different academic disciplines, it would not be appropriate to make comparisons of the scientific influence between scholars from different fields. The h-index can also be biased towards authors who publish in high-impact journals or who have a larger number of publications. Also, the h-index may be subject to inflation caused by excessive self-citations, resulting in an overestimation of the author's research significance. In general, research articles are authored by a group of scholars who may not have contributed equally to this work. The h-index provides full credit for all citations to every author, which may lead to an inequitable evaluation of individual research significance [51]. In this context, the scientific community has designed several new metrics to acknowledge and evaluate the scientific influence of researchers based on this credit. Sekercioglu [6] proposed a method that assigns credit to all researchers based on their proportional rank. Trueba and Guerrero [52] employed the arithmetic counting method to distribute the credit to all researchers.

Dienes [53] computed the correlation between the h-index and h2-index using a dataset of 19 professors. In 2008 Schreiber [54]introduced a new index called the hm index, which uses the number of co-authors to rank researchers. The experiments were conducted using a database of physicists comprising information from both conference proceedings and journal publications [55]. Cameron [44] utilized the impact factor as a tool to identify individuals with high levels of competence in their respective fields. In 2007, a group of researchers conducted a systematic evaluation of the g-index in comparison with the h-index, a-index, and r-index using datasets from 26 physicists. Their analysis revealed that the g-index is a more appropriate indicator than the h-index for assessing the cumulative significance of a scientist's publication. In 2016 researchers [56] utilized the h-index, g-index, and complementary h-index to evaluate and rank researchers in the domain of mathematics. In 2018, researchers [11] evaluated the h-index and several of its variants, some based on citation intensity and others on publication age. They used a diverse dataset from the field of civil engineering to identify the metrics that were most effective in assessing the research significance of scholars.

In 2019 Ameer and Afzal [57] conducted an impact evaluation of the h-index and its variants, with a focus on both quantitative and qualitative indices. This study utilized a large dataset from the field of neuroscience to identify the most potential metrics for evaluating the research significance of scholars. Researchers in [58], [59], and [60]conducted a systematic evaluation of citation intensity-based indices of the h-index, on a large dataset of the mathematics domain. The main objective of these evaluations was to determine the most effective metrics for evaluating the research significance. In 2021 Usman et al. [61] researchers conducted an evaluation on a comprehensive dataset of civil engineering to identify the potential metrics that affect author performance evaluation. A most recent study Alshdadi et al. in [62] researchers proposed a set of rules that utilized the top five highest-performing indices across various fields. They gathered data from 500 researchers within each field. The results demonstrate that their proposed rules were able to retrieve 70% of the awardees within the top 100 results. In 2019, Zhang et al. [63] conducted a thorough review of multiple metrics used for evaluating and predicting the impact of researchers. They state the argument that no single metric adequately quantifies the evaluation of a scholar's impact. Also, Bai et al. [64] conducted a comprehensive survey of various techniques employed for quantifying success in science. They systematically categorized these assessment metrics into different categories. However, the researchers concluded that despite the existence of numerous parameters for assessing success in science, there are still potential issues that remain unknown. Furthermore, in 2023, much like the present study, several recent studies have been conducted in the field of mathematics literature. These studies have utilized parameters based on publication and citation counts [60], as well as parameters based on the age of publications [4]. However, none of these studies have delved into the realm of parameters grounded in a substantial number of authors, which constitutes the primary innovation introduced by this research. Although numerous ranking parameters are available in the literature, no universal agreement on research quality constructs or the best metrics to identify the most influential researchers in various fields. Previous studies have attempted to determine the significance of ranking parameters through hypothetical or imaginary case scenarios. There is no standard benchmark for these scenarios. However, we contend that the true behavior of potential metrics can only be understood through empirical investigations using a large dataset of a specific domain. From the literature we have identified several points which are not addressed by already existing studies.

- As per our knowledge, no studies used a substantial amount of author count-based metrics to assess the potential metrics for a specific domain.
- The number of award winners used by different studies are less than or equal to 250, and the dataset related to awardees are limited up to 2013.

- In literature, mostly studies utilized an imbalanced dataset for evaluation purposes.
- We applied these metrics to the dataset and identified several potential metrics that can be utilized to quantify the impact evaluation of researchers in the mathematics domain.

In this study, we have taken into account the aforementioned points that have not been addressed in existing studies.

III. METHODOLOGY

Figure 1 displays the architecture diagram for the proposed methodology. Fourteen author count-based metrics have been evaluated in this research. For evaluation purposes, the prestigious awards achieved in the field of mathematics on a national and international level serve as a benchmark. Ultimately, the goal was to determine the potential metrics for the researcher's impact evaluation in the field of mathematics.

A. DOMAIN SELECTION

Our study focuses on the field of mathematics to evaluate the author's count-based metrics. This field was selected due to its strong interdisciplinary connections with other branches of science, including physics, computer science, and chemistry. Moreira et al. in 2015 performed the task of expert finding against particular domain [65]. They stated that evaluating ranking parameters across multiple fields is essential for finding and promoting employees in the organization. Through evaluations across diverse areas, a better understanding of the effectiveness of ranking parameters and their potential for different fields can be gained. This can facilitate and identify opportunities for improvement and advancing research in various disciplines.

B. BENCHMARK DATA SET

To evaluate the various ranking metrics in our current study, we obtained lists of awards from various mathematical societies that present internationally prestigious awards. In total, 24 such awards were included in our study. These awards are widely recognized within the mathematical community and are considered significant accomplishments for mathematicians and researchers. These 24 international awards are granted by various distinguished mathematical societies and organizations. These include the[1] London Mathematics Society (LMS), the[2] International Mathematical Union (IMU), the[3] Norwegian Academy of Science (NASL), and the[4] American Mathematical Society (AMS). These organizations are committed to promoting and advancing mathematics, while also providing support for mathematicians in their research and academic pursuits throughout the world. Ayaz and Afzal [11], Ain et al. [58], Ghani et al. [59] are among the researchers who have used awardees from these societies as a benchmark in their studies.

[1]https://www.lms.ac.uk/
[2]https://www.mathunion.org/
[3]https://dnva.no/norwegian-academy-science-and-letters
[4]https://www.ams.org/home/page

This is primarily due to the lack of better benchmarks available for evaluating these indices. The awards given by these societies are highly esteemed and competitive in the mathematical community and are granted based on a rigorous evaluation of the quality and originality of the researcher's work. The distribution of awards across various societies is illustrated in Figure 2.

C. DATASET COLLECTION

Collecting data for a particular domain typically requires the participation of domain experts. This is due to the various branches and classes within the domain, requiring specialized knowledge to ensure accurate and comprehensive data collection. Mathematics incorporates a diverse range of branches, covering numerous subfields such as algebra, geometry, calculus, probability theory, number theory, and many more. Each branch within mathematics requires specific expertise and knowledge to effectively collect data and conduct research. One source of categorizing these diverse branches of mathematics is through the Math Subject Classification (MSC) scheme [52]. The MSC scheme utilizes a hierarchical classification system to organize and classify different subfields and topics within mathematics domain. This classification system helps researchers and experts to navigate and identify several topics in the areas of mathematics. The latest version of this classification system is MSC2020. We manually identify several terms from the Math Subject Classification (MSC) scheme and collect the metadata of researchers from Google Scholar. Also gathering a substantial volume of data manually and subsequently verifying its relevance to a particular domain is also a challenging task After manually collecting all the data, we proceed to verify whether it belongs to the domain of mathematics or not. We collected a large and diverse dataset of 1050 records, comprising 525 non-awardees researchers data and 525 awardees researchers data. The awardee's data are collected by visiting various awarding societies' websites and collecting the names of researchers who received awards from 1990 to 2023. To address the class imbalance problem, we included an equal number of non-awardees in the analysis. [58], [59]. The method of selecting non-awardees involves sorting the authors based on the average value of all their indices. Then, an equal proportion of records is selected from the top, middle, and bottom rankings, ensuring that every type of non-awardees are included.

We utilized the Publish or Perish platform Harzing, 2023 [66] to extract data by their name and years. Since we employed a hold-on strategy, we collected records of the researchers before the year of receiving the award. The Publish or Perish software utilizes a sophisticated algorithm to extract both the primary data and accompanying metadata of authors from Google Scholar.

The author, publication, and citation data are gathered using Google Scholar. Data on authors' research activities, such as publications, citations, and co-author networks, can be obtained from several sources i.e., Web of Science,

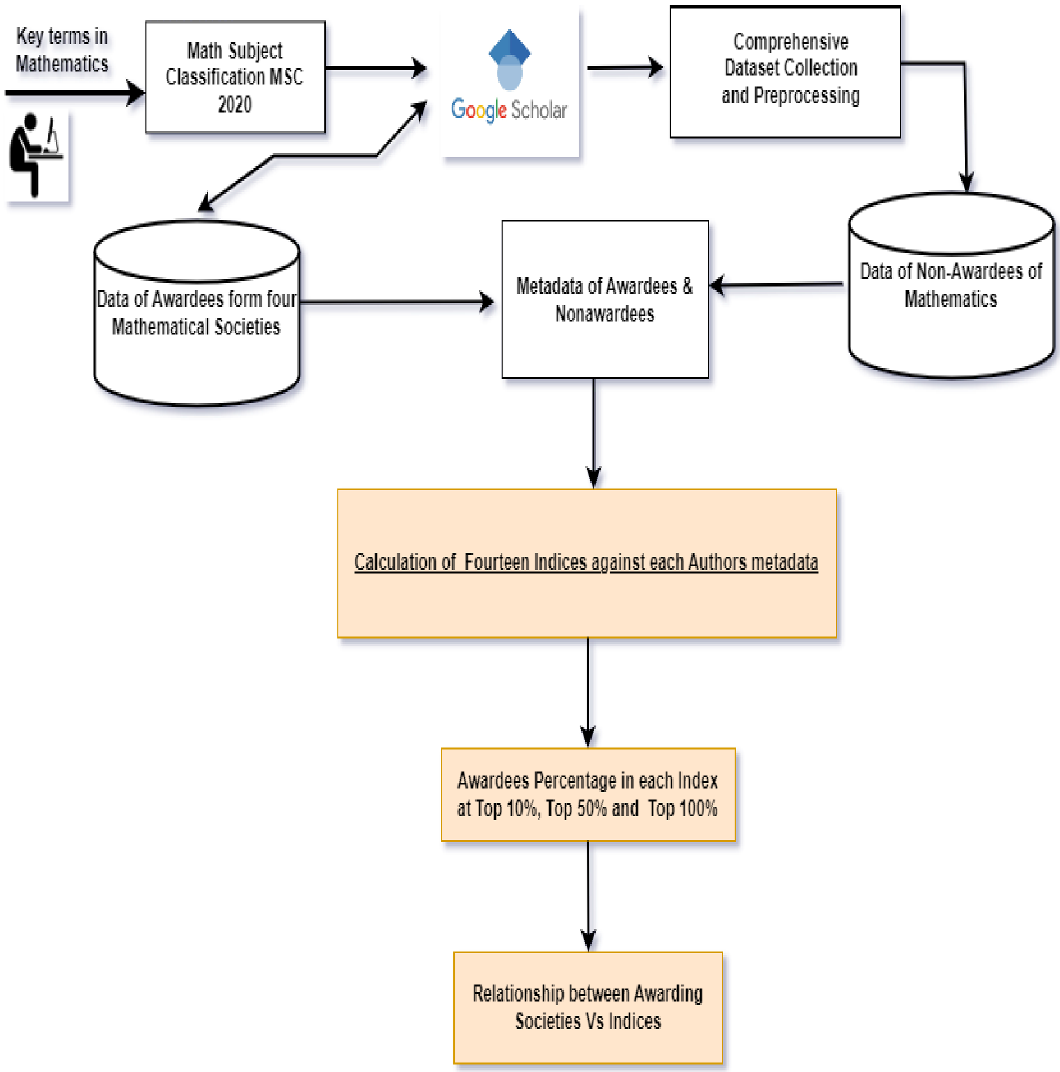

FIGURE 1. The block diagram of the proposed methodology.

Scopus, etc. These sources have access issues, whereas Google Scholar is a publicly available online resource that provides a wide range of information on a variety of scientific fields and citation indexing. In addition, Google Scholar is a dynamic and constantly updated platform, with new data uploaded weekly, ensuring that the information it provides is always up-to-date and relevant [67].

To extract data of the researchers, Publish or Perish used Google Scholar. The input for this process was provided in the form of the author's name and award year, and the software returned the author metadata, including publication year and author information. To ensure the fairness of the dataset, we collected non-awardee data in the same quantity for each year, corresponding to the number of awardees in that year. An example of our methodology is as follows:

In 1990, the total number of awardees was 11, and therefore, we collected 11 non-awardee data before 1990, following the same approach for other years are taken as shown in Figure 3.

D. DATA PREPROCESSING

Once the data has been collected, it is further cleaned and verified. To do this, several steps need to be performed.

Step 1. Removal of invalid characters i.e. ($, %, , #, &,,,,).

Step 2. The verification process involves determining whether papers belong to mathematics journals or conferences.

Step 3. Author disambiguation is performed which involves removing and eliminating duplicates and correcting any ambiguous first or last names of authors.

The characteristics and properties of the final data set for evaluation, after verification of the above steps, are shown in Table 1.

E. COMPUTATION OF METRICS ON DATASET

After the data had been gathered and preprocessed, fourteen metrics have been individually computed using the collected dataset. The inventor of these metrics, their brief discription and computation formulas are given below:

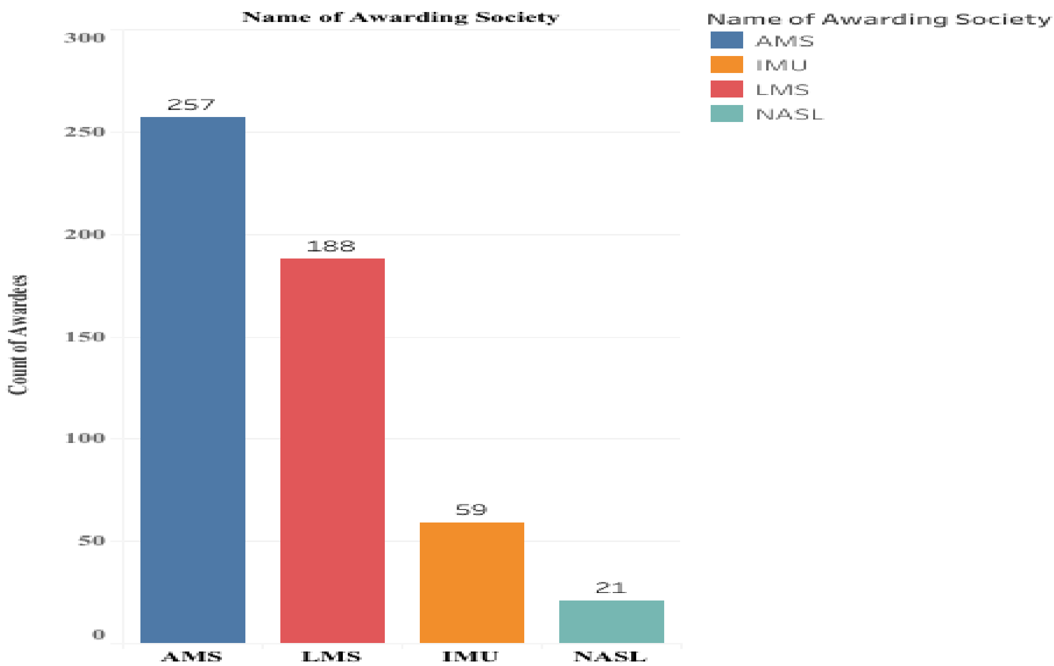

FIGURE 2. Awards distribution across different societies.

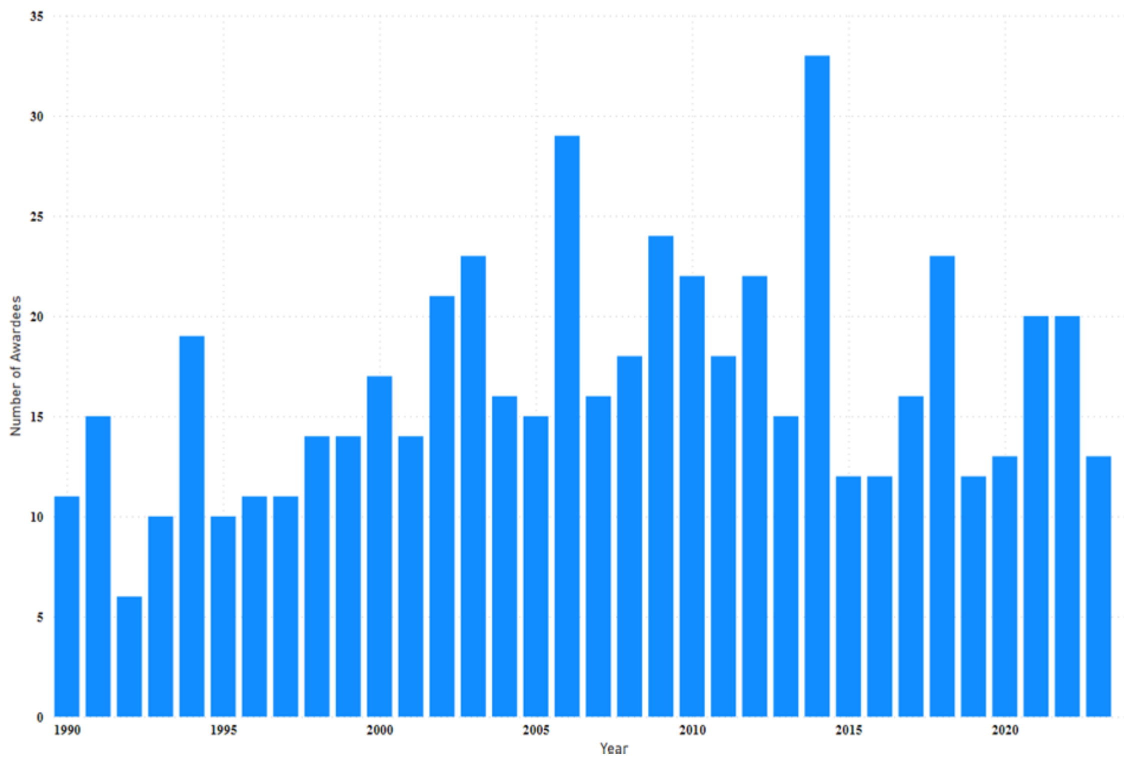

FIGURE 3. Year-wise awardees Count.

1) HI INDEX

The Hi-Index [68] of a scholar is defined as the ratio of the h-index and the average number of scholars in the h-core articles. Mathematically it can be expressed as:

$$h_i = \frac{h}{Avg_a} \tag{1}$$

TABLE 1. Dataset description.

Researchers	Count
Total number of researcher	1050
Total number of awardees	525
Total number of non-awardees	525
Total number of citations	14370007
Total number of publications	204896

2) HF INDEX

The hf is a fractional counting method [69] that maintains the original publication rank while normalizing citations. In this method, the citation count of each paper is divided by the number of co-authors resulting in a normalized citation count. Mathematically it can be expressed as:

$$\frac{Yh_f}{\phi(Yh_f)} \geq h_f \quad (2)$$

3) GF INDEX

In gf index [69] the publication rank remains unaltered while normalizing the citation count by dividing it by the number of co-authors for each paper. The normalized citation count is then sorted in descending order, and the summation of these normalized citation counts is calculated. Mathematically it can be expressed as:

$$gf = \sum_{i=1}^{gf} \frac{Y_i}{\phi_i} \geq g^2 f \quad (3)$$

4) gF INDEX

This method employs fractional counting [70] where the citation count remains unchanged, while the effective rank is determined by the publication rank. Mathematically it can be expressed as:

$$gF = (\sum_{i=1}^{k} \frac{1}{\phi(i)})^2 \leq \sum_{i=1}^{k} y_i \quad (4)$$

5) HI INDEX

The hi-index [71] represents the number of papers authored individually by an author that have garnered at least hi citations. Mathematically it can be expressed as:

$$hi = \frac{h^2}{N_a(T)} \quad (5)$$

6) HM INDEX

This is a modified version of the h-index [72] that considers multiple co-authorship by fractionally counting papers based on the inverse of the number of co-authors. Mathematically it can be expressed as:

$$r_{eff}(r) = \sum_{r'=1}^{r} \frac{1}{a(r')} then c(r(h_m)) \geq h_m \geq c(r(h_m)+1) \quad (6)$$

7) K NORM INDEX

The k-norm index [73]is a modified version of the k-index that considers normalized citations instead of absolute citations. Mathematically it can be expressed as:

$$k-norm = h-norm + (1-(h-\frac{norm^2}{\sum_{j=1}^{h-norm} citnorm_i})), \\ \vee h-norm1andk-norm = 0, \\ ifh-norm = 0 \quad (7)$$

8) W NORM INDEX

The w-norm index [73] is a modified version of the w-index that considers normalized citations instead of absolute citations. Mathematically it can be expressed as:

$$w-norm = h-norm + (1-(h-\frac{norm^2}{totalcit-norm})), \\ \vee\ h-norm0andw-norm = \\ \frac{totalcit-norm}{1+totalcit-norm},\ if\ \ h-norm = 0 \quad (8)$$

9) GM INDEX

The gm-index [74] is a modification of the g-index that takes into consideration multiple co-authorship. In this method, each article is assigned a fractional weight based on the number of co-authors it has. Mathematically it can be expressed as:

$$g_{m \leq} C_{eff}(g_m)\ where\ C_{eff}(r_{eff})\ and\ S_{eff})(r_{eff=\sum_{\acute{r}=1}^{r(r_{eff})}} \frac{1}{a(\acute{r})} c(\acute{r}) \quad (9)$$

10) PURE H INDEX

The difference between the hi-index and the pure h-index [75] lies in the denominator. In the hi-index, the denominator is the average number of scholars in the h-core articles, whereas in the pure h-index, the denominator is the square root of the average number of scholars in the h-core articles. Mathematically it can be expressed as:

$$h_p(A) = \frac{h}{\sqrt{E(author)}} \quad (10)$$

11) FRACTIONAL H-INDEX

The fractional h-index (hf) [76] of a scholar is achieved when hf of their articles have at least hf fractional citation count each. Mathematically it can be expressed as:

$$h_f = max(k \leq \frac{cit(k)}{author(k)}) \quad (11)$$

12) FRACTIONAL G-INDEX

The fractional g-index (gf) [76] of scholars is attained when gf of their articles have at least g2 f cumulative fractional citation count each. Mathematically it can be expressed as:

$$g_f = max(\sum_{k=1}^{p} \frac{cit_k}{Author(k)} \geq p^2) \quad (12)$$

13) HI NORM INDEX

The hl-norm [77]is a modified version of the h-index that normalizes citations based on the number of authors per paper.

Once all these metrics were individualy computed, we generated separate ranking lists for each metric. Fourteen different ranking lists of authors were then obtained and further examined to respond to the three fundamental research questions under discussion

IV. RESULTS AND DISCUSSIONS

In this section, we presented and discussed the findings of our study.

A. RQ1: CORRELATION OF COMPUTED METRICS

The main goal of comparing these ordered lists is to examine the underlying connection and the degree of resemblance between these metrics. We employed the Spearman correlation coefficient to measure the correlation. The mathematical formula for calculating the Spearman correlation coefficient is presented in equation below [78].

$$r_s = 1 - \frac{6\sum d^2}{n(n^2-1)} \tag{13}$$

The Spearman correlation is a nonparametric measure of the strength and direction of association that exists between two sets. The computed correlation coefficients between the ranked lists are displayed in Figure 4. Typically, a weak correlation exists between two variables when the absolute value of the correlation coefficient is between 0.00 and 0.50. Moreover, a correlation value lies within the range of 0.5 to 1.00 is typically considered to denote a strong linear relationship between the variables, while value less than 0 considered negative correlation. Figure 4 employs a colour scheme to represent the correlation coefficients, with strong values displayed in green colour, weak correlation values in orange colour and blue representing negative correlation. The correlation output demonstrates that there are more strong correlation coefficients than weaker ones. However, the detection of weak correlation coefficients for certain metrics in the dataset implies that their rankings differ significantly from those of other metrics. This finding may have significant implications for the analysis and interpretation of the results. The answers to the first research question inspired us to investigate additional questions.

B. RQ2: POTENTIAL VALUE OF EACH METRIC IN IDENTIFYING AWARDEES AT THE TOP 10% TO TOP 100% OF RANKED LISTS

For the second research question, initially an analysis was conducted to assess the influence of metrics on ranking the top awardees. Next, the frequency of awardees' appearances in each metric was examined, including the top 10%, top 50%, and top 100% of the generated ranked lists. We ranked each author individually according to each metric and also determined the percentage of each awardee for every metric. Then, we noted where each award recipient stood on the ranking lists and determined how many awardees fell within the top 10%, top 50%, and top 100% of each list.

According to Figure 5 the top 10% of authors account for 60% of awardees who have the highest hf index scores. While retrieving 30% awardees, the gf index and fractional g-index produce the same results.

The figure 6 shows that the hf index and fractional g-index have outperformed other indices by retrieving 42% of awardees within the top 50% of authors. The lowest performance is observed for the case of the gm index, and gF index by retrieving 4 percent awardees.

From the data displayed in Figure 7, it is evident that the fractional g index and hf index have surpassed all other metrics in retrieving top awardees, with 49% and 47% of awardees appearing in the top 100 of ranked list, respectively. In contrast, the gm index and gF index have shown low performance in retrieving awardees, as they only retrieved 2% of the top awardees in the top 100 of ranked list.

C. RQ3: DEPENDENCY OF AWARDING SOCIETY WITH EACH METRICS RESULTS

This section discusses the third research question, which focuses on identifying the awarding society that bestows awards based on these metrics. The frequency of award winners in the top 10%, 50%, and 100% of the ranked list is looked at to further explore this research subject. As stated earlier, our data set consists of 525 awardees researchers and an equal number of 525 non-awardees researchers to ensure fairness and eliminate any bias. Out of the 525 awardees, 257 were affiliated with AMS, 59 with IMU, 188 with LMS, and 21 were from NASL, as shown above in Figure 2. It has been a common belief that award recipients have a strong research background, indicated by a high number of publications and citations. This has led many to expect that all awardees would rank in the top 10% of authors when sorted by these metrics. However, recent analyses have revealed that this assumption is not always accurate, and there have been instances where some award recipients do not meet this expectation. Figures 8, 9, and 10 presented below illustrate the results of the indices for different societies.

By analyzing the dependence of awarding societies on the author count-based metrics, we have identified the following observations.

1) AMS

- a) In the top 10% results, the fractional h index outperformed all other metrics by retrieving 100% of awardees in a ranked list. Moreover, the fractional g index succeeded in retrieving 66% of awardees. Furthermore, the k norm index and w norm index retrieved 50 percent of awardees.
- b) In the top 50% results, the fractional g index outperformed all other indices by retrieving almost 52% of awardees. Moreover, the fractional h index retrieved up to 46% of awardees. Furthermore, the

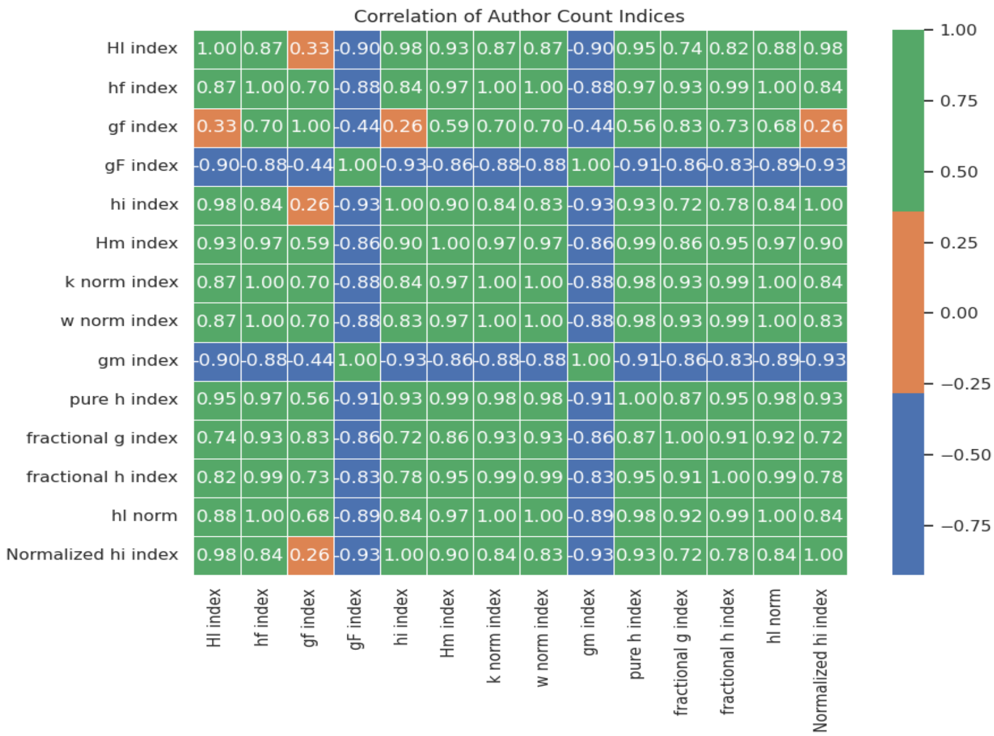

FIGURE 4. Spearman correlation matrix among 14 author-level citation metrics.

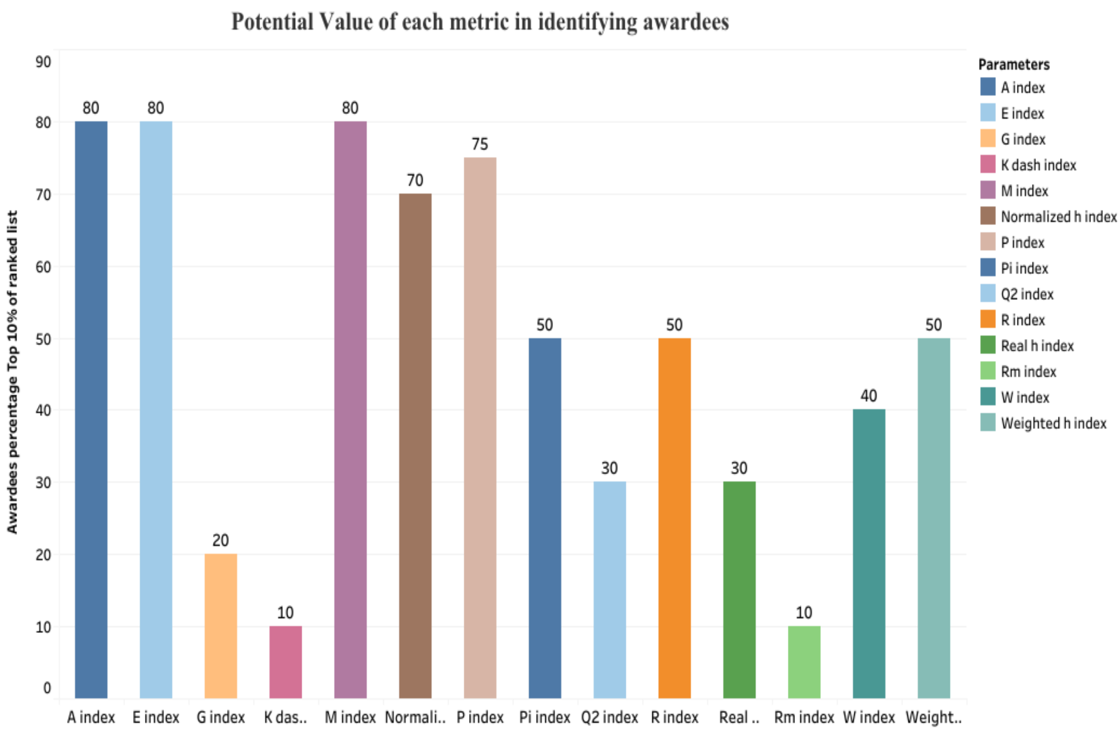

FIGURE 5. Potential vale of each metric at top 10% of ranked lists.

lowest performance was shown by the HI index by retrieving 28 percent of awardees.

- c) In 100% results, gF and gm index outperformed all other indices by retrieving 50 percent of the awardees,

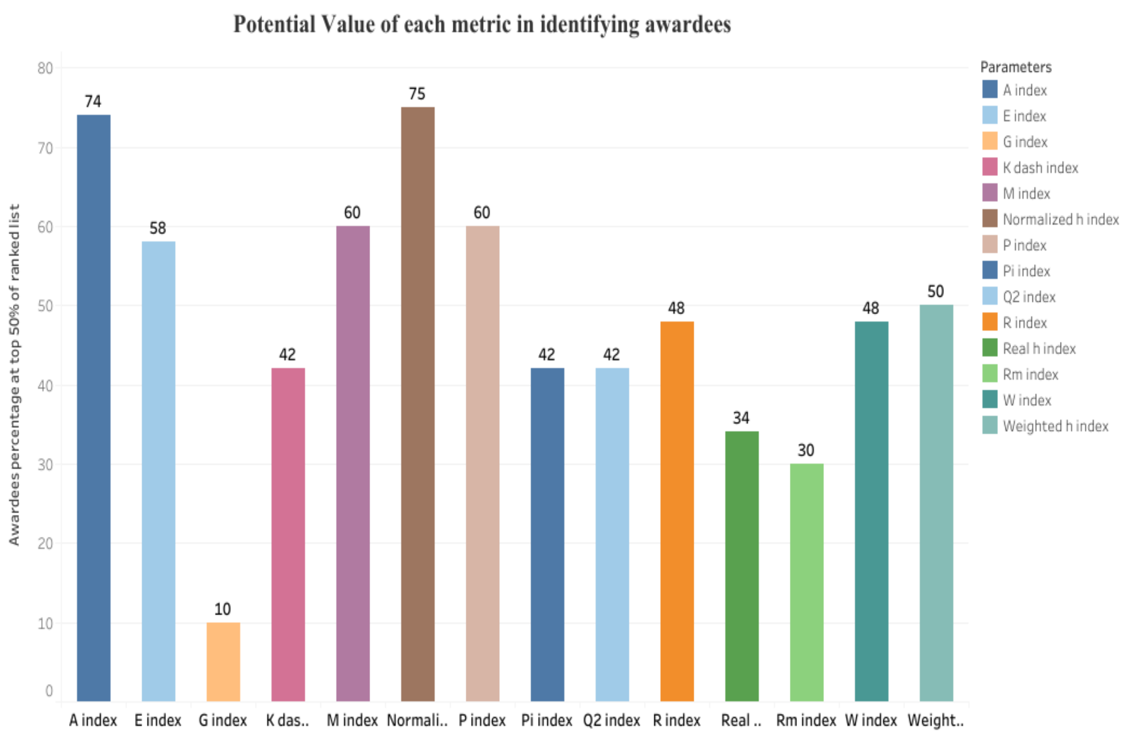

FIGURE 6. Potential vale of each metric at top 50% of ranked lists.

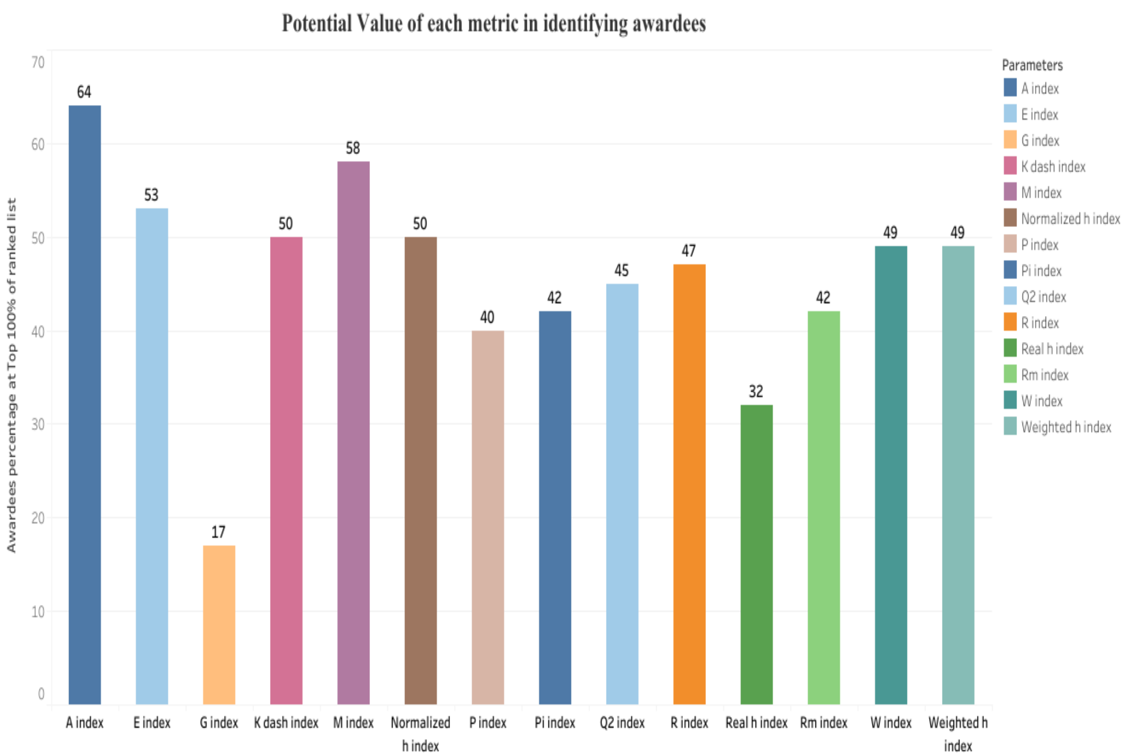

FIGURE 7. Potential vale of each metric at top 100% of ranked lists.

while the fractional g index retrieve 44% awardees. The HI index shows low performance by retrieving 26 percent of awardees.

2) IMU

- a) In the top 10% percent result, the Hm index brought a maximum number of awardees from IMU society and

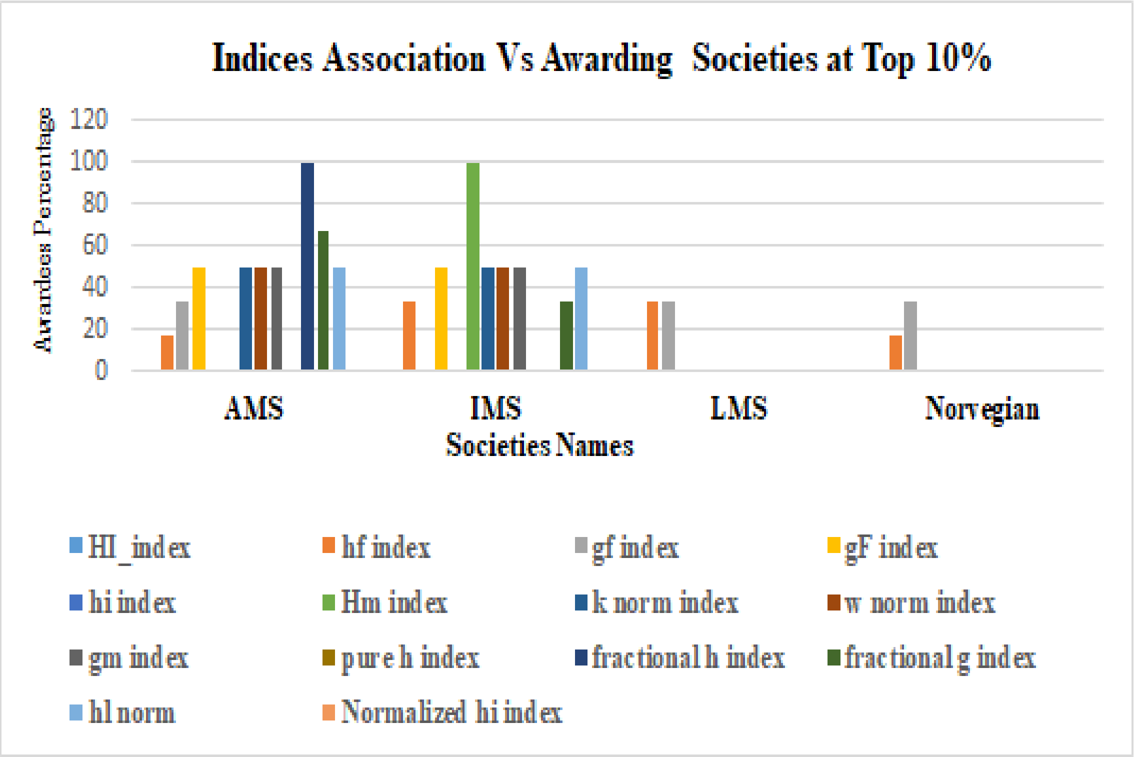

FIGURE 8. Variations of metrics on awardees societies at top 10%.

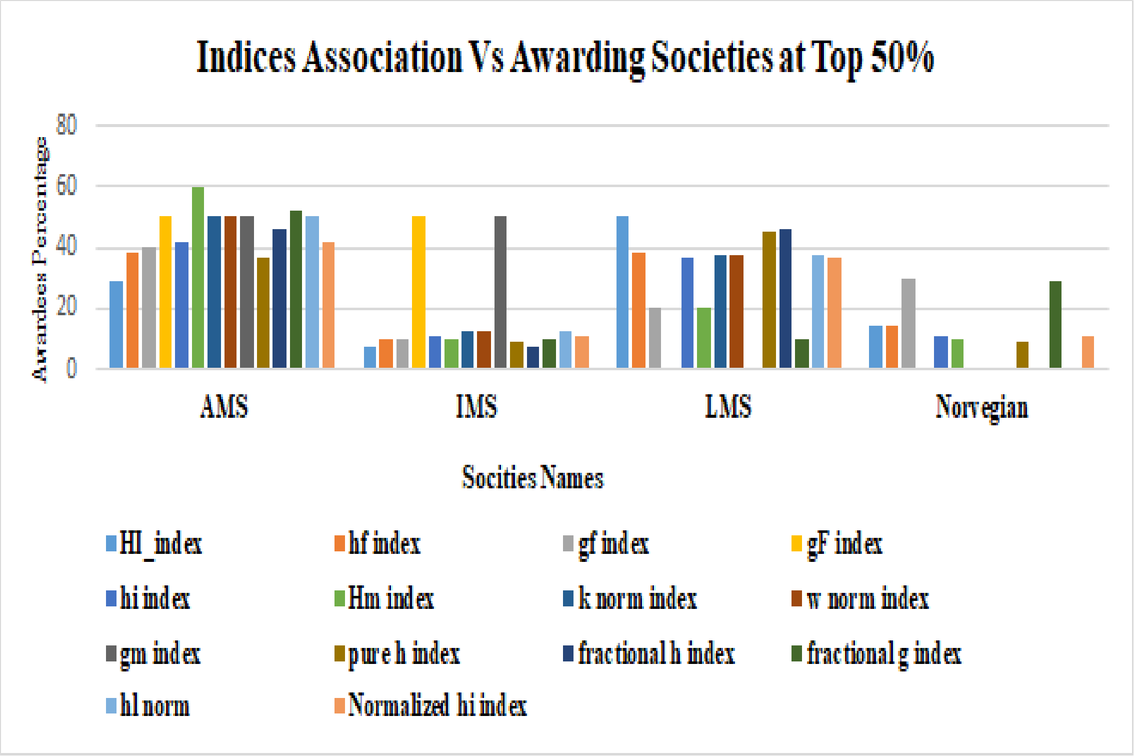

FIGURE 9. Variations of metrics on awardees societies at top 50%.

exhibited a performance level of 100%. Moreover, the gf index and k norm index show average performance by retrieving 50 percent awardees, while the HI index, gf index, and pure h index return no results.

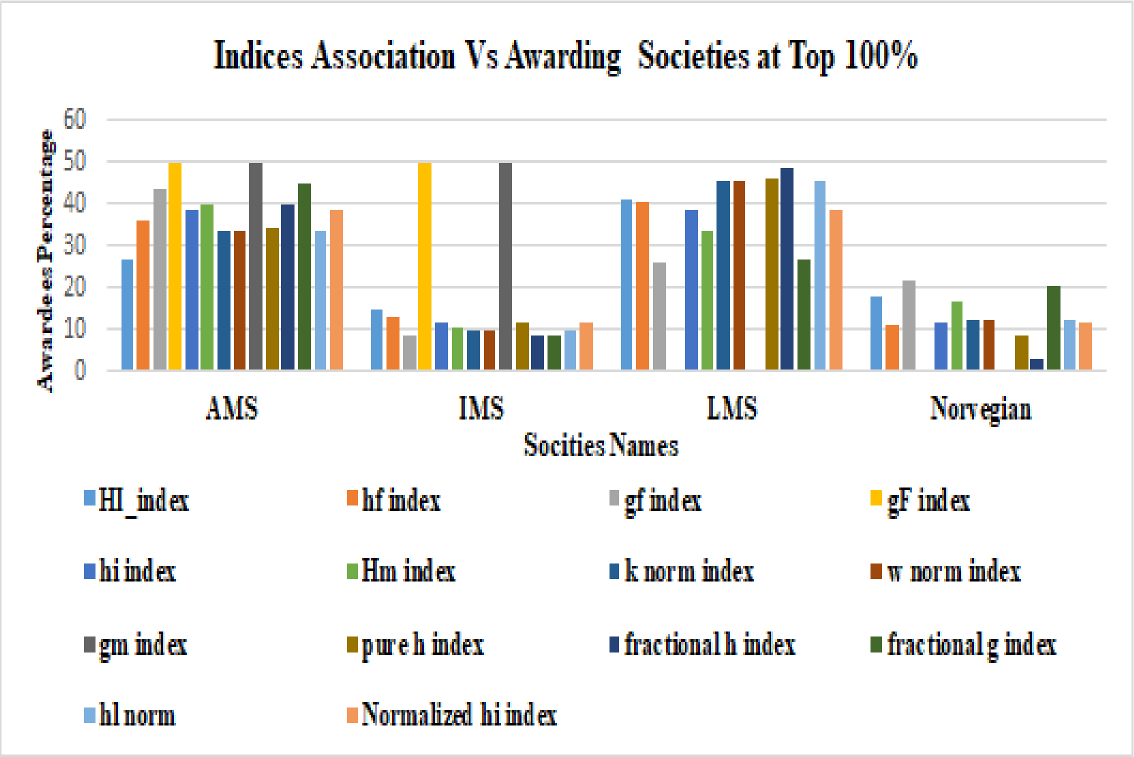

FIGURE 10. Variations of metrics on awardees societies at top 100%.

- b) In the top 50% results, the gm and gF index outperformed all other indices by retrieving 50% awardees. The performance of the k norm and w norm index shows average performance by retrieving 12.5% of the awardees.
- c) In 100% results, the gm and gF index outperformed all other metrics by retrieving 50% of awardees. The fractional h index shows the lowest performance by retrieving 8 percent of awardees.

3) LMS
- a) In the top 10% results, hf and gf indexes outperform all other metrics by retrieving 33 percent awardees, while the remaining one has returned nothing.
- b) In the top 50% results, the HI index outperforms all the other indices by retrieving 50 percent of awardees. The pure h index and fractional h index retrieved 46 and 45 percent of awardees, respectively.
- c) In the top 100% results, the fractional h index outperformed all other indices by retrieving 49 percent of awardees. The pure h index retrieved 45 percent of awardees.

4) NASL
- a) In the top 10% results, the gf index outperformed all other indices by retrieving 33 percent awardees. The hf index retrieved 16 percent of awardees while the remaining indices return nothing.
- b) In the top 50% results, the fractional g index retrieved 28 percent awardees which is higher than all indices result. The hf index and hi-index retrieved 14 percent of awardees.
- c) In the top 100% results, the gf index outperformed all other indices retrieved up to 21%. The hm index shows the average performance by retrieving 16 percent of awardees while the gm index and gF index return nothing.

The overall analysis showed that different metrics perform differently for different societies, and some metrics are better suited for certain societies than others. For example, the fractional g-index was found to be more suited for AMS as it outperformed other indices in all types of ranked lists, while the gf and gm index were found to be better suited for IMU, hf index and fractional h-index for LMS, and gf index for NASL society. In addition, analyzing the performance of different metrics in identifying award winners from different societies, this study provides insights into the awarding and recognition process of different societies. Researchers and analysts can use this information to develop more targeted and efficient strategies for predicting and honoring awardees, which can ultimately improve the overall process of recognizing deserving individuals in their respective fields. Moreover, the identification of strengths and weaknesses of different societies in terms of their approach to selecting and recognizing awardees can also help to inform future improvements in the awarding and recognition process.

V. CONCLUSION

Evaluating the scientific influence of a scholar holds significant importance within the scientific community due to its several benefits. Numerous parameters have been proposed by research community to acknowledge the most influential researchers within a specific domain. The current state-of-the-art literature review clearly demonstrates that these metrics have been proposed in a diverse range of hypothetical or imaginative case scenarios. From these metrics, we have picked fourteen different author count-based metrics. In this study, we have conducted an analysis of these selected author count-based metrics. For experimental purposes, we utilized a dataset covering a period of two decades, from 1990 to 2023, consisting of 525 non-awardees researchers and 525 awardees researchers picked from esteemed scientific societies in the field of mathematics.

To address our first research question, we computed the correlations among the indices to assess their similarities and differences. From the result we notice a high degree of correlation among the majority of the metrics such as HI index and Hf index, indicating that their rankings are largely consistent. However, we also observed some indices with weak correlations such as gf index and normalized hi index which implies that their rankings differ from those of other metrics. This finding emphasizes the significance of carefully selecting appropriate metrics for evaluating author productivity and significance, as different metrics may yield varying results. For addressing second research question, we analyzed the awardees occurrences across different ranked list records such as, top 10, top 50, and top 100 of each metric. This investigation provides valuable insights into the relative performance of awardees across various metrics. For the top 10% of the ranked list the hf-index brought 60 percent of awardees while none of the other indices brought more than 32 percent of awardees. For top 50% of ranked list hf index brought 42 percent of awardees whereas gm index and gF index brought only 4 percent of awardees. For top 100% of the ranked list fractional g index brought 49 percent of awardees. Whereas gm index brought only 2 percent of awardees.

To address our last research question, we performed an analysis to represent the association between metrics and awarding societies of mathematics. As we have collected the data of international awardees affiliated with four prestigious Mathematics societies, namely the American Mathematical Society (AMS), the International Mathematical Union (IMU), the London Mathematical Society (LMS), and the Norwegian Academy of Science and Letters (NASL), as a benchmark to assess the efficacy of these metrics. From analysis we determine the extent that how much these societies rely on the metrics to evaluate their potential in accurately measuring author productivity and significance. For example, the fractional g-index was found to be more suited for AMS as it outperformed other metrics in all types of ranked lists for this society, while the gf and gm index were found to be better suited for IMU, hf index and fractional h-index for LMS, and gf index for NASL society.

Despite the proposal of numerous metrics and parameters in the field, aimed at quantifying the impact evaluation in science, there is still no universally accepted criteria. Therefore, further research is necessary to develop more standardized solutions in this area.

VI. FUTURE WORK

In future studies, our objective is to expand the scope by incorporating additional metrics and integrating them with various statistical and other methods to create a hybrid approach. Moreover, we aim to enhance the diversity of the dataset by including other domains such as computer science, civil engineering, and more.

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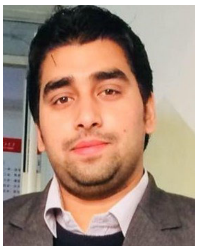

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