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Research collaboration and knowledge development in Africa: the case of neonatal conditions

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Abstract
The literature has discussed the positive/negative effects of research collaboration (RC). However, no study looks at the effect of RC especially international research collaboration (IRC) on key developments in a research area. Using Main Path Analysis (MPA), I examined the literature on neonatal conditions (NC) produced by African scientists between 2000 and 2019. I found the (1) estimates of deaths of children under five years and their causes, with a focus on neonates and stillbirths, (2) usefulness of tools to collect data on NC-related variables, (3) identification of interventions to reduce deaths, and (4) treatment of hyperbilirubinemia in African neonates as the most important developments in NC in Africa. The high presence of articles with RC, in the MPA, especially those involving IRC between one or more scientists from a single African country and scientists from several non-African countries (60% of the studies) highlights the positive effect of RC on key developments of an area. About 40% of the articles refer the Saving Newborns Lives programme, the Child Health Epidemiology Reference Group (CHERG) or the departments of the World Health Organization (WHO).

Keywords Neonatal conditions · Main path analysis · Research collaboration · Africa · World Health Organization

Introduction

In Africa, RC has been pointed out as an important means of enhancing the continent's scientific capabilities. The Science, Technology and Innovation Strategy for Africa 2024 (AUC, 2014, p. 38), the National Science, Technology and Innovation Policy (2017–2020)[1] of Ghana, and the National Science, Technology and Innovation Policy[2] of Rwanda (p. 21) highlight the need to concentrate efforts around RC.

[1] https://mesti.gov.gh/wp-content/uploads/2017/07/Draft-National-STI-Policy-Document-10-July-2017.pdf
[2] https://www.mineduc.gov.rw/index.php?eID=dumpFile&t=f&f=17135&token=c64ea84e90450da78859 8d96cc37bcd124d001e7

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The acknowledgement of the importance of RC is not limited to policy documents. The vast literature that examined the patterns (e.g., Boshoff, 2009; Owusu-Nimo & Boshoff, 2017), driving factors (e.g., Muriithi et al., 2018; Owusu-Nimo & Boshoff, 2017), effects (e.g., Schmink et al., 2020; Zdravkovic et al., 2016), networks (e.g., Adams et al., 2014; Vieira & Cerdeira, 2022), and asymmetries (e.g., Nago & Krott, 2020; Owusu-Nimo & Boshoff, 2017) related to IRC in Africa are also relevant to strength the role of RC in the continent (Vieira, 2022).

However, the literature has not examined the effect of RC, in particular IRC, in key knowledge in Africa. Are the key developments of an area the result of RC, especially IRC? If they are, therefore, we can state that RC has been shapping the main developments of a research field.

The paper examines this gap by looking at the scientific knowledge developed by African scientists related to NC. The WHO determines the disability–adjusted life year (DALY)[3] for several health conditions classified into three broad cause group. NC belong to the group of communicable, maternal, perinatal, and nutritional conditions. The preference for this subject stem from its position regarding productivity losses in Africa. A study concluded that the diseases affecting Africans were responsible for a substantial loss of health, estimated at 629 603 271 DALYs in 2015 for the WHO African region, and that NC are the third largest cause of productivity losses in Africa (GDP losses amount to Int$347 336 223 573[4] in 2015 (WHO, 2019)). These high losses and the fact that I was pregnant at the time of this study (a very personal motivation) are the main reasons for choosing NC.

The study makes several contributions. First, it is the first study to examine the presence of RC on the main trajectories of development of a research area. Second, if the main developments of a research area are a consequence of RC, then we add to the theoretical stream dealing with the effects of RC. Third, policymakers have empirical evidence that can be used as input for RC–related policy decisions, especially in resource-limited settings. Fourth, it is the first study to unveil the main developments on NC in Africa, according to MPA. Fifth, from a methodological perspective, I showed how the MPA can be extended to study a variable of interest, RC.

The paper is structured as follows: In the next section, I draw on the literature to develop a framework for the effects of RC; in the methodology, I describe the data collection and the MPA; in the results and discussion, I present and discuss the statistics on the number of articles on NC, the citation network and the MPA; in the conclusions, I list the main findings and limitations of the study.

Framework

The literature has discussed the effects of RC from a positive and negative perspective. Collaboration may occur between scientists working at institutions that are subject to different laws, rules, norms, and missions. Therefore, it is to be expected that the effects will be different from the perspective of each type of institution (Arza, 2010; Welsh et al.,

[3] It is a measure of overall disease burden expressed as the number of years lost due to ill-health, disability or early death. It is calculated as the sum of the Years of Life Lost (YLL) due to premature mortality and the Years Lost due to Disability (YLD) for people living with a health condition or its consequences.

[4] International dollars—a hypothetical unit of currency that has the same purchasing power parity that the US dollar had in the United States at a given point in time.

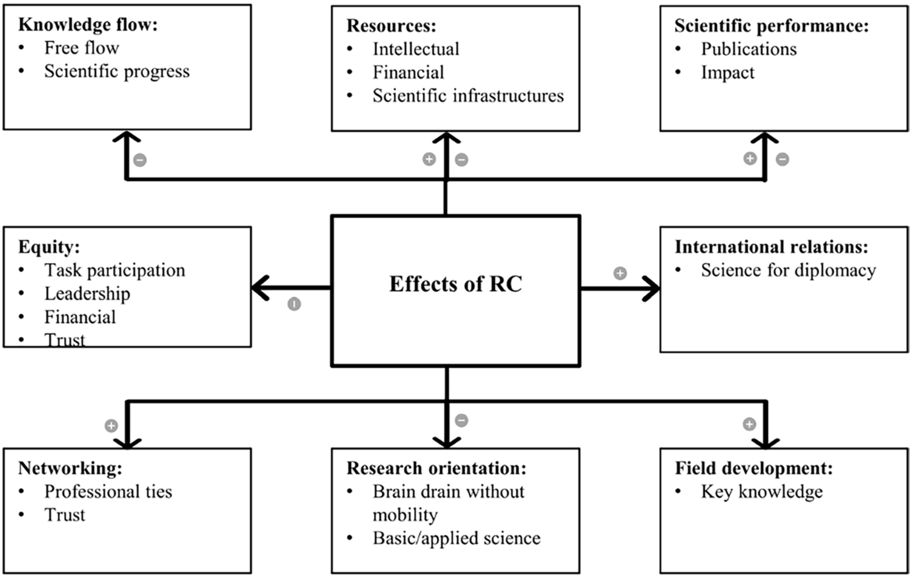

Fig. 1 Framework of the positive/negative effects of RC from the perspective of academic scientists

2008). Here, I focus on the literature addressing the effects from the perspective of universities to present a framework on the positive/negative effects (Fig. 1).

Resources

Scientists who lack scientific expertise, infrastructures and funding to conduct their research seek RC with other scientists (Katz & Martin, 1997). Therefore, the positive effect of RC on access of resources is widely highlighted in the literature.

In university-industry collaborations (UICs), scientists working in an academic environment often cite access to funding for students and additional research money as a benefit (Ankrah & Al-Tabbaa, 2015; Arza, 2010; D'Este & Perkmann, 2011; Lee, 2000; Meyer-Krahmer & Meyer-Krahmer, 1998; Perkmann et al., 2013; Tartari & Breschi, 2012; Welsh et al., 2008). Also, the intellectual resources arising from these relationships can provide new insights into the research agenda and lead to new projects (Arza, 2010; Garcia et al., 2019; Welsh et al., 2008). However, this type of collaboration can also result in the denial of resources. There is evidence that academics involved in UICs decline requests from other academics to share data and knowledge as consequence of agreements of confidentiality. On the other hand, they are also more likely to be denied access to other scientists' research findings (Blumenthal et al., 1996; Campbell et al., 2000; Tartari & Breschi, 2012; Welsh et al., 2008).

In RC between scientists from high-income countries (HICs) and low- and middle-income countries (LMICs) or low-income countries (LICs), also known as North–South collaborations (NSCs), scientists from the South cite access to funding for conferences, the development of infrastructures, and access to scientific equipment as benefits in addition to funding for doctoral students (e.g., Chandiwana & Ornbjerg, 2003; Efstathiou et al., 2014; Kok et al., 2017; Matenga et al., 2019; Noormahomed et al., 2017; Tierney et al., 2013).

Scientists from the South also have cited the improvement of expertise through the access to new knowledge (Mathai et al., 2019; Paina et al., 2013; Tierney et al., 2013).

Scientific performance

Without claiming to be exhaustive, behind this positive effect may lie the fact that scientific problems are becoming increasingly complex and only the combination of skills and scientific expertise of several scientists makes it possible to cope with these situations. Ultimately, it is expected that one will arrive at knowledge that would not exist if a single scientist were to devote himself to these problems. At the same time, combining different intellectual resources will enable more rigorous critical thinking and increase the quality of new knowledge. Moreover, tacit knowledge can be better shared via RC (Gertler, 2003; Storper & Venables, 2004), which will contribute to improving the quality of the knowledge.

The empirical literature confirms the increase in the number of publications (Achachi et al., 2016; Gulbrandsen & Smeby, 2005; Mirnezami & Beaudry, 2022; Ranga et al., 2003; Sabah et al., 2019), and their impact (Abramo et al., 2009; Aldieri et al., 2018; Mirnezami & Beaudry, 2022; Polyakov et al., 2017) as a benefit.

However, the literature also reflects on the negative effects. UICs can end up with the non-, delayed, or incomplete publication of research findings (Meyer-Krahmer & Meyer-Krahmer, 1998; Walsh & Huang, 2014; Zinner et al., 2009). Surveys examining NSCs have shown that scientists from the South are absent as authors of publications, despite actively and fundamentally contributing to research (Dahdouh-Guebas et al., 2003; Elobu et al., 2014; Matenga et al., 2019). In both situations and despite the possible increase of scientific expertise and the access to resources, the scientific performance of scientists as measured by the number of publications and their impact can not be evaluated. Regarding the NSCs, the effects go beyond scientific performance. Mistrust emerges and can affect future RC as scientists need to be involved in trusting relationships to achieve outcomes that are more important than their individual efforts. On the other hand, the contribution of the South to scientific knowledge published in scientific sources is underestimated.

Networking

The contact between scholars that results from RC enables the creation of socially embedded relationships involving trust (Boschma, 2005). The interactions based on trust enable the exchange of knowledge and ideas (Dhanaraj et al., 2004; Sherwood & Covin, 2008). The stronger these interactions become, the more likely the participation in joint future projects, i.e. the network created will persist. Also, the trust created can spread through the networks of individual scientists involved in RC, increasing the chances of meeting other scientists and in this way expanding professional ties (Newman, 2001). Scientists have cited increased networking as a benefit of RC (Currie-Alder et al., 2020; Munung et al., 2017; Schmink et al., 2020; Tierney et al., 2013; Welsh et al., 2008).

International relations

Science diplomacy have been used to (1) underpin foreign policy objectives with scientific advice (science in diplomacy), (2) address global challenges (diplomacy for science), and

(3) improve international relations between countries despite significant tensions between them (science for diplomacy) (Society, 2010; Turekian et al., 2015). RC has been used in science for diplomacy. Scientific cooperation agreements and large-scale research facilities have been established between nations that have conflicts to improve international relations between them and address global research problems. Examples include the agreements between the US and URSS to conduct research activities in a joint framework, the European Organisation for Nuclear Research in Europe, and the Synchrotron Light for Experimental Science and Applications in the Middle East in Jordan (Rungius et al., 2022). In short, science for diplomacy draws on the soft power of RC to improve international relations.

Knowledge flow

The knowledge that emerges from UICs can be disseminated in journals, conferences, or it can be used to create a patent that gives intellectual property rights (IPR). The discussion around IPR has addressed the positive/negative effects. As positive, we have the increased capacity that IPR can offer in implementing the commercial and social benefits of the new knowledge (Hellmann, 2007). As for negative effects, there is the "anti-commons" hypothesis. This is related to the fact that IPR can hinder the free flow and dissemination of knowledge, which can prevent scientific progress (Etzkowitz, 1998; Heller & Eisenberg, 1998; Murray & Stern, 2007). The literature has shown that for knowledge that is both disseminated in the scientific literature and protected by IPR, the granting of IPR is associated with a statistically significant and modest decrease in knowledge accumulation as measured by forward citations (in academic publications, Murray & Stern, 2007), i.e. knowledge flow is lower than for knowledge disseminated only in scientific literature.

Equity

In RC, equity should be a desired aspect for all scientists. Since the literature dealing with equity is vast, I will focus on NSCs where inequalities can have a devastating effect.

Several funding agencies (e.g., the Bill and Melinda Gates Foundation, the National Institutes of Health, the Research Council in the United Kingdom (UK) and the Wellcome Trust) support NSCs to tackle scientific problems relevant to the South, while contributing to increase research capacity in those countries.

However, power imbalances have been observed. Studies have reported the non-participation of Southern scientists in defining the research questions, planning and designing the various project components, deciding on the distribution of financial resources, and taking the lead (Costello & Zumla, 2000; de Schweinitz et al., 2009; Graef et al., 2019; Matenga et al., 2019; Nago & Krott, 2020; Schmink et al., 2020). Southern scientists usually provide access to local communities and collect the data, but in some RC their expertise is not sought after in analysing, interpreting and disseminating the results (Boshoff, 2009; Matenga et al., 2019; Nago & Krott, 2020; Owusu-Nimo & Boshoff, 2017).

These inequalities may result in a limited role for Southern scientists in the academic aspects of the work, transfer of knowledge and technology, and capacity building in the South (COHRED, 2013; Costello & Zumla, 2000). Furthermore, trusting interactions are not developed, which is not desirable, as trust is essential for promoting the exchange of knowledge and ideas.

Research orientation

In UICs, academics have mentioned that they choose to collaborate with industry on research topics that enable outcomes with commercial applications, even if this means moving towards research that is different from what has been done or that is not in line with the research agenda of public universities (Arza, 2010; Welsh et al., 2008; Zinner et al., 2009). These can be very damaging, especially if the new results are of lower societal value than those expected from universities that receive public funding to create socially useful knowledge. This type of collaboration can also mean a shift away from basic research in favour of applied research (Ankrah & Al-Tabbaa, 2015).

It has been showed that in NSCs the research agenda is set by the North and in many cases scientific problems are not prioritised to reflect the priorities of the South (Edejer, 1999; Elobu et al., 2014; Kozma & Calero-Medina, 2019; Nago & Krott, 2020; Wolffers et al., 1998). However, the low public and private investment in research and the low salaries of scientists from the South leave them without power to negotiate with scientists from the North (Wolffers et al., 1998).

The result is, on the one hand, a brain drain without mobility, as trained scientists use skills and acquire knowledge that is not essential for solving local problems. On the other hand, if scientists from the South constantly collaborate with those from the North, they will eventually become isolated from other colleagues in the South (Wolffers et al., 1998). To the extent that this isolation increases, there are no opportunities to build national networks that could address local problems.

Field development

Due to the increasing complexity of scientific and societal challenges, scientists have increasingly joined forces to conduct research. It is expected that a team of scientists is better able to deploy the resources needed to address a particular scientific and societal problem. The involvement of multiple scientists brings greater expertise in the form of tacit and codified knowledge, advanced equipment and social ties (Bozeman & Corley, 2004). All these resources are expected to lead to scientific breakthroughs by expanding the diversity of the knowledge pool and linking distant or similar sources of knowledge. Big Science communities are examples of a pool of resources aimed at achieving scientific breakthroughs. These communities, composed of dozens or hundreds of scientists, with access to extremely advanced scientific facilities and largely funded by various nations, are expected to provide answers to fundamental scientific questions and practical solutions to global problems in all areas of science.

However, the advances achieved through RC implies managing and mitigating several challenges. In large teams aiming to integrate knowledge from a multidisciplinary, interdisciplinary, or transdisciplinary perspective, effective communication and coordination of tasks must consider the epistemic culture of the disciplines involved (Hall et al., 2012).

When a scientific or societal problem requires the integration of knowledge from a transdisciplinary perspective, the greater time and effort required to achieve the final goal(s) compared to the other perspectives must be considered (Vogel et al., 2014).

Each scientist brings valuable expertise and may have his/her own goals (Bruneel et al., 2010; Winter & Berente, 2012). If the goals of these scientists do not coincide, this can lead to conflicts.

Other barriers related to RC include the geographical, cultural, and political distance between scientists from different countries[5] (Cerdeira et al., 2023; Vieira et al., 2022).

Thus, if RC involves a pool of resources that an individual scientist does not have access, and if it requires careful handling of the challenges involved, then the effort is only justified if the goal is to arrive at outstanding knowledge, i.e., knowledge that may represent the most important developments in an area.

Methodology

Data identification

I searched the keywords related to NC validated by peers in Confraria & Wang, 2020 in the titles, abstracts and keywords of each article, indexed in the Web of Science Core Collection (WoS) and published between 2000 and 2019, to find the relevant articles. The search query I developed is the following:

((ts = "Preterm birth" OR ts = "Birth asphyxia" OR ts = "birth trauma" OR ts = "Neonatal sepsis" OR ts = "neonatal infection*" OR ts = "Gastroschisis" OR ts = "Jaundice" OR ts = "Necrotizing enterocolitis" OR ts = "Persistent pulmonary hypertension of the newborn" OR ts = "Intrauterine growth restriction" OR ts = "Bronchopulmonary dysplasia" OR ts = "infant apnoea" OR ts = "infant respiratory distress syndrome" OR ts = "asphyxia at birth" OR ts = "anaemia in neonates" OR ts = "neonatal alloimmune thrombocytopenia" OR ts = "bronchopulmonary dysplasia" OR ts = "cardiac failure in neonates" OR ts = "hyaline membrane disease" OR ts = "hypocalcaemia in neonates" OR ts = "hypoglycaemia of the newborn" OR ts = "hyponatraemia in neonates" OR ts = "hypothermia in neonates" OR ts = "intestinal obstruction in neonates" OR ts = "pulmonary interstitial emphysema") and (cu = "South Africa" OR cu = "Egypt" OR cu = "Nigeria" OR cu = "Ethiopia" OR cu = " Rep Congo" OR cu = "DEM Rep Congo" OR cu = "Tanzania" OR cu = "Kenya" OR cu = "Algeria" OR cu = "Sudan" OR cu = "south sudan" OR cu = "MORocco" OR cu = "Uganda" OR cu = "Mozambique" OR cu = "Ghana" OR cu = "angola" OR cu = "somalia" OR cu = "Ivory Coast" OR cu = "cote ivoire" OR cu = "Madagascar" OR cu = "Cameroon" OR cu = "Burkina Faso" OR cu = "Niger" OR cu = "Malawi" OR cu = "zambia" OR cu = "mali" OR cu = "Senegal" OR cu = "Zimbabwe" OR cu = "Chad" OR cu = "Tunisia" OR cu = "Guinea" OR cu = "Guinea bissau" OR cu = "Equat Guinea" OR cu = "Rwanda" OR cu = " Benin" OR cu = "Burundi" OR cu = "Eritrea" OR cu = "Sierra Leone" OR cu = "Togo" OR cu = "Libya" OR cu = " CENT AFR REPUBL" OR cu = "Mauritania" OR cu = "Liberia" OR cu = "Namibia" OR cu = "Botswana" OR cu = "Lesotho" OR cu = "Gambia" OR cu = "Gabon" OR cu = "Mauritius" OR cu = "Eswatini" OR cu = "swaziland" OR cu = "Djibouti" OR cu = "Comoros" OR cu = "Cape Verde" OR cu = " SAO TOME & PRIN " OR cu = "Seychelles") and py = 2000–2019).

I extracted the metadata of 1784 articles published by at least one scientist (not all authors of a publication are scientists in the strict sense of the word, but for simplicity I use this word) whose affiliation is to an institution in Africa (hereafter African scientists). However, the use of discipline–specific terms imposes limitations that affect the accuracy

[5] A full discussion of the challenges posed by these distances can be found elsewhere (e.g.,Cerdeira, Mesquita, & Vieira, 2023; Vieira, Cerdeira, & Teixeira, 2022). Due to limited space in this journal, these challenges are not discussed in detail here.

of the methodology, due to the multiple meanings and multiplicity of discipline–specific terms required to represent a topic. Then, I analysed each article and selected those related to NC in Africa. The final set has 1250 articles. I considered those articles that:

- mention in the clinical trial, or other population sample, African participants (e.g., Venkatesh et al., 2019). If the origin of the participants in the study is not indicated, I only considered the articles that were written exclusively by African scientists,
- compile statistics at the global level and specifically for Africa on causes of death and NC (e.g., Lozano et al., 2012),
- in the studies obtained through a meta-analysis are reported clinical trials conducted in Africa, or other population samples with Africans (e.g., Romero et al., 2012).

As for the approach to extract the articles on NC, I must emphasise the less positive points.

It can happen that non-African scientists are researching on NC without the collaboration of African scientists and therefore research on NC is not included. This behaviour is known in the literature as parachute science, where scientists, usually from HICs and well-equipped, arrive in non-native regions or populations, usually in resource-poor areas, collect information and samples, and return to their home country to conduct research with this information, ignoring the knowledge of local scientists or others on the subject (e.g.,Stefanoudis et al., 2021).

However, the literature has shown that in the poor populations that face the greatest burden from disease, that burden is given the least medical research attention by the international community, mainly those from the HICs. Most of the research on Medical and Health Sciences (M&HS), which includes NC, have been done by HICs and they have addressed their local scientific problems, which are very different from those of Africa (Atal et al., 2018; Evans et al., 2014). In the specific case of NC, it has been shown that at the global level, there is very little research in relation to its burden (Rafols & Yegros, 2017), a burden that is very prevalent in Africa and contributes heavily to global statistics (e.g., Ou et al., 2022).

Finally, in the set obtained not all the research may be related to the NC in Africa. It has been mentioned that foreign funding aimed at joint research by African and non-African scientists has in several cases been allocated in a blind way, reflecting donor politics and preferences rather than addressing the real problems of local populations (Gaillard, 1992; Swingler et al., 2005). In the specific case of medical and health research, it has been shown, in research involving African and non-African scientists, that while 67% of the total 520 clinical trials conducted in Africa addressed local scientific problems, in 14% the research addressed the needs of developed countries (Swingler et al., 2005).

Through this approach, I tried to avoid as much as possible research that is not according to local needs. However, I must admite that a complete validation is only possible with the involvement of the African community specialised in NC.

Main path analysis

The citations in articles contain information on how the knowledge disseminates, and therefore, they have been widely accepted for reviewing the intellectual structure and longitudinal trajectories of a particular area.

Using the citations, I was able to construct a bibliographic network (directional and acyclic) and determine its density, number of components, in-degree, out-degree and betweenness centrality for each node. In constructing the network, I disregarded the citations made by the target articles to articles other than the target/core articles, i.e. I used a closed system that was also applied in several studies (e.g., Batagelj et al., 2017; Ho et al., 2014; Maltseva & Batagelj, 2019).

In disregarding the citations to these articles, I aim to:

1. Avoid the high presence in the MPA of articles that are not related to NC.
2. Avoid the high presence in the MPA of articles on NC that do not address NC in Africa but NC on subjects that are more relevant in other regions.

While concerning the first point it is difficult to discuss how likely this scenario is, with regard to point 2, I would say that the probability could be high, if we consider that most of the studies in the M&HS, to which the NC belongs, have been conducted by scientists from HICs, i.e. high resource countries (this research area implies high amounts of resources) (Emdin et al., 2015; Rafols & Yegros, 2017). At the same time, the topics addressed in HICs are based on local needs, which are very different from those in Africa (Atal et al., 2018; Evans et al., 2014).

However, I must recognise the limitations. It may be that research on NC conducted only by non-African scientists, or research on topics other than NC conducted by African and/or non-African scientists, has yielded results that are important contributions to research on NC in Africa. In both cases, the results of this research are not observed in the MPA.

The MPA focus on sequences of edges and nodes, called search paths, to identify the most significant historical path(s) in the target citation network (Hummon & Doreian, 1989). The idea behind MPA is that the main path(s) summarise(s) the main developments in each area as well as how the main ideas build upon each other. A detailed description of the methodology can be found in the Supplementary Material (SM).

After identifying the articles in the MPA, I analysed the presence of articles with RC. As for IRC, I examined occurrences between: (1) African scientists all from the same country and non-African scientists (IRC_{inter}); (2) only African scientists from different countries (IRC_{intra}); (3) African scientists from different countries and non-African scientists ($IRC_{inter\text{-}intra}$). As for DRC, I included articles that only represent RC within boundaries between scientists working in the same or different institutions.

In the analysis, I used Gephi 0.10.1 to construct the network and determine the statistics and Pajek to do the MPA.

Results and discussion

The knowledge on NC, and published through articles, have been increasing over time. In 2000–2009 there are 180 articles indexed in the WoS and 1070 in 2010–2019 (Fig. 2), about 6 times the number of articles in 2000–2009.

As for RC, the number of articles with DRC and IRC increased (Fig. 2) but the representativeness of those with DRC decreased from about 49% (most representative in 2000–2009) to 44% in 2010–2019. Articles with IRC account for about 55% of total articles in 2010–2019, compared to about 47% in 2000–2009.

Egypt, South Africa, Nigeria, Tanzania, and Kenya contributed the most to NC research (SM, Table A1); they produced about 63% of the total articles. The United

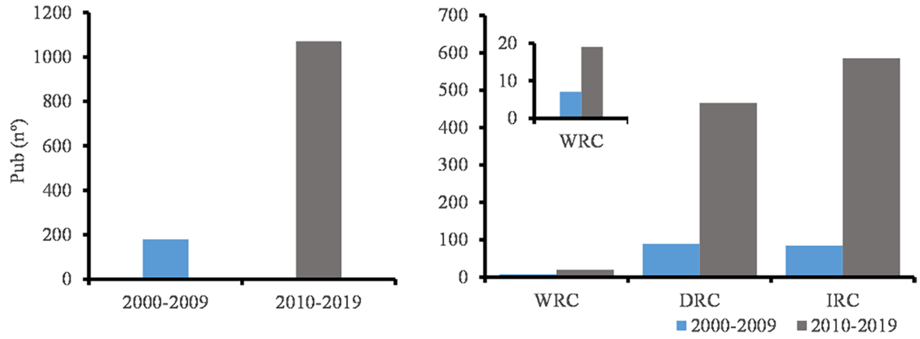

Fig. 2 The total number of articles on NC published by African scientists and indexed in the WoS, and the total number of articles without collaboration (WRC), with DRC and IRC

Table 1 The number of articles with DRC or IRC in the MPA, the relative weight of each type of collaboration given the total number of articles in the MPA(Pub_{MPA}) and the total number of articles of each type of RC in the database (last column)

Collaboration type	Pub (no)	Pub_{MPA} (%)	Pub (%)
DRC	6	24	1.08
IRC	19	76	2.84

Table 2 The number of articles with IRC_{inter_intra} and IRC_{inter} in the MPA, and the relative weight of each type of collaboration given the total number of articles in the MPA (Pub_{MPA}) and the total number of articles of each type of IRC in the database (last column)

Collaboration	Pub (no)	Pub_{MPA} (%)	Pub (%)
IRC_{inter_intra}	4	16	3.67
IRC_{inter}	15	60	2.77

States of America (USA) and the UK have been the main partners (SM, Table A2). India and Pakistan also feature in the top 10. A detailed analysis of the articles produced in collaboration with these countries revealed research with multinational clinical trials conducted in India, Pakistan, African countries, and other regions. Also, the high mortality rate due to poor NC is an unfortunate reality in India, Pakistan, and South Asia in general. Therefore, it is not surprising that both regions are collaborating to address scientific issues on NC.

Figure 3 shows the network for the 1250 articles on NC. Eliminating the citations to articles that are not the target resulted in a less dense network than the one with all cited documents. Of the total possible links, only 0.1% (density equal to 0.001) are observed. In terms of degree distribution, both citations received and made are right-skewed, with most nodes receiving and/or making no or few citations and a few nodes making many citations (Fig. 4; Table A4 in SM).

In the network, we see a giant component (in the centre) comprising 761 nodes, and several components with isolated nodes (a total of 396, see Table A3 in the SM). Looking at the giant component, it is not easy to decipher the knowledge flow. Even if you sort the

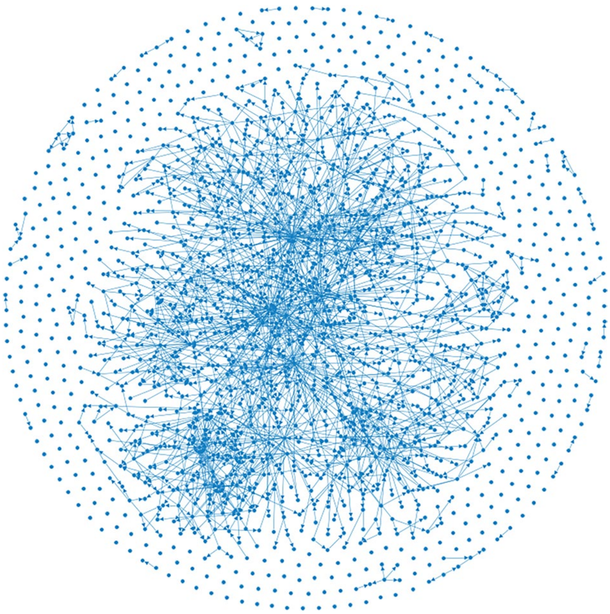

Fig. 3 Direct network for the 1250 articles on NC. The network was obtained using the Fruchterman Reingold algorithm

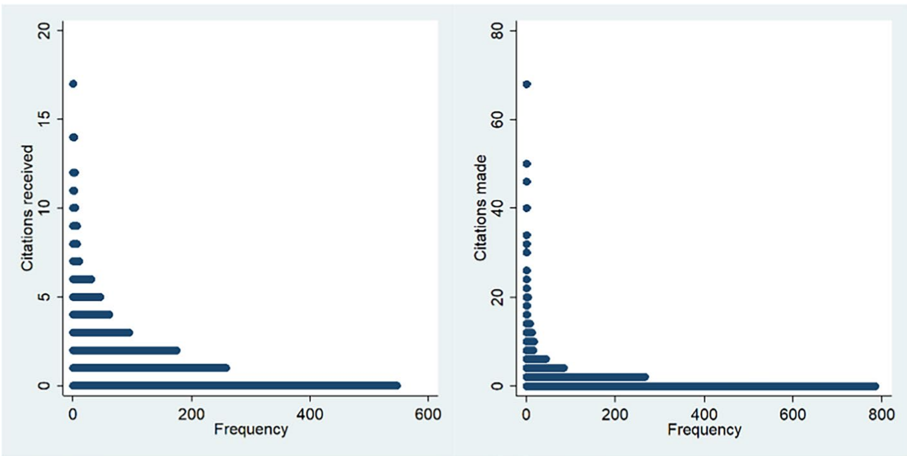

Fig. 4 Frequency distributions of citations received and made

network, the graph is too large to interpret and draw the main developments of the NC. Therefore, the MPA is expected to expand our knowledge of the most important pathways.

As for the MPA, the subnetwork with the top 5 edges is characterised by the absence of patterns of convergence-divergence (SM, Figure A1). These patterns are seen in the subnetworks that contains the top 10, 15 and 20 edges (SM, Figures A2 and A3 and Fig. 5 below, respectively). In Figures A2 and A3 the nodes are the same, the difference is on the edges. In Figure A3, we see two more edges; one between node 55_2009 (Pattinson et al., 2009) and 11_2011 (Lawn et al., 2011) and another between node 3_2012 (Blencowe et al.,

Table 3 The average number of authors according to the type of collaboration

Collaboration type	No of authors (average)
DRC	3.0
IRC	13.1
IRC_{inter_intra}	30.5
IRC_{inter}	8.5

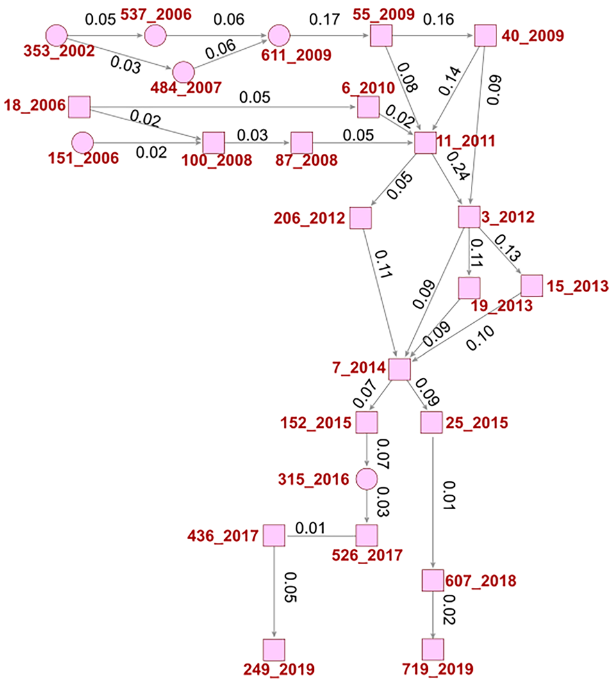

Fig. 5 MPA according to the different types of research collaboration: DRC (ellipse) and IRC (box). It includes as seed the top 20 edges. The links' weights are normalized

2012) and 7_2014 (Lawn et al., 2014). In Fig. 5, the number of nodes increases to 25 and includes all nodes from Figures A2 and A3, we have three sources, and several points of convergence-divergence where 11_2011 and 7_2014 stand out (4 links point inwards at both).

Choosing the MPA that best represents the main developments on NC is a complex task, as there is no way to define the optimal number of top edges to consider. A restrictive selection could lead to the exclusion of studies that represent important developments. On the other hand, selecting a large number of edges could lead to subnetworks that are difficult to interpret when many paths are displayed. Therefore, I describe the subjects addressed by the studies in Fig. 5 (it considers the 20 top edges) focusing on the points of convergence/divergence. The main conclusions of the studies are not mentioned in what follows, but a brief description can be found in the SM.

The topics covered can be summarised as follows:

- Estimates of death of children under five years with a focus on neonates and stillbirths

- Identification and estimates of major causes of death
- Identification and estimation of deaths due to "avoidable factors"
- Development and usefulness of tools to collect data on variables relevant to NC
- Identification of interventions to reduce the number of deaths
- Treatment of a condition that is common in neonates in Africa- hyperbilirubinemia.

In this set of studies there are those that present estimates and epidemiological data for countries other than Africans, i.e. they are comprehensive studies. However, Africa is discussed because of the highest number of deaths.

In Fig. 5, the path whose source is node 353_2002 (Buchmann et al., 2002), contains studies dealing with intrapartum-related birth asphyxia and intrapartum stillbirths in Africa and other countries. The studies addressed obstetric causes and preventable factors. It also highlights the crucial role of tools as audits in collecting information (e.g. the main causes of death) that can be used to define interventions to reduce high infant mortality, especially in LMICs.

There are three points of divergence (the source, the node 55_2009 (Pattinson et al., 2009) and 40_2009 (Lawn et al., 2009)).

The initial study of intrapartum-related birth asphyxia was disseminated in two articles (node 55_2009 and 487_2007) that addressed similar issues (the causes of death from intrapartum hypoxia, preventable factors, and the ultimate causes of death of infants born asphyxiated).

The study of perinatal mortality audits (55_2009) in LMICs was disseminated in two studies. Node 40_2009 examined the interventions needed to reduce intrapartum stillbirths and intrapartum-related neonatal deaths worldwide and in LMICs in particular. Intrapartum care is discussed from different angles, as is the crucial role of perinatal audits, which were discussed in 55_2009. Node 11_2011 addressed the lack of statistics on stillbirths and provided epidemiological data to make recommendations to reduce the high rates, especially in LMICs. In discussing ways to improve national data, they drew on the 55_2009 findings and emphasised the importance of perinatal audits. In summary, the themes of the two studies are very similar.

The study in 40_2009 and already described was disseminated by two papers dealing with stillbirths and preterm births. In 11_2011, the authors used the results of 40_2009 to highlight the role of improved care in reducing stillbirths. In 3_2012 (Blencowe et al., 2012), the lack of national data on preterm births is stressed. Estimates are given for 184 countries, including African countries, with Africa standing out because of its high preterm birth rate. In discussing the main causes of preterm birth, they looked at 40_2009 to state that in Africa, provider-initiated preterm births (induction of labour or elective caesarean section) are rare and therefore these events can not be considered as causes.

In Fig. 5, the path whose source is node 18_2006 (Lawn et al., 2006), acknowledges the need to have estimates of the main causes of death in children under five years, with a focus on neonatal deaths. The study in 18_2006 used estimates to obtain statistics on the leading causes of neonatal death in 2000 worldwide and by region, including Africa. The study was disseminated through two papers that examined different topics, but both related to death in children under five years. In 100_2008 (Edmond et al., 2008), the authors assessed the accuracy of verbal autopsy (VA) as a tool to collect information on causes of death. Accuracy was assessed using causes of death reported by VA and those collected from four hospitals in central Ghana. The authors based their examination of accuracy on the classification system for causes of death developed in 18_2006. In 6_2010 (Black et al., 2010), the authors estimated the main causes of death of children under five years in 2008 worldwide, by region and country. They used the model presented in 18_2006 to estimate the main causes of death in neonates.

In Fig. 5, the path whose source is node 151_2006 (Baiden et al., 2006), like the previous path, acknowledges the need for statistics on causes of death of children under five years (including disaggregated data by type of death (perinatal, neonatal and stillbirths) and location of death, especially in sub-Saharan Africa (SSA) where most deaths occur. The authors argue that these figures are essential for setting strategies to reduce deaths and for developing and evaluating the performance of maternal and newborn health programmes. In addressing these issues, the authors used VA and Ghana as case studies.

All the above paths converge to node 11_2011, which was disseminated by 206_2012 (Pitt et al., 2012) and 3_2012 that are very different in terms of theme. In 206_2012, the authors examined funding to benefit only newborns or also to improve the health of other population groups and provided statistics for several countries, including those in Africa. In comparing the results of this study with those of 11_2011, the authors emphasised the consistency of the findings; stillbirths receive too little attention on the global health agenda. The study on node 3_2012, just described, used the study in 11_2001 to provide an overview of the definitions and variable cut-offs for pregnancy outcomes related to preterm births, and stillbirths, and used this information to identify statistics on preterm births for 184 countries, including Africans.

The study in 3_2012 was disseminated through three papers [19_2013 (Christian et al., 2013), 15_2013 (Lee et al., 2013) and 7_2014]. In 19_2013, the authors addressed the risk of stunting, wasting and being underweight in children aged 12–60 months in LMICs. As low birth weight can be associated with child growth, and preterm birth is related to low birth weight, the authors relied on the high preterm birth rates estimated in 3_2012 to highlight the need for estimates of stunting, wasting and underweight due to preterm birth. In 15_2013, the lack of national estimates for neonates born too small for gestational age at full term (term-SGA) and the co-occurrence of small for gestational age with preterm birth (preterm-SGA) in LMICs is highlighted. Using the statistics in 3_2013 on preterm birth, the authors present national and regional estimates of term-SGA and preterm-SGA in 138 LMICs, including Africans. Finally, in 7_2014, the authors aimed to review the status of newborn health and progress since the 2005 Lancet Neonatal Survival Series. The results of 3_2012 were used to discuss the estimated consequences of preterm birth in terms of neonatal mortality and stunting.

All the above paths converged to node 7_2014, a comprehensive study on newborn health and progress since 2005 as stated above. The research then diverged into two major paths that addressed different subjects.

The studies representing nodes 25_2015 (Althabe et al., 2015), 607_2018 (Massawe et al., 2018) and 719_2019 (Moshiro et al., 2019), looked at countries in Africa, Asia and America, and investigated the strategies to reduce the high rates of neonatal deaths. The administration of antenatal corticosteroids and antibiotics were the central themes.

The studies representing nodes 152_2015 (Slusher et al., 2015), 315_2016 (Olusanya et al., 2016), 526_2017 (Greco et al., 2017), 436_2017 (Keahey et al., 2017) and 249_2019 (Bell et al., 2019) are relate to hyperbilirubinemia in the context of African countries. Based on the high number of term or near-term newborn babies that are affected by hyperbilirubinemia as reported in 7_2014, these studies examined the performance of new procedures for the treatment of hyperbilirubinemia and tools used to estimate total serum bilirubin.

Looking at Fig. 5 and considering the previous description, nodes 11_2011 and 7_2017, important points of convergence-divergence, and to a less extent node 3_2012 stand out in the MPA. If we look at the betweenness centrality, the crucial role of these studies in the network also becomes clear. These nodes are among the top 3 nodes with the highest value (see Table A4 in SM). Thus, they have been very important in mapping key developments in the field of NC in Africa, the results they have arrived at are considered outstanding according to the MPA, and they are also actors whose findings drive research on NC in Africa, i.e. the knowledge gained feeds into other and different research topics within NC. Of the remaining nodes in the MPA (excluding the sources and sinks), 7 are in the top 25 with the highest betweenness centrality. Although the focus of the MPA is on the links in the network and not on the nodes, the results on betweenness centrality can be seen as a first, albeit weak, validation process of the obtained trajectory.

Finally, 10 of the 25 articles in the MPA refer to the Saving Newborns Lives programme, the Child Health Epidemiology Reference Group (CHERG) or some of the departments of WHO. In 7 of the 10 articles mentioned in the previous point, estimates on various topics (e.g., stillbirths, neonatal deaths, preterm birth rates) are reported at the global level or for LMICs. This highlights the crucial role of international organisations and their programmes in shaping key knowledge paths in each region.

As for RC, DRC is present in 24% of the total studies in the MPA and IRC in the rest (Table 1). Despite the similar presence of articles with DRC and IRC in the whole dataset, articles with DRC in the MPA account for 1.08% of the total articles with DRC in the database. In Fig. 5, the path that includes source 353_2002 contains mainly articles with DRC, 4 out of 6 studies if we consider node 40_2009. This path is observed in all MPAs, although node 484_2007 only appears in the MPA with the top 20 edges. This underlines the importance of African scientists developing knowledge on issues that are of great importance for the social and economic development of the continent. As scientific problems emerge and are researched, others are uncovered and could attract the attention of scientific actors from other regions.

As for the number of authors per paper, the average in articles with DRC is three authors per article, a very low number when compared with the other types of collaboration (Table 3).

The breakdown by type of IRC (Fig. 6) shows the presence of studies with IRC_{inter_intra} and IRC_{inter}, the latter being the most common (60% of the total nodes in the MPA, Table 2).

The studies with IRC_{inter_intra} addressed (1) perinatal audits, (2) estimations of stunting, wasting and being underweight in children aged 12–60 months due to preterm birth, (3) estimations of term SGA and preterm SGA, and (4) a hospital-based intervention to reduce neonatal mortality; the use of antenatal corticosteroids. In this type of collaboration, I also found the highest number of authors per article: 30.5 (Table 3). Consensus regarding this high number of authors is not possible. Since the studies refer to research conducted in LMICs, I initially thought that the high number of authors might be because the studies deal with clinical trials conducted in several LMICs. However, only in Althabe et al., 2015 (25_2015), did the 46 authors refer to clinical trials conducted in multiple countries.

All these studies addressed LMICs globally, except the one on 25_2015, and report results for African countries.

As for the IRC_{inter}, the topics studied are also diverse. This type of collaboration appears in the nodes that represent important points of convergence (11_2011 and 7_2014) and divergence (7_2014, two distinct paths emerged). Given the relevance of the issues addressed in the African context, I would expect collaborations involving African scientists from several countries. This is not the case, and even in both studies only three out of 21

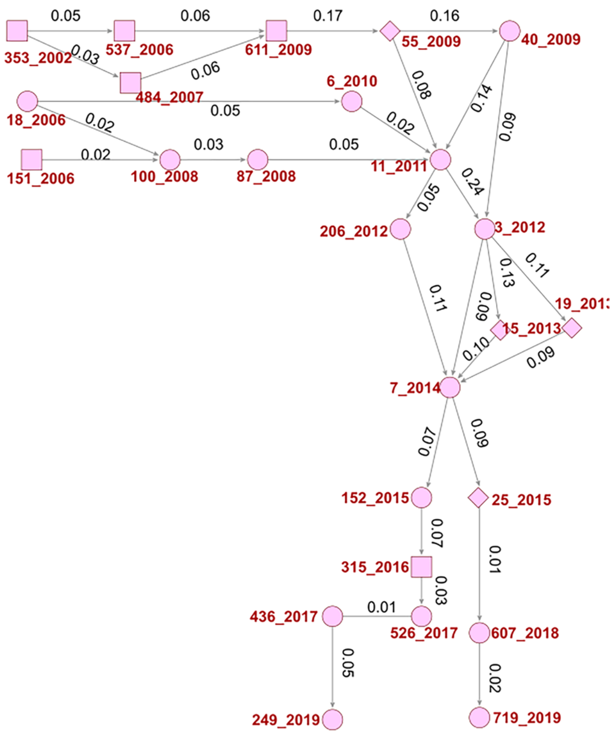

Fig. 6 MPA according to the different types of IRC: DRC (box); IRC_{inter} (ellipse); IRC_{inter_intra} (diamond). It includes as seed the top 20 edges. The links' weights are normalized

authors indicated institutions in Africa as affiliations (South Africa and Uganda). It is interesting to note that both studies are from Lancet study groups. The studies on 11_2011 and 7_2014 are the second in a series of six papers on stillbirths and a series of five papers on newborn health, respectively.

As for the African and non-African countries involved in the studies in the MPA, I found 9 out of 54 African countries (according to the United Nations (UN), Fig. 7), a very low number considering the high number of deaths in this region due to poor NC. Of all the African regions (according to UN), the countries of Central Africa are not represented in the MPA. All countries, except Egypt, belong to SSA, where high mortality have been estimated. In several studies, most of the countries in this set appear in the top 10 African countries that have produced more publications (e.g., Cerdeira et al., 2023; Vieira & Cerdeira, 2022). Therefore, besides their outstanding position in the continent in terms of volume of publications, their research plays a crucial role in defining the main trajectories in NC in specific. Moreover, their involvement in the International Research Networks (IRNs) in M&HS is an opportunity to expand the African network in NC. These countries, with the exception of Malawi and Zambia, are among the 10 African countries with the highest centrality in IRNs in M&HS (Vieira & Cerdeira, 2022). They also stand out in their region in the number of bilateral collaborations with other African countries within and outside the region in M&HS (Vieira & Cerdeira, 2022).

As for the non-African partners, the US and the UK were involved in a larger number of articles (Fig. 7). Several other countries also known for their outstanding scientific achievements were identified (e.g., Switzerland and Sweden). There are several partners from Asia, South and Central America (although the number of publications is small). The

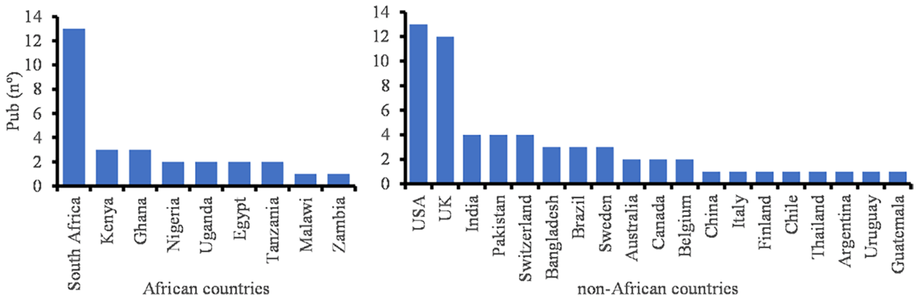

Fig. 7 The total number of articles of the African and non –African countries that appear in the MPA

explanation could be that these regions are also affected by a high mortality rate due to poor NC.

Conclusions

Research on RC is extensive, and the literature has highlighted six intellectual areas: drivers, patterns, effects, networks, measurement, and asymmetries (Chen et al., 2019; Vieira, 2022). The area dealing with the effects is at the heart of this study. The positive/negative effects of RC have been analysed, especially IRC. However, there is no study that looks at the effect of RC on key developments in a research area.

Looking at the literature, I developed a framework for the positive/negative effects of RC from the perspective of universities where I introduced the perspective dealing with the way RC drives the key developments of a research area. Then, I looked at articles published by African scientists on NC and applied MPA to examine the contribution of RC, particularly IRC, to key developments on NC in Africa.

The findings lead to a number of implications for both theory and practise:

- RC leads to positive/negative effects in terms of resources, scientific performance, networking, international relations, knowledge flow, equity and research orientation. Positive effects were observed in terms of resources (access to intellectual, financial and scientific infrastructure), scientific performance (rise of publications and impact), network (growth of professional ties and trust) and field development(RC, especially IRC, allows arriving at outstanding knowledge in a given field). Negative effects were also observed in terms of resources (denial access to data and knowledge when these come from a UICs), scientific performance (scientists from NSCs are not included as co-authors in publications despite their involvement in research, in UICS, delay non- or incomplete publications of research results, and mistrust). In addition, negative effects have been identified in terms of knowledge flow (no knowledge flow in the case of UICs due to IPR), equity (in NSCs, scientists from the South can be excluded from some research tasks, from deciding on the allocation of funding and from leadership) and research orientation (in UICs, research can be misaligned with the agenda of public universities and focus more on applied than basic science, in NSCs, conducting research that does not meet local needs leads to a brain drain without mobility).

- RC, especially IRC, dominates the studies retained in the MPA. Therefore, the theoretical stream dealing with the effects of RC and IRC, in particular, can be broadened to include the effect of RC on key developments in a research area, i.e., through RC, specially IRC, it is possible to arrive at outstanding knowledge, knowledge that is considered as the most important, in a given field.
- In a resource-constrained setting, policies to strengthen national scientific systems should consider that RC, as a source of intellectual, financial, and physical resources, can play a crucial role in achieving scientific breakthroughs according to local needs.
- In research on NC conducted in Africa, estimates of deaths and their causes, identification of preventable factors, interventions to reduce deaths, tools to collect data on NC-related variables, and treatment of hyperbilirubinaemia were the key developments according to MPA.
- In the research on NC conducted in Africa, only South Africa, Kenya, Ghana, Nigeria, Uganda, Egypt, Malawi, Tanzania, and Zambia appear in studies in the MPA. These countries are among the African countries with the highest centrality in IRNs in M&HS, so they represent an opportunity to expand knowledge on NC in Africa.
- In the research on NC conducted in Africa, the US and the UK are the main partners. Two countries with high centrality in the IRNs in M&HS and that are known by their outstanding scientific achievements.
- In the research on NC conducted in Africa, the intervention of the Saving Newborns Lives programme, Child Health Epidemiology Reference Group (CHERG), or some of the departments of WHO is highlighted showing the crucial role of these entities in shaping key knowledge in a region.
- From a methodological perspective, the streaming dealing with MPA should extend its applicability to examine the impact of variables that may be of interest, i.e., go beyond the usual identification of the main path(s).

Limitations

Apart from the reservations I have expressed about the approach used to arrive at the articles on NC and the use of a closed system in MPA, I must acknowledge the limitations of the study in terms of the over selectivity of the MPA and the lack of external validation of the main path obtained.There are also the limitations related to the chosen database, but they are well known in the scientific community.

As far as over selectivity is concerned, the identified main path often consists of only a few publications, even if the network has several thousand publications. These few publications may not fully represent the main developments. Although algorithms such as the key route allow us to select the number of edges to be included, if the number is too high, we can end up with a main path that contains less significant links or that overlaps with existing paths to a large extent (Martinelli, 2012), thus blurring the governing structure of knowledge dissemination paths.

Regarding the validation of the key developments arrived at using MPA, Hummon & Doreian, 1989 looked by corroborative evidence using several events: historical account, the presence of authors that gained Nobel Prizes and nodal weighting. The authors concluded that the publications identified by MPA were indeed representative of the most important developments in DNA research. Barberá-Tomás et al., 2011 have also found a high proportion of the most important patents in the technological evolution of the artificial disc in the main path identified by MPA. Filippin, 2021 using the opinion of experts as a validation method, found that in the semiconductor industry, although important patents on this topic were found in the key developments reported by MPA, some others were missing. They cited the over selectivity of the MPA and the use of patents as an outcome to measure innovation as possible explanations for these missing patents.

Although the studies mentioned above point to a good capacity of the MPA in identifying key developments in a field, in this study the validation of the results from the MPA was not carried out due to the difficulty in arriving at a satisfactory methodology. A historical review made by the scientific community in Africa dealing with NC could initiate some validation. Although the results for betweenness centrality highlight several of the articles found in the MPA, I must concede that given that the focus of the MPA is on links/edges and not nodes, a more sophisticated validation method is required, and this should be considered by the reader.

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Declarations

Conflict of interest The author declares no conflict of interest.

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