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Temporal evolution of human mercury exposure in the Amazon: a scientometric approach

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SUMMARY
Due to the current global attention to mercury exposure and toxicity, as well as its various consequences on ecosystems and human health, new scientometric tools help to better understand the issues involved. In this literature research, studies of the risk of human exposure to mercury in populations of the Brazilian Amazon biome in the last three decades were contemplated using scientometric techniques, bibliographic docking, authors, citations, and keywords. The analyses of the period from 1991 to 2019 enabled the selection of 130 articles. There was the identification of the main research institutions, classification and interrelations of the main thematic axes of the studies in the Amazon biome and most cited authors. The most referenced articles on this theme and the main bioindicators were ordered. The results show that most of the studies were carried out along rivers and with riverside populations. In the sample universe, there is a predominance of localities on the Tapajós and Madeira Rivers. Most researchers work only with internal partnerships, without interaction with other scientific groups. The hair matrix is the main bioindicator of Hg exposure used by the authors. For future perspective, this paper has the potential to represent a general temporal understanding of human exposure to mercury in the Amazon and its main bioindicators.

Keywords: Amazon, biomarkers, scientometry approach and mercury toxicity.

1 INTRODUCTION

Studies on the environmental dynamics of Hg are of global interest. According to Okpala et al. (2017) and Basu et al. (2018), the impacts of land use and climate change on the Hg cycle are linked to ecosystem changes and global atmospheric and oceanic cycles. Exposure to low levels of Hg can lead to serious genotoxic problems, raising questions in the last decade about the safety of current MeHg exposure limits (Ha et al. 2016). Studies by several authors, like Malm et al. 1997; Malm, 1998; Roulet et al. 2000; Dolbec et al. 2001; Lemire et al. 2009; Malm et al. 2010; Fonseca et al. 2014; Veja et al. 2018, state that seasonal flooding of rivers and their floodplains regulate the production and bioavailability of methylmercury (MeHg) to food networks. The identification of elevated Hg concentrations in fish and human populations, among those who live far from gold mining activities, has led to proposals for other primary sources of Hg (Bisinoti and Jardim, 2004; Passos and Mergler, 2008; Faial et al. 2014; Martín-Doimeadios et al. 2014; Bastos et al. 2015; Castilhos et al. 2015; Langeland et al. 2017; Weinhouse et al. 2017).

Human biomonitoring is used as a tool to support the early detection of exposure to toxic agents, in an attempt to reduce harmful effects on human health. For this, it is necessary to determine these agents, as well as to define acceptable levels of exposure and also to perform the analysis of probable health aggravations related to this exposure (Amorim, 2003; Arrifano et al. 2018; Cerbino et al. 2018; Freitas et al. 2018; Wyatt et al., 2019).

It turns out that there are several gaps to the quantitative understanding of how intrinsic and extrinsic factors that act in molecular, individual, and global spheres can interfere on the risk of Hg exposure, toxicity, and health-related impacts (Eagles- Smith et al. 2018). The neurological effects in humans over time require further studies (Ratcliffe et al. 2015). Currently, there is a need for the integration of a database with repositories of scientific publications aimed at future risk assessments.

In this perspective, studies in the Amazon are heterogeneous, dependent on various factors, there is no trend in results, and some areas have not been studied. A large part of the Amazonian population can be considered exposed to the different chemical forms of Hg. Thus, this investigation quantifies scientific progress aimed to identify and integrate studies related to Hg exposure in the Amazon region by examining different human matrices and using scientometric tools. This approach identifies and indicates solutions to the social reality of the researcher and research and, above all, contributes to verify the themes and gaps that have not been widely studied.

2 METHODS

The database used in this study adopted the Web of Science (WoS) Core Collection relating to Hg exposure routes and their possible impacts on the Amazonian population. The search strategy adopted the following nomenclature: TI = (* mercury * OR Hg OR methylmercury AND exposure OR exposed) AND TS = (hair * AND fish AND Amazon) and the searches were conducted in English. Starting from an initial result of 751 articles searched in October 2019, 130 articles covering the period from 1991 to 2019 were selected and followed the numerical ordering from 1 to 130, with the 1st being the article published in 1991 and the last in 2019.

The selection criteria were papers that addressed human exposure to Hg and MeHg and research in the Amazon region. The rest of the results, including review articles, was excluded because it was not developed in the Amazon, since the axis of this work is to catalog studies that aimed to assess the exposure and toxicity on the Brazilian Amazon population, and also what the different kinds of samples used in the articles were. It is important to note that only after 1991 the authors' keywords and abstracts became freely accessible on the Web of Science platform. The articles analyzed in this review were published in international and national scientific journals. All of them were collected from electronic sources. Then, we identified the researchers and research groups working on this theme, organized them according to their respective institutions, and tabulated their academic productions and study sites.

HistCite ™ software, version 9.8.24 (Philadelphia, PA, USA) was used to extract information related to the authors with the hightest number of publications and/or most cited, year of publication, most frequent words and journals with the highest number of published articles.

The connection maps were prepared with VOSViewer ™ software, version 1.6.11 (Leiden, The Netherlands), to graphically identify the correlations of scientific publications based on the same keywords used in the initial Web of Science search. Circles and lines increase in size according to how strong or weak the density of researchers in relation to their collaborative networks is. In the co-authorship analysis, authors who had only 1 article were excluded because they did not qualify in the collaborative network. In the network of citations and authors, we established a minimum of 5 articles by each of the authors to represent collaborative clusters.

The software JAMOVI - 1.0.1.0 was used to check relations between the articles that used different methods of research to identify the degree of Hg exposure, either through hair sample, blood, urine or fish intake, and whether these articles applied neuropsychological tests, which identify the impairment of neuropsychomotor development. The data from the 130 articles were entered into an excel spreadsheet, in order to generate a binary file related to the type of Hg exposure route used in the authors' research. Multivariate statistical analysis was used for cluster analysis though an algorithm with Euclidean distances, with complete "Linkage". The data were run in XLSTAT 2019.

3 RESULTS

Cluster analysis applied to the general profile of the 130 selected articles showed 12 matrices, and the cophenetic correlation coefficient was 0.914. The hierarchy shows 3 main groups (1,2,3). Group 1 showed hair as the main highlight, complementing the group in which there is food research and children's matrices. These three matrices were the most frequently found in the researched articles and had the smallest increase in intragroup variance and all other matrices described in the work.

Group 2 was characterized by the usage of fish to assess the aquatic environment and the exposure of riparian populations. The average centroid distance showed that the articles that used fish are the most similar to each other. For group 3, the urine was the main highlight, commonly used to determine total Hg, mainly in studies with population exposed to Hg in occupational environments, such as gold mining. Complementing this group, we have blood, environmental indicators, indigenous people, neuropsychological assessment, exposure to Hg through vaccines, breast milk, and neurological assessment. In this group, there is a robust correlation between articles that used vaccine as the route of exposure and breast milk applied in neurological and neuropsychological tests.

In the cluster, the fish matrix is highlighted as the main route of human exposure. Note that group 2 was used together with groups 1 and 3. The hair in group 1 is used with food survey and in children. However, it also connects with groups 2 and 3, and both use it as a bioindicator. Group 3 has a direct correlation with group 2, with an emphasis on containing other matrices that are used in articles with a specific purpose and in different populations.

The hierarchy of the 130 analyzed articles, depending on the variables, resulted in 4 groups (A, B, C, D), with a copheenetic correlation coefficient of 0.65, according to the numerical ordering of the articles (**Figure 1**). For group A, the centroid were the articles with the blood variable, followed by the hair articles. The trend of these 24 articles were studies that investigated the following Hg exposure bioindicators: hair, blood, urine, and food intake. In group B, the 41 articles developed studies to assess Hg concentration in fish.

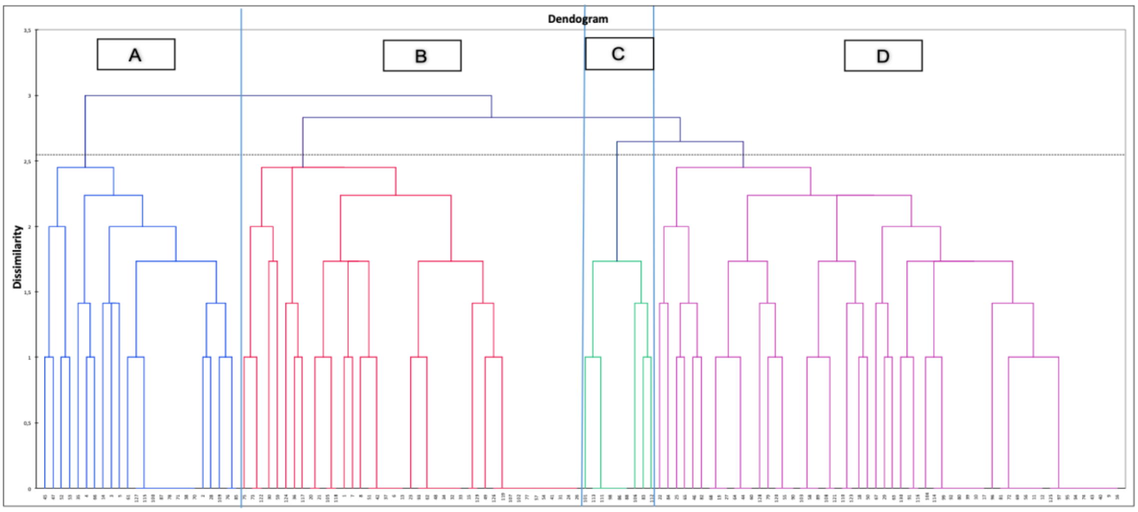
In group B, the articles with the fish samples were the highlight in the centroid of the group, and the greatest distance between the centroids of group B was in relation to group C. In view of this statement, there is an understanding that the articles that use the fish matrix (group B) were little used in articles with children, neuropsychological and neurological assessments (group C). It was also found that no studies researched the fish matrix along with neuropsychological assessment to better understand the consequences of Hg bioaccumulation for Amazonian communities.

Group C with 9 articles consists of the variables neuropsychological assessment, neurological assessment and children, with an average in the centroid of 0.647, indicating that the studies are quite similar to each other and with the least intragroup variance. The smallest distance to the centroid of group C was towards group D, and this seems to be due to the fact that the hair matrix, belonging to group D, is widely used by researchers to assess the load of THg in the human body. The longest distance between the central objects was with Group B, a fish matrix.

Group D, with 56 articles with hair, food and children survey matrices, has high intragroup variance and the main class centroid was the hair matrix. The shortest distance from the centroids of group D was towards group A, as they used equal matrices, such as hair and food survey, and, in opposition, the highest centroid distance was towards group C.

The total result of the decomposition of variation for the optimal classification shows that the intragroup is greater than the intergroup, since the matrices present significant differences, validating the existence of the apparent trend in the distances between the attempts. In this perspective, we found that 89 articles, groups A, C and D, used the hair matrix as a bioindicator of Hg, corresponding to approximately 68.5% of total publications. It is evident in the detailed hierarchy of articles that, in the context of quantification of the studies, the scientific community uses hair in most of the papers and observes a gap due to the low utilization of neuropsychological assessment.

Figure 1. Hierarchization of the 130 articles on mercury contamination in human populations in groups: A - 24 studies with the hair, blood, urine and food survey matrices; B - 41 papers with the fish matrix; C - 9 papers with hair, children, neurological tests and neuropsychological tests matrices; D - There are 56 works with hair, food survey and children matrices.



The bibliographic coupling presented through the VOSviewer software means that the articles refer to another common article in their bibliographies. The analysis of the main bibliographic couplings in Hg exposure research in the Amazon (**Figure 2**) showed 5 groups (1A, 2A, 3A, 4A, 5A) unifying different researchers and their main article links, with only one cluster that is not connected to the other four. The largest circles within each cluster group refer to the articles of the most cited authors.

Group 1A is formed by Guimarães, J.R.D. from the Plotter Laboratory of the Federal University of Rio de Janeiro - UFRJ, Fillion, M. from the Centre de recherche interdisciplinaire sur la biologie, la société et l`environnement - Université du Québecà Montréal - Canada, together with Barbosa, F. from Pharmaceutical Sciences College of Ribeirão Preto - USP and Aline Philibert from Université du Québecà Montréal, form a working group on Hg exposure, linked to two other groups, 2A (Dórea, J.G.) and 3A (Malm, O. e Mergler, D.).

Group 2A is formed by Barbosa, A.C, Dórea, J.G. and Bernardi, J.V.E., from the University of Brasilia - UnB, together with Hacon, S.S. from the National School of Public Health of the Oswaldo Cruz Foundation, Marques, R.C. from the Federal University of Rio de Janeiro - UFRJ, Roulet, M. from the Université du Québec à Montréal - Canada and Bastos, W. from the

Federal University of Rondônia - UNIR. Group 3A composed by Malm, O. from Radioisotope Laboratory - UFRJ and Penna-Franca, E. from Federal University of Rio de Janeiro - UFRJ; Mergler, D, Dolbec, J. and Lebel, J. from Centre d`étude des interactions biologiques entre la santé et l`environnement - Université du Québecà Montreal, Lucotte, M. - Université du Québecà Montreal, Canada; Bastos, W.R. from Federal University of Rondônia - UNIR and Boischio, A.A.P. from State University of Feira de Santana - UEFS, Bahia.

Group 4A is formed by Oliveira, E.C. and Santos, E.S.B from the Human Ecology and Environment Laboratory, Evandro Chagas Institute - Pará, together with Muller, R.C.S. and Alves, C.N., Department of Chemistry, Federal University of Pará - UFPA and Sarkis, J.E., Institute for Energy and Nuclear Research, Isotopic Characterization Group, University of São Paulo - USP. This group is connected both to the first cluster (1A - Fillion, M. and Guimarães, J.R.D.), and to the second cluster (2A - Dórea, J.G.).

Group 5A does not connect to any other cluster. This cluster includes Hsu-Kim, H. from Civil and Environmental Engineering, North Carolina, Bullins, P. from Duke Global Health Institute, Duke University, North Carolina, Meyer, J.N., Berky, A.J. and Pan, W.K. Nicholas School of the Environment, Duke University, North Carolina.

Among all 130 articles, 31 eligible authors stand out as having highlighted circles and lines, indicating a strong connection with the other 5 collaborative groups identified in **Figure 2** and also shown in **Table 1**.

Figure 2. Bibliographic coupling network Hg exposure research on Mercury contamination in human populations between 1991 and 2019 in group. Main authors of the groups: 1A - Amoras, W.W., Barbosa, F., da Silva, D.S., Fillion, M. Guimarães, J.R.D. and Philibert, A .; 2A - Barbosa, A.C., Bastos, W., Bernardi, J.V.E, Dórea, J.G., Hacon, S.S., Marques, R.C. and Roulet, M .; 3A - Bastos, W.R., Boischio, A.A.P., Dolbec, J., Lebel, J., Lucotte, M., Malm, O., Mergler, D. and Penna-Franca, E .; 4A - Alves, C.N., Oliveira, E.C., Santos, E.S.B., Muller, R.C.S. and Sarkis, J.E .; 5A - Berky, A.J., Bullins, P., Hsu-Kim, H., Meyer, J.N. and Pan, W.K.

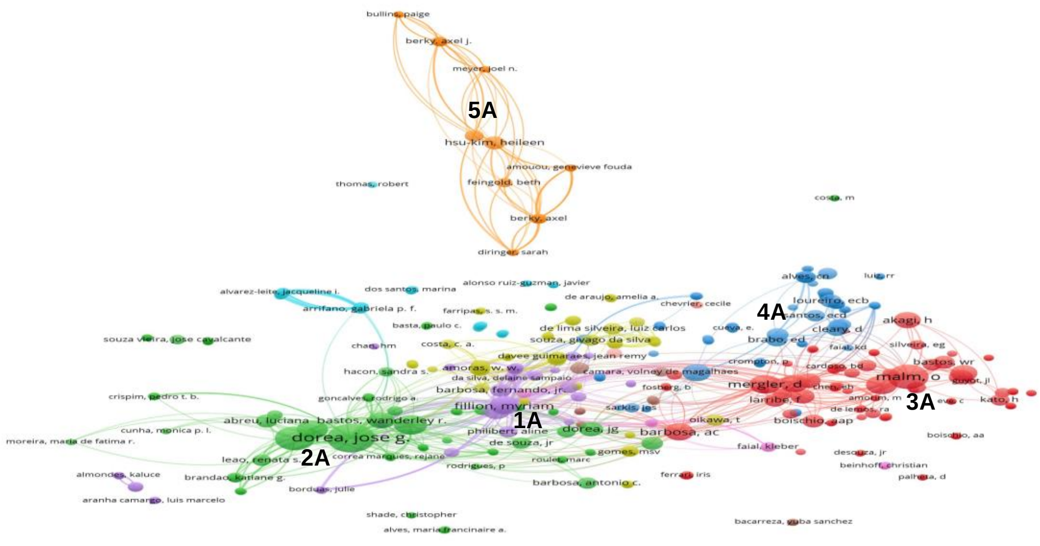
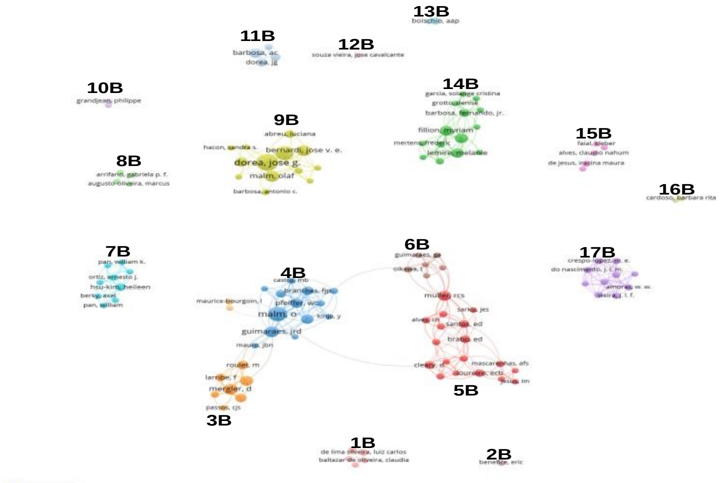


Figure 3 identifies 4 connected groups and 1 group respectively, the circles are highlighted by the ranking of the main co-authors and they are also in the ranking of citations, they are: Mergler, D. (3B); Malm. O. (4B); Brabo, E.D. (5B) and Guimarães, J.R.D (6B) and Dórea, J.G (9B), all enabled in the collaboration network. In the co-authorship analysis (**Figure 3**), authors who had only 1 article were excluded, originating a network with 17 clusters and 356 links.

Figure 3. Co-authorship network and respective research teams on Hg exposure research in the Amazon between 1991 and 2019. Main authors: 1B - Baltazar de Oliveira, C. and de Lima Silveira, L.C.; 2B - Benefice, E.; 3B - Laribe, F., Mergler, D., Passos, C.J.S. and Roulet, M.; 4B - Branches, F.J.P., Guimarães, J.R.D., Malm, O., Pfeiffer, W.C.; 5B - Alves, C.N., Brabo, E.D., Cleary, D., Loureiro, E.C.B., Mascarenhas, A.F.S., Muller, R.C.S., Santos, E.D. and Sarkis, J.E.S.; 6B - Guimarães, G.A. and Oikawa, T.; 7B - Hsu-kim, Beillen., Ortiz, E.J., Pan, W.K., Berky, A. and Pan, W.; 8B - Arrifano, G.P.F. and Augusto-Oliveira, M.; 9B - Abreu, L., Barbosa, A.C., Bernardi, J.V.E., Dórea, J.G., Hacon, S.S. and Malm, O.; 10B - Grandjean, P.; 11B - Barbosa, A.C. and Dórea, J.G.; 12B - Souza Vieira, J.C.; 13B - Boischio, A.A.P .; 14B - Barbosa, F., Garcia, S.C., Grotto, D., Fillion, M., Lemire, M. and Mertens, F.; 15B - Alves, C.N., de Jesus, I.M., and Faial, K.; 16B - Cardoso, B.R.; 17B - Amoras, W.W., Crespo-Lopez, M.E., do Nascimento, J.L.M. and Vieira, J.L.F.

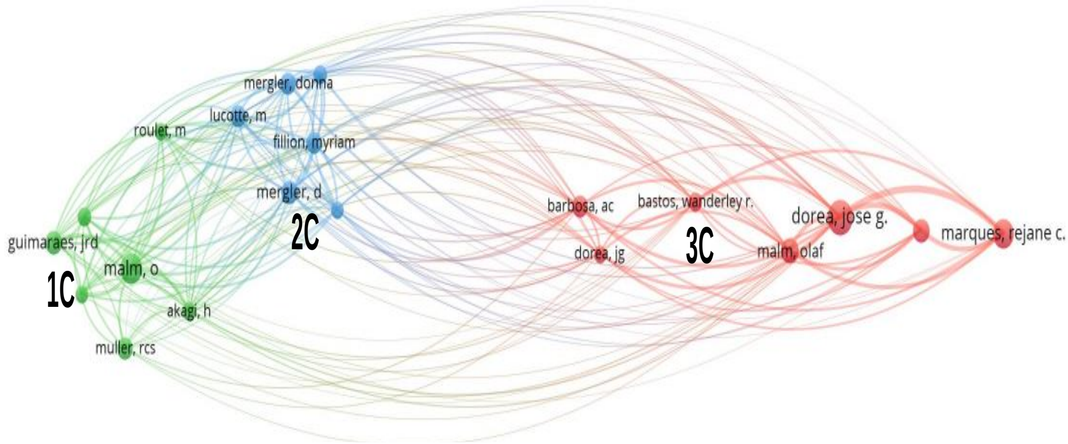


Cluster 5B gathers 18 authors, such as Muller, R.C.S., Santos, E.D., Brabo, E.D., Mascarenhas, A.F.S., Loureiro, E.C.B., Alves, C.N. and Sarkis, JES, mostly from institutions in Pará, and are related to clusters 4B (Malm, O., Guimarães, J.R.D., Pfeiffer, W.C. and Filiais, F.J.P.) and 6B (Guimarães, G.A. and Oikawa, T.). The former is composed by 13 researchers, mostly professors from UFRJ. Cluster 3B (Mergler, D., Roulet, M., Laribe, F., Passos, C.J.S.) has 7 researchers from Canada, UFRJ and UnB and is linked only to 4B (Malm. O., Guimarães, J.R.D., Pfeiffer, W.C. and Branches, F.J.P.). (**Figure 4**).

We identified groups that are independent and do not connect to any other cluster: 7B (Hsu-kim, Beillen, Ortiz, E.J., Pan, W.K., Berky, A. and Pan, W.), 9B (Dórea, J.G.), 14B (Fillion, M., Barbosa, F., Lemire, M., Mertens, F., Grotto, D. and Garcia, S.C.), and 17B (Crespo-Lopez, M.E., Do Nascimento, J.L.M., Amoras, W.W. and Vieira , J.S.E.). The remaining clusters are composed of 5 authors at most (8B; 10B; 11B; 13B; 14B; 15B; and 16B).

In the citation and author network, we set a minimum of 5 articles for each of the authors, resulting in 130 articles. According to the citation table generated by the Web of Science (WoS) Core Collection, the most cited author, with 1137 citations in 14 articles, was Malm, O., followed by Dórea, J.G. with 397 citations in 19 articles, Mergler, D. with 763 citations in 8 articles, Lucotte, M. with 682 citations in 7 articles, and Guimarães, J.R.D. with 631 citations in 8 articles.

Figure 4. Association networks between authors and citations of research on Hg exposure in the Amazon between 1991 and 2019 (research groups from Amazonian and Canadian institutions). Main authors: 1C - Akagi, H., Guimarães, J.R.D., Malm, O., Muller, R.C.S. and Roulet, M.; 2C - Fillion, M., Lucotte, M. and Mergler, D.; 3C - Barbosa, A.C., Bastos, W.R., Dórea, J.G., Malm, O. and Marques, R.C.



In Figure 4, there are 3 clusters, identified by different colors. Cluster 1C is led by Malm, O., has 7 researchers and makes 18 connections with the other two clusters. Cluster 2C has Professor Mergler, D. as the central node and 6 other authors with 19 connections. Cluster 3C has Dórea, J.G. as the main researcher, along with 7 other authors, and makes 19 links. The total number of links was 181.

All these group leaders have relevance because they indicate that all the study axes are connected in their work and within the groups. The scientific output in **Table 1** shows that most of the authors of the networks in this association are also in the ranking of the most cited articles.

When analyzing co-occurrences with all keywords in the 130 articles, the criterion was that the word appeared in the title or abstract of at least 5 publications. "Methylmercury" was the most frequent word, with 64 occurrences, followed by "mercury" (54), "fish" (51), "Amazon" (49), and "hair" (43).

All these words are linked to all the others. These 5 main groups are related to human exposure to methylmercury and mercury in the Amazon region through fish consumption and measured trough concentration in hair. There is a sequence in the orders in which the words appear, following the hierarchy of articles (**Figure 1**).

4 DISCUSSION

Regarding research with fish, the Evandro Chagas Institute, along with the Federal University of Pará generated the majority of the papers, followed by the work developed by Malm, O. and his collaborators (Federal University of Rio de Janeiro). Furthermore, the term "fish" appeared as a keyword in 51 articles, being the third most prominent keyword among the 130 articles.

According to the citation table generated by the Web of Science (WoS) Core Collection, following other studies, the year 2000 stood out for the number of scientific articles produced:

14 publications. In 2000, there was a peak of publication on mercury contamination in the Amazon Basin and a slight decrease in the last two years (Hacon et al., 2008). The year 2018 came second with a total of 10 published papers, and third was the year 2014 with 8 articles.

Most studies used hair as a matrix to assess Hg concentration. Almost all articles included Brazilian groups and some international collaborations. Dórea, J.G. (University of Brasília) developed most of the articles that used hair as a matrix for Hg concentration in 2014, in partnership with 25 other researchers, corresponding to 19% of the total, standing out as the main author of this scientometric survey. The number of international institutions cooperating with Brazilian researchers is small in recent years (2 institutions) and the same results that Canadian research institutions have become the main Brazilian partners (Hacon et al., 2008).

In recent years, an exchange between research groups has been noticed; today, work is being developed by new researchers. The Federal University of Rio de Janeiro and the University of Brasilia continue their research activities with Hg and its contaminant sources.

Although these research efforts have produced large amounts of data, they have proved unable to provide a conclusive picture of human contamination by mercury in Amazonia and have left many questions unresolved. Despite the prevalence of Brazilian researchers in the studies, this overview showed that there is still no reference dose of mercury for Amazonian populations.

4.1 BIBLIOGRAPHIC COUPLING

The work of the authors of group 1A (Barbosa, F., Fillion, M. and Guimarães, J.R.D.) was developed predominantly in the Tapajós River, focusing on understanding human exposure and possible influences of dietary habits, lifestyle, and environmental indicators (sediment, soil, water and atmosphere) (Nyland *et al*. 2011).

The studies by the authors of group 2A (Dórea, J.G.) were largely conducted in the Madeira River (Rondônia), followed by the Negro River (Amazonas), and the Tapajós River (Pará), aiming to assess the risk of human exposure to Hg in the Amazon region. These articles report that species belonging to the top of the aquatic food chain have higher Hg concentrations (Hacon et al. 2014; Rodríguez Martín-Doimeadios *et al*. 2014; Bastos *et al*. 2015; Castilhos *et al*. 2015; Faial et al. . 2015; Olivero-Verbel et al. 2016; Langeland et al. 2017; Guida et al. 2018; Lino et al. 2018). Marques et al. (2014 and 2016) found that the mothers' education level influences the neurodevelopmental outcome of the children community, but they detected low level of impairment, with no evidence of the impact of EtHg and HHg levels.

The lead author of Group 3A, Malm, O., and his collaborators worked primarily on the Madeira and Tapajós Rivers. Malm et al. (2010); Hacon et al. (2014); Guida et al. (2018) and Lino et al. (2018) show that Hg concentration in the population is related to fish consumption, with an increase if the consumption was of carnivorous fish. They also compare these concentrations between the Tapajós and Madeira Rivers, corroborating the claims of cluster 2A, with similar responses in both groups, as you can see the link between the Fillion, M. (1A), Dórea, J.G. (2A) and Malm, O. (3A) groups in Figure 3.

In cluster 4A, authors have focused on studies to assess Hg toxicity risks, considering the process of bioaccumulation of Hg in fish and its consumption by Tapajós River communities (Passos and Mergler 2008; Nyland et al. 2011; Olivero-Verbel J. et al. 2016). Conglomerate 5A, led by researcher Hsu-Kim, H., features researchers from the United States who have conducted work with children in Peru in the Madre de Dios River region. According to Weinhouse et al. (2017), MeHg exposure increases the likelihood of anemia in high-risk environments, especially those in mining areas. In addition, Wyatt et al. (2019) reported that changes in antibody levels and child protection were associated with indicators of malnutrition, Hg exposure, and their interaction.

Group 1A (Barbosa, F., Fillion, M. and Guimaraes, J.R.D) connects to group 3A (Mergler, D. and Malm, O.). This shows that they have references from each other's work. Group 2A (Dórea, J.G.) cites authors from group 1A (Barbosa, F., Fillion, M. and Guimarães, J. R.D.) and group 3A (Mergler, D. and Malm, O.). The number of links predominated in group 3A, with Malm, O. In group 4A, researchers Brabo, E. and Santos, E. Stood out for making links with group 2A (Dórea, J.G.), and with researcher Malm , O. (3A) as the core. Finally, group 5A (Hsu-Kim, H.) works with the Peruvian Amazon region and does not collaborate with any work on the Brazilian Amazon region and its authors. Although there is joint reference work, the new researchers no longer relate to the authors who had the most notoriety in the "clusters" in the bibliographic coupling.

4.2 MAIN CO-AUTHORS CITATIONS ANALYSIS

The most cited publications showed the network of the main authors and their respective groups of collaborators: Cluster 1C (Akagi, H., Guimarães, J.R.D., Malm, O. Muller, R.C.S. and Roulet, M.); then cluster 2C (Fillion, M., Lucotte, M. and Mergler, D.); finally, cluster 3C (Barbosa, A.C., Bastos, W.R., Dórea, J.G., Malm, O. and Marques, R.C.). Table 1 lists the 10 most cited articles in the database, with the participation of those authors. Some authors are seen in more than 1 cluster, as is the case of Malm, O. (1C and 3C). The Hg averages are above 10 $\mu g\ g^{-1}$ in most studies and in 8 of them they used the hair matrix to assess the mercury load in the human body.

Table 1. Most cited papers between 1991 and 2019 with authors (year), location, bioindicator of Hg exposure and average Hg concentration (µg g-1).

Rank	Authors (Year)	Locality	Bioindicator de exposure	Mean Hg ((µg g-1)
1	Malm, O. (1998)	Brazilian Amazon	-	-
2	Lebel, J.; Mergler, D.; Branches, F.; Lucotte, M.; Amorim, M.; Larribe, F.; Dolbec, J. (1998)	Brasília Legal, Pará	Hair	>10
3	Grandjean, P.; White, R.F.; Nielsen, A.; Cleary, D.; Santos, E.C.O. (1999)	Tapajós River, Pará	Hair	>10
4	Malm,O.; Branches, F.J.P.; Akagi, H.; Castro, M.B.; Pfeiffer, W.C.; Harada, M.; Bastos, W.R.; Kato, H. (1995)	Tapajós River, Pará	Hair	15
5	Akagi, H.; Malm, O.; Branches, F.J.P.; Kinjo, Y.; Kashima, Y.; Guimarães, J.R.D.; Oliveira, R.B.; Haraguchi, K.; Pfeiffer, W.C.; Takizawa, Y.; Kato, H. (1995)	Alta Floresta, Mato Grosso e Jacareacanga, Pará	Hair	30
6	Dolbec, J.; Mergler, D.; Passos, C.J.S.; Sousa de Morais, S.; Lebel, J. (2000)	Tapajós River, Pará	Hair	9

7	Akagi, H.; Malm, O.; Kinjo, Y.; Harada, M.; Branches, F.J.P.; Pfeiffer, W.C.; Kato, H. (1995)	Tapajós River, Pará	Hair	2
8	Lebel, J.; Roulet, M.; Mergler, D.; Lucotte, M.; Larribe, F. (1997)	Tapajós River, Pará	Hair	13.45
9	Guimarães, J.R.D.; Meili, M.; Hylander, L.D.; et al. (2000)	Tapajós River, Pará	-	-
10	Barbosa, A.C.; Jardim, W.; Dórea, J.G.; Fosberg, B.; Souza, J. (2001)	Negro River, Amazonas	Hair	>10

Source: Research data.

According to the citation table generated by Web of Science (WoS) Core Collection, the following authors stood out as the most cited authors with relevance and centrality in the "clusters" groups: 1C (Guimarães, J.R.D. and Malm, O.), 2C (Mergler, D.) and 3C (Dórea, J.G.). In first place was Dórea, J.G., which is explained by his extensive and productive professional career, having worked with almost all the Hg exposure matrices with several co-authors. (**Table 2**).

Table 2. Top 10 most cited authors from 130 articles analyzed with records

Rank	Authors citation	Records
1	Dórea, J.G	90
2	Guimarães, J.R.D	53
3	Mergler, D.	53
4	Malm, O.	49
5	Bastos, W.R.	44
6	Lucotte, M.	43
7	Barbosa, F.	40
8	Crespo-Lopez, M.E.	28
9	Feng, X.B.	27
10	Marques, R.C.	27

Source: Research data.

4.3 KEYWORD TREND ANALYSIS

In the keyword trend, a large part of the studied populations was exposed to different sources of Hg, with a predominance of MeHg (Dórea et al. 2012; Pinheiro et al. 2012; Hacon et al. 2014; Bastos et al. 2015; Marques et al. 2016; Arrifano et al. 2018). The word "exposure" occupied the eighth position in the ranking of occurrences, but among the 10 most cited articles, 7 of them contained the word "methylmercury" and / or "mercury" (**Table 3**).

Table 3. Ranking of top 11 keyword occurrences and total link strength

Rank	Keywords	Occurrences	Total link strength
1	Methylmercury	64	413
2	Mercury	54	346
3	Amazon	48	333
4	Fish	51	327
5	Hair	43	296
6	Fish consumption	41	253
7	Basin	30	220

8	Exposure	31	195
9	Contamination	23	178
10	Brazilian Amazon	27	177
11	Methylmercury exposure	25	157

Source: VOSviewer™, version 1.6.11 (Leiden, The Netherlands)

Other authors (Valdelamar-Villegas, J. and Olivero-Verbel, J. 2019) state that residents of riverine communities are more vulnerable to MeHg exposure than miners, due to frequent fish consumption. Lino et al. (2018) suggest that the population establish a decrease in the consumption of carnivorous fish and give preference to the consumption of herbivorous and illiophagous species in order to reduce Hg exposure. In the review by Basu et al. (2018), they propose that the world population is exposed to a certain amount of mercury and that there is a mobility of exponents between regions and countries.

5 CONCLUDING REMARKS

The present scientometric analysis of 130 articles showed that there is knowledge about Hg toxicity in the academic community. Scientists communicate, work with common goals, and a network of co-authors exists. The discussions in the papers showed a gap in how safe exposure to Hg and MeHg is considered. In addition, the source of Hg exposure for Amazonian populations was inconclusive. The articles researched for this review highlight that MeHg exposure affects the well-being and health of the population. This study suggests that standardized biomonitoring programs need to be developed to allow for general comparisons and trends. Furthermore, additional efforts are needed to integrate databases for risk assessment purposes. Finally, it remains difficult to conclude on the public health implications of Hg exposure in Amazonia. Human health risks are associated with a variety of social and economic aspects and need to be assessed in the local Amazonian context.

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