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***Abstract*—As the the quality of research and spectrum of the publications are improving day by day, the citation parameter h-index [1] alone seems not sufficient to measure authors' performance. The citation is the relationship between two papers when one paper refers to another paper. In way to resolve the said issue, in this paper we have introduced a new author indexing parameter, h_c-index based on the influence of the co-authors' h-index level. Our newly introduced index (h_c) looks through the co-authorship genealogy tree of an author and subsequently measures the related citation impacts created by every co-authors. This mechanism gives more accurate measurement for calculating author's citation index and the same we have observed in our experimental analysis, where we have seen substantial impact improvement while comparing actual h-index with h_c-index for top 10 authors from Web of Universities[1] ranking.**

***Index Terms*—Citation Network, Author Indexing, Author Collaboration, Co-authorship Relation, Collaboration Probability (CP)**

I. Introduction

An author's performance or quality is determined on the basis of his/her h-index. h-index [1] is calculated from the citations received by the publications of a particular author. But after long years of study and observations, it can be concluded that an author can not be judged based on his h-index only. As we mentioned earlier, the h-index consists of citations of his/her papers but it is seen that many authors who have published a lot of works, that are having fewer citations, resulting in the decreasing of the h-index. On the other hand, some authors may have done a few works with some of their scholars or co-authors that have obtained a very high citation count resulting in a higher h-index for them. Hence, the h-index is not enough for analyzing an author's quality or performance.

The ongoing method of calculating the h-index based on citations to determine quality of an author is full of loopholes as it does not gives the appropriate credit the authors deserves. So, to cope-up with this issue and to correct the system errors, we introduced a new kind of index which calculate a modified h-index value consist of the h-index of the author but will also get the impact values obtained from the influence of the co-authors.

In contrast to the existing works, we have observed that in few articles, the authors have introduced new indexes based on different parameters. Indexes such as h-index, i10-index, and g-index, do not consider the number of co-authors or the researcher's sequence number in the author's list of a publication [2]. There exist many metrics but most of them are susceptible to manipulation. One of the earlier indexing mechanism, U-Index [3] was proposed to determine the author's contribution to academic knowledge. It is based on citation count per annum and the impact factor of the publication journal. Similarly, there are many other proposed indexes like f-index, c-index, mh-index [4], fi-index [5], t-index [6], etc, but none of the articles have used co-author influence factor to determine the author impact. In this article, we proposed a new modified h-index, h_c index which is computed by considering the author's own h-index, co-author's influence, and contributing factors.

A. Motivations & Objectives

Here, we highlighted the main motivational points for our work and also states our exact contribution. **Firstly,** co-author's counts and sequence are not considered in any of the previously existing indexes [2]. Moreover, most of the indexes can be manipulated which result's in incorrect impact values. **Secondly,** our main motivation of this paper is to consider the co-author influence with the contributing factor to determine an author's quality, which is not performed by any of the previously existing work. **Lastly,** co-author influence is important for every new author to get the first ignition in his research field.

[1] https://www.webometrics.info/en/hlargerthan100

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B. Challenges & Contributions

Our main objective in this article is to analyze the author's performance or author quality with the help of h_c index which is a modified h-index. We collected the list of 5 authors followed by their co-authors up to 2 levels. With these collected data we constructed an author-co-author genealogy tree. From this tree, through the bottom-up approach, we calculated the co-author influence from each level and finally added it to the author's h-index following a few required mathematical operations. Finally, we obtained two kinds of modified h-index based on the collaboration probability. From this, we concluded that the h_c index increases with an increase in the level of co-author. Now when calculated with the collaborative probability, the modified h-index is found uniform but without it, we observed a huge difference between the h-index and the h_c index which is non-uniform.

The article is arranged into seven major sections: Introduction followed by Related Work, then Dataset Preparation and then Methodology after that Experiment, Results & Discussion, and finally, Conclusion and future scope.

II. Related Work

In this section, we reviewed some of the peer-reviewed works on citation and author indexing techniques.

Seu et al. [7] proposed a relation between the h-index of authors by considering their subsequent publications. Bi et al. [8] highlight the four problems or limitations when the h-index is used to determine the impact of a particular author. Drolet et al. [9] proposed an Author Impact Factor (AIF), that determines the authorship position and number of co-authors to remove biasness and impose fairness in the research field. Fiorillo et al. [5] proposed a new index and named it as Fi-Index to measure the author's h-index reliability. Giulio Formoso [10] proposed a novel approach to promote fairer criteria to determine the author's impact in the research field. Huang et al. [11] proposed the relationship between the h-index of abstract authors and the likelihood of subsequent publications. Sanyal et al. [12] defined the new mentorship index as g_m-index for enhancing the academic success of mentoring activity. Damaceno et al. [13], have studied the relationship that depends on academic age, metric Uses Descendants, Fecundity, and Genealogical Index. Rossi et al. [14], have introduced the Genealogical index, which finds the depth of the tree and each level has the same number of children. Heinisch et al. [15], identified the advisor among co-author using machine learning technique. The paper Bhattacharya et al. [16] shows the issue, challenges, and application for the discovery of research genealogy on a large-scale academic dataset. Garcia et al. [17] to measure the average no of articles/Quality of journals per year and graduation year-wise number of publications. Eduardo et al. [18], showed that the popular metric of publication productivity includes quantities on an individual's citation record. Panagopoulos et al. [19] proposed KPIs tend to monitor the evolution and share some values in the research work over time and from those clusters, they are able to separate the high dynamics scholars. Lienard et al. [20], have shown an evaluation of the academic family tree to find out how the pattern of the network of mentors and mentee grow their academic success. Zhang et al. [21] presented a review of recent developments in author impact evaluation and prediction. The paper of Wang et al. [22] has Various problems, the academic relation analysis faced was Time-dependency, scalability, and latent relationship when done as a collaborative network.

III. Data Set Preparation

TABLE I
Statistical Metric information on 20 researcher.

Author Name	h-index	Pub.Count	Cit.Count
Satyadev Nandakumar	3	30	65
Aryabartta Sahu	6	51	117
Ruchir Gupta	8	209	601
Mayank Singh	9	66	291
Sathya Peri	10	100	404
Gadadhar Sahoo	10	42	342
Krishna Prasad Miyapuram	11	125	543
Kotaro Kataoka	11	84	431
Hemangee K Kapoor	12	126	566
Sudharsan Iyengar	12	141	561
Sanasam Ranbir Singh	13	1248	2030
Sushanta Karmakar	15	109	1040
Antony Franklin	15	145	1141
Dharavath Ramesh	18	176	1115
Ranveer Singh	19	861	3319
Arobinda Gupta	21	1547	2015
Kolin Paul	24	206	1944
M Balakrishnan	43	340	8129
Pushpak P Bhattacharyya	49	998	11242
Krithi Ramamritham	83	618	23844

First of all, we searched for the faculties of the computer science department of various IITs. Then we calculated the publications to citations ratio for each of the faculty members in the lists. Those faculty members who have a greater value for the ratio calculated are considered our authors. For our research paper, we have collected the data sets of 20 faculties/authors who has the highest ratio value. After this, we obtained the data sets of all the co-authors of the authors we selected. Then we inspected the data sets and eliminated the duplicate or ambiguous names to obtain the final corrected data set for co-authors of a particular author. The data set we obtained is termed the first level of co-authors. We then followed the same procedure to obtain the second level of co-authors selecting the first level co-authors as our authors for the second level. Following the above step, we can find out the l-levels of co-authors for a particular author. For our research, we have taken 20 authors from the list and considered their two levels of co-authors. Finally, we obtain our data set for the research work. Table I represents our data where it can be seen there are several authors who have many publication counts, but their citation count and hence the h-index is not up to their publications. On the other hand, some authors have comparatively less publication count, but the citation and h-index are high. Hence we collected the data set keeping a combination of both the above conditions.

IV. Methodology

In this article, we considered the h-indexes of respective author, say A, and his/her co-authors set $C = \{t_1, t_2, t_3, ...t_n\}$ where, n is the number of co-authors of author A. Similarly, co-authors of co-author set as per level wise it follows the BFS algorithm from this genealogy co-authorship tree. Now, each of the node's modified h-index is calculated using the below equation 1:

$$(h_c - index)_A = (h - index_{own})_A + (inf)_A \quad (1)$$

where, $(h - index_{own})_A$ *Author's Own h-index* and $(h_c - index)_A$ is *Author's modified h-index from the co-author's influence factor*. The influence factor or $(\text{inf})_A$ is computed using equation 2:

$$(inf)_A = \frac{1}{n}\sum_{t=1}^{n}(W_t \times (h_c - index)_t \quad (2)$$

If the author is in the last level then he/she doesn't have any co-author. In that case: $(\text{inf})_A = 0$

We computed the weights using two different approaches, using which the influence factor and hence the final h_c-index is obtained. The two approaches are elaborated below:

A. Share based approach:

In this approach, each of the nodes is allocated with a contribution-based variable weight value, which is denoted as W_S (from algorithm 1), where *S* means *Share*. The formula to compute the weight value is presented in Equation [3]:

$$W_s = \frac{P_A \cap P_t}{P_A} \quad (3)$$

, where P_t is the collaboration papers of the author with his/her respective co-authors and P_A is the total number of papers of the respective co-author. W_s values are different for all the co-author having the same level. In equation 2, we have represented it W_t where t is all co-author numbering.

The whole approach is illustrated clearly using a two level author co-author genealogy tree in Fig. 1, where we have considered a author A_1 who has two co-authors A_{11} and A_{12} in the first level and author A_{11} has one co-author A_{111} in the second level. Now we will consider the second or last level author i.e A_{111} first. As the author A_{111} has no co-author, hence the influence will be 0. The h-index of A_{111} is 6. As the influence impact is 0, therefore the h_c-index of author A_{111} will be the same as his/her h-index, i.e, 6. Now, we consider the first level authors i.e A_{11}, h-index=4 and A_{12}, h-index=3. Similarly as A_{111}, A_{12} has no co-authors, hence A_{12} has 0 influence and hence h_c-index will be same as his/her h-index, i.e, 3. But author A_{11} has a co-author A_{111}. The node is allocated the share-based weight, W_s. So, the W_S between author A_{11} and co-author A_{111} is 0.03 [using eq 1] and the h_c-index of A_{111} is 6. Hence the influence from author A_{111} will be 0.18 [using eq 2]. Hence the h_c-index of [A_{11}] is 4.18 [using eq 3] Now author A_1, h-index = 5, have two co-authors, i.e, A_{11}, h_c-index = 4.18, W_S= 0.04[using eq 1] and A_{12} , h_c-index = 3, W_S=0.05 [using eq 1]. Hence author A_1 will get influence from both A_{11} and A_{12}. Influence from A_{11} and A_{12} is 0.1586 [using eq 2]. Hence the h_c-index of Author A_1 will be 5.1586 [using eq 3].

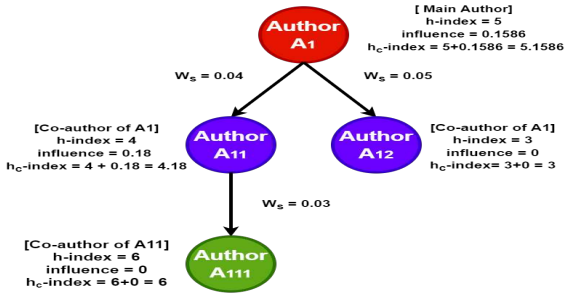


Fig. 1. Pictorial example of co-authorship Network considering the contribution of the author with their co-author (Share based Approach)

Algorithm 1 Calculate weight value of each node: W_s(share based)

1: $n \leftarrow$ no of child node presents in same level.
2: $P_A \leftarrow$ publication set of parent author A.
3: $P_t \leftarrow$ publication set of parent author's A co-author t.
4: $s \leftarrow$ co-author t node number initialise to 0
5: **while** $s \leq n$ **do**
6: $\quad W_s \leftarrow \frac{count(P_A \cap P_t)}{count(P_A)}$
7: **return**(W_s)
8: **end**

B. Level based approach:

In this approach, we allocated the same weights to every node of the same level. The weight value to compute the weight value is depicted in equation 4:

$$W_l = \frac{1}{l} \quad (4)$$

where l is the level number of the genealogy tree where the weight is allocated.

This level based approach is illustrated using the similar two level author co-author genealogy tree in Fig. 2, where we have considered a author A_1 who have two co-authors A_{11} and A_{12} in the first level and author A_{11} has one co-author A_{111} in the second level. Now we will consider the second or last level author i.e A_{111} first. As the author A_{111} has no co-author, hence the influence will be 0. The h-index of A_{111} is 6. As the influence is 0, therefore the h_c-index of author A_{111} will be the same as his/her h-index, i.e, 6. Now, we consider the first level authors i.e A_{11}, h-index=4 and A_{12}, h-index=3. Similarly as A_{111}, A_{12} has no co-authors, hence A_{12} has 0 influence and hence h_c-index will be same as his/her h-index, i.e, 3. But author A_{11} has a co-author A_{111}. As A_{111} lies in the second level, hence the level based weight of the node will be 0.5 [using eq 4]. So, the W_L between author A_{11} and co-author A_{111} is 0.5 and the h_c-index of A_{111} is 6. Hence the influence from author A_{111} will be 3 [using eq 2] Hence the h_c-index

of A_{11} will be 7[using eq 3]. Now, the top most author of the tree i.e, A_1 having h-index=5, have two co-authors, A_{11}, h_c-index=7 and A_{12}, h_c-index=3. Similarly as A_{111}, the weight values of A_{11} and A_{12} will be 1[using eq 4]. So, the influence from A_{11} and A_{21} will be 5 [using eq 2]. Hence, finally the h_c-index of author A_1 will be 10 [using eq 3].

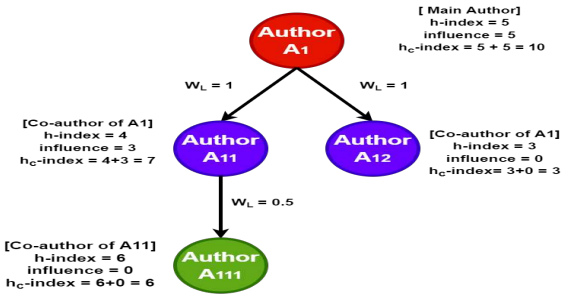


Fig. 2. Pictorial example of co-authorship Network without considering the contribution of the author with their co-author (Level based approach)

Algorithm 2 Calculate weight value of each node: W_{ls}(level based)

```
n ← no of child node presents in same level.
s ← co-author t node number initialise to 0
l ← co-author t node level position in tree & initialise to 1
L ← total level of the tree
while l ≤ L do
    while s ≤ n do
        W_ls ← 1/l
return(W_ls)
end
```

V. Experiment

In this section, we have discussed the different experiments that we have performed in this article.

Following the above step, we have now considered two conditions to obtain the h_c-index or the newly modified h-index:

1) Share-Based (considering the author's collaboration with his/her co-authors as the node weight.)
2) Level-Based (considering the author's level based weights).

Considering the above conditions, we have computed the h_c-index and compared them with author's own h-index.

A. Considering author's collaboration with co-authors:(Sharing Based)

It is the normal condition that we discussed in Methodology section. We considered the level wise weight factor along with the Collaboration Probability (CP) and obtained the h_c-index according to it. The results are presented in table II and plotted in fig 3.

B. considering the author's level based weights: (Level Based)

In this condition, the level wise weight factor is considered to obtain our newly proposed h_c-index. The results are presented in table III and plotted in fig 4.

VI. Results & Discussion

Now we see that, after computing the h_c-index using the two conditions mentioned in section V, we have got a huge difference between the modified h-index of the two conditions.

A. Sharing Based Weight

The results of the first condition i.e considering the share-based weights are presented in Table II. In this condition, it is observed that the difference between the h-index and the h_c-index is not very high. From the table, we can observe, for author **Sanasam Ranbir Singh** the percentage increase of the h-index to h_c-index has reached **65.92%**. The h-index was **13** and after adding share-based influence it increased to **21.57**, which is an indication good quality author.

TABLE II
Comparison Table between h-index and Share based h_c-index.

Author Name	h-index	Level	h_c-index	Percen--tage Increase
Satyadev Nandakumar	3	2	3.71	23.75
Aryabartta Sahu	6	2	6.84	14.01
Ruchir Gupta	8	2	9.09	13.65
Mayank Singh	9	2	13.2	46.67
Sathya Peri	10	2	11.80	17.98
Gadadhar Sahoo	10	2	11.35	13.50
Krishna Prasad Miyapuram	11	2	12.09	9.93
Kotaro Kataoka	11	2	12.85	16.82
Hemangee K Kapoor	12	2	12.89	7.38
Sudharsan Iyengar	12	2	12.41	3.44
Sanasam Ranbir Singh	**13**	**2**	**21.57**	**65.92**
Sushanta Karmakar	15	2	17.5	16.67
Antony Franklin	15	2	15.99	6.60
Dharavath Ramesh	18	2	21.48	19.33
Ranveer Singh	19	2	24.08	26.74
Arobinda Gupta	21	2	30.78	46.58
Kolin Paul	24	2	25.1	4.58
M Balakrishnan	43	2	44.46	3.40
Pushpak P Bhattacharyya	49	2	51.79	5.69
Krithi Ramamritham	83	2	84	1.20

The variation of the h-index of an author to the h_c-index of that author with collaboration probability is illustrated clearly in Fig. 3 with the help of a bar plot. From the plot, we can observe that the level of co-author is directly proportional to the value of the h_c-index. The overall increase variation of the two indexes is uniform and not very high.

B. Level Based Weight

The result of the second condition, i.e the level-based h_c-index, is presented in the Table III. In this condition, it is observed that the difference between the h-index and the h_c-index is huge.

Now, the variation of the h-index of an author to the h_c-index of that author without collaboration probability is

Fig. 3. Variation of h-index and share based h_c-index

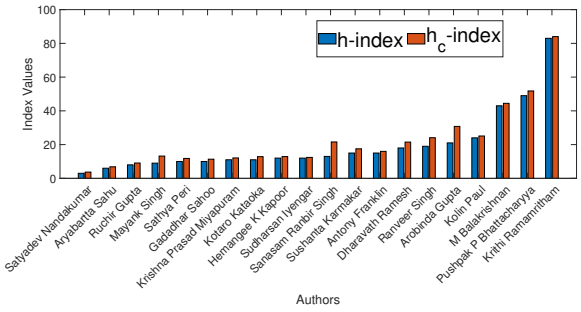
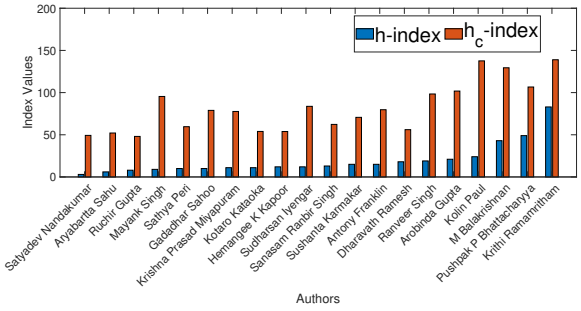


Fig. 4. Variation of h-index and level based h_c-index



depicted in Fig. 4 with the help of a similar bar plot. From the plot, we can observe that as the level of co-author increases the value of the h_c-index also increases. But unlike the previous case, the overall increase variation of the two indexes here is non-uniform and very high.

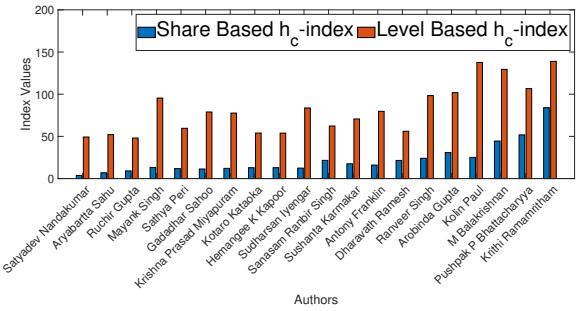
TABLE III
COMPARISON TABLE BETWEEN h-INDEX AND LEVEL BASED h_c-INDEX.

Author Name	h-index	Level	h_c-index	Percen--tage Increase
Satyadev Nandakumar	3	2	49.28	1542.67
Aryabartta Sahu	6	2	52.10	768.33
Ruchir Gupta	8	2	48.06	500.75
Mayank Singh	9	2	95.42	960.22
Sathya Peri	10	2	59.58	495.80
Gadadhar Sahoo	10	2	78.92	689.20
Krishna Prasad Miyapuram	11	2	77.64	605.82
Kotaro Kataoka	11	2	53.96	390.55
Hemangee K Kapoor	12	2	53.86	348.83
Sudharsan Iyengar	12	2	83.72	597.67
Sanasam Ranbir Singh	13	2	62.30	379.23
Sushanta Karmakar	15	2	70.66	371.07
Antony Franklin	15	2	79.7	431.33
Dharavath Ramesh	18	2	56.06	211.44
Ranveer Singh	19	2	98.36	417.68
Arobinda Gupta	21	2	101.82	384.86
Kolin Paul	24	2	137.6	473.33
M Balakrishnan	43	2	129.42	200.98
Pushpak P Bhattacharyya	49	2	106.64	117.63
Krithi Ramamritham	83	2	138.94	67.40

C. Comparative analysis between share based and level based weight

The bar graph shown in Fig. 5, depicts the variation of the modified h-index of an author with collaboration probability (Share Based) to the h_c-index of that author without collaboration probability (Level Based). From the plot, we can observe that as the level of co-author increases the value of the h_c-index, for both the cases it also increases. But its also observed that the blue graphs which include the collaborative property show a uniform increase in their h_c-index as compared to the orange graphs where the collaborative property is excluded showing a high non-uniform increase.

Fig. 5. Variation of share based h_c-index and level based h_c-index.



So, without considering the collaboration probability, the co-author's all work's impact will be given to the author. This is not a correct transfer of impact.

Hence, considering the collaboration factor and calculating the h_c-index is the correct approach.

D. Case Study: Satyadev Nandakumar authors influence h_c-index

In section *B*, i.e. condition of considering level based weight, from table I it is observed that author **Satyadev Nandakumar** have got huge influence from his co-authors. His h_{own} or simple h-index was **3**. But after level-based influence, the modified h-index or h_c-index reached to **49.28** and the percentage increase is **1542.67%**. This result seems to be incorrect. So, to judge the correctness of this result, we specially performed a case study on this author. The level-wise author co-author genealogy tree is represented in tabular form in table IV. The h-index and the influence of the co-authors are illustrated through the bar plot in fig 6.

Now from the table and the figure, we can observe that the co-authors of the author **Satyadev Nandakumar** have a very high h-index count and due to level-based weight, their whole influence is get adding up to their authors. Hence this is the reason for the huge increase of the h_c-index of author **Satyadev Nandakumar**.

VII. CONCLUSION & FUTURE SCOPE

Although we have our proposed indexing mechanism over a small number of authors, but have seen promising result in term of h-index accuracy. As the author ranking depends on

Fig. 6. Effect of h-index of an author Satyadev Nandakumar set level based weight value

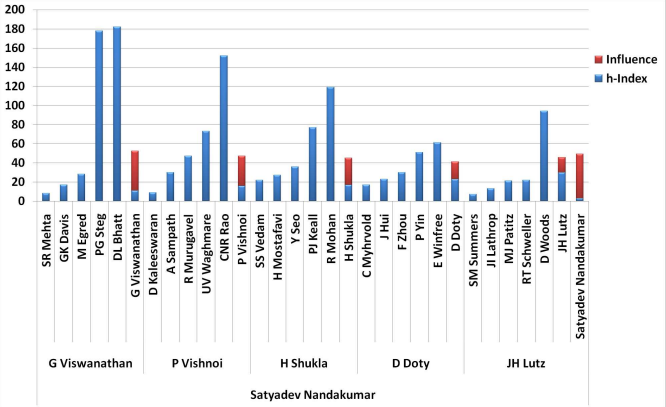


TABLE IV
CASE STUDY OF AN AUTHOR SATYADEV NANDAKUMAR SET LEVEL BASED WEIGHT VALUE

Root Author	Level 1	Level 2	h-Index	Level hc	Influence
Satyadev Nandakumar			3	49.28	46.28
	D Doty		23	41.2	41.3
		C Myhrvold	17	17	0
		E Winfree	61	61	0
		F Zhou	30	30	0
		J Hui	23	23	0
		P Yin	51	51	0
	G Viswanathan		11	52.3	31.1
		DL Bhatt	182	182	0
		GK Davis	17	17	0
		M Egred	28	28	0
		PG Steg	178	178	0
		SR Mehta	8	8	0
	H Shukla		17	45.1	28.1
		H Mostafavi	27	27	0
		PJ Keall	77	77	0
		R Mohan	119	119	0
		SS Vedam	22	22	0
		Y Seo	36	36	0
	JH Lutz		30	45.7	18.2
		D Woods	94	94	0
		JI Lathrop	13	13	0
		MJ Patitz	21	21	0
		RT Schweller	22	22	0
		SM Summers	7	7	0
	P Vishnoi		16	47.1	15.7
		A Sampath	30	30	0
		CNR Rao	152	152	0
		D Kaleeswaran	9	9	0
		R Murugavel	47	47	0
		UV Waghmare	73	73	0

the author h-index, citation, and the number of publications, so, the h-index only depends on the direct relationship between the two papers. Next phase, we have established the co-authorship genealogy tree for different levels. At last, we concluded that as the level of co-author increases the value of the h_c-index, for both cases (share-based and level based) this metric also increases. However, we also observed from these two cases that the share-based evaluation gives more exact solution as this includes the share factor which is the number of publications for each of the co-authors with the above-level author.

In this article, we have used a small number of authors' datasets and a simple programming approach to obtain the modified h-index. In future work, we will use a wide range of dataset to obtain the modified h-index. Lastly, we can also apply the index with the help of Machine Learning approach to obtain the h-$_c$-index.

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