Toxicological Distribution of Mercury Concentrations in Abiotic and Biotic Environments: A Systematic Review and Meta-Analysis

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Abstract

Background: Mercury (Hg), in particular methyl-mercury (Methyl-Hg), is a potentially dangerous heavy metal with special physicochemical features including environmentally persistent, bio-accumulative, bio-concentrated, and bio-magnification. Thus, it has the potential to be high risk to both human and environmental health. However, there are few studies quantifying mercury toxicity in all environmental components, especially in developing countries. Therefore, the aim of this systematic review and meta-analysis was to determine the amount of mercury present in various environmental components.

Methods: Preferred Reporting Items for Systematic Reviews (PRISMA) updated criteria were used for the flow diagram. PubMed, Medline, Web of Science, Embase, previous reviews, reports, and other methods were searched as databases. A thorough search was conducted for all studies published 2000-2023 using keywords and MeSH terms with Boolean logic operators (AND, OR). The titles and abstracts returned by the search were screened. Data were extracted using a prescribed Microsoft Excel. The mean concentration of Hg in soil, blood, fish and dust, and plant leaf was estimated using STATA version 17. The random effect model with a 95% confidence interval was used at a p-value of less than 0.05.

Results: A total of 208 records were searched from PubMed (n=33), Medline (n=39), Web of Science (n=37), Embase (n=23), previous reviews (n=18), reports (n=5) and via other methods (n=53). This review revealed that different concentrations of Mercury (Hg) are found in various components of the environment. This review found the mean mercury concentration in fish was 1.60 µg (95% CI: -0.02, 3.22 µg), soil 0.32mg/kg (95%CI: -1.25, 1.90mg/km) , dust 0.47 mg/kg (95% CI: -1.10, 2.04mg/km) and water bodies 0.55 µg/dm3 (95% CI: -1.04, 2.13), plant 28.96 mg/kg (95% CI: -22.57, 80.49 mg/kg), and human blood at 0.92 µg/L (95% CI: -0.72 µg/L, 2.57).

Conclusions: This systematic review and meta-analysis concluded that the methyl- mercury form is the most prevalent in both biotic and abiotic as compared to other forms of mercury. Nevertheless, limited research has been found in low- and middle-income nations, where the majority of raw mercury is produced. Moreover, the review suggested that international cooperation, national policies, and regulations on mercury management are crucial for minimizing the harmful effects of both biotic and abiotic mercury components.

***Keywords*:** Abiotic, Biotic, Concentration, Distribution, Mercury, Toxicological

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Introduction

Mercury (Hg) is most commonly found in the Earth's crust, where the Hg chemical element is very predominant. The shiny silver appearance of mercury has given rise to the term "liquid silver" (Bensefa-Colas *et al.,* 2011; Bensefa-Colas *et al*., 2019). There are different types of mercury that are harmful to the human body; it can be found in fish that have ingested methyl-Hg (Bensefa-Colas *et al*., 2011). WHO considers mercury as one of the top ten chemicals or groups of chemicals of major public health concern (WHO, 2017). Methyl-mercury (Methyl-Hg), a type of Hg, is a po-

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tentially dangerous metal with special physicochemical features; it is environmentally persistent, able to bio-accumulate, bio-concentrate, and bio-magnify in air, water and soil. Thus, it is high risk to both human and environmental health (NRC, 2000).

Methyl-Hg may cause serious health problems and is a threat to the development of the child in utero and in early life (Posin *et al.,* 2023; Zhang *et al*., 2016). The biological pathway to mercury exposure is through ingestion of contaminated food such as Hg containing fish and shellfish (WHO, 2017), inhalation or absorption (via the skin) of Hg vapors at the worksite during the processing of industrial and household wastes, and the use of pharmaceutical drugs or cosmetics. Mercury can easily cross the blood–brain barrier and placenta, can be excreted in breast milk and transmitted to the fetus. It passes into the human body through the digestive system, respiratory system, and the skin; it is absorbed within the body in varying rates (Ye *et al*., 2016).

There are few studies on the measurement of Hg toxicity in all environmental components worldwide, especially in developing nations with weak legal and regulatory frameworks and inefficient methods for controlling and preventing Hg toxicity and its emission (EHD, 2002). Mercury is a widespread chemical exposure and environmental pollutant with several forms of Hg that can lead to Hg intoxication syndromes (Posin *et al*., 2023). As described above, it is an important pollutant that can be transported globally due to its long lifetime in the atmosphere and thus it can affect the global environment and impact food systems. The sensitivities of the air-surface exchange, atmospheric transport, and budget of Hg to projected 2000–2050 changes in climate and land use/land cover with a global chemical transport model (Posin *et al*., 2023; Zhang *et al.,* 2016).

Model comparison shows that the probabilistic essence of the advanced model prevents the underestimation of the deterministic model caused by using the geometric means of the Hg contents of metal concentrates, and the consideration of the removal compensation effect leads to more accurate estimation of the overall Hg removal efficiency of cascaded air pollution control devices was recommended (Coa *et al.,* 2022). In response to the projected climate change, the annual mean wet deposition flux increases over most continental regions and decreases over most of the mid-latitude and tropical oceans (Posin *et al.,* 2023; Zhang *et al*., 2016). The mean Hg wet deposition flux over northern and southern high latitudes increases by 7% and 8%, which increases precipitation. The combined effects of changes in climate, land use and land cover increase Hg deposition to the continental biosphere and decreases Hg deposition to the marine biosphere (Posin *et al*., 2023; Zhang *et al*., 2016).

Moreover, the physical, chemical, and kinetic properties of the various forms of Hg play an important role influencing the clinical manifestations, the extent and nature of lesions, and the tissue distribution of Hg. Consequently, the bioaccumulation is extensive in tissues such as the brain, kidney, and fetus (Posin *et al.,* 2023; Zhang *et al*., 2016; Barry, 2022). Methyl-Hg interferes with metabolic activity, resulting in degeneration and necrosis in many tissues, with the brain and fetus most susceptible. Methyl-Hg is mutagenic, carcinogenic, embryotoxic, and highly teratogenic (Barry, 2022). Thus, as is discussed above, mercury is hazardous to both natural ecosystems and people (Park *et al*., 2008).

Minamata disease is caused by exposure to methyl-Hg, however, there is some controversy about whether it is due to low, moderate, or high grade exposure (Ye *et al*., 2016). The emerging trends of Hg toxicity studies provide up-to-date information for a better understanding of the toxicological distributions, which is significant for prevention and control methods (Bjørklund *et al*., 2017). Research from the past several decades has indicated the sources of Hg emissions, its routes and cycles through the ecosystem, and implications on the environment and human health (EHD, 2019).

However, there are no studies quantifying the toxicological concentrations of Hg and its distribution in the environmental components. Thus, the current goal of this systematic review and meta-analysis was to identify the concentrations of Hg and its distribution in all environmental components. To answer this, the following three hypotheses were made and a search was completed: What is the geographic distribution of mercury toxicity around the world? Where are the highest Hg toxicity concentrations found? Which aspects of

the environment were most likely to contain the highest concentrations of mercury sediment?

Materials and Methods

Review Method

The Preferred Reporting Items for Systematic Reviews (PRISMA) updated criteria was used for flow diagram accordingly to nine statements of appraisal checklist of this protocol, and adapted from the validated tool (Page *et al*., 2021).

Eligibility Criteria

All studies published 2000- 2023, published in English language with full texts and abstract available in English with clear objective and methodology, and studies which included quantitative outcomes were included in this review. Available data globally from all environmental components including living organisms were included. Studies published prior to 2000, with non-English, without clear objectives and methodology were excluded.

Searching Database and Strategies

Eight reviewers (AB, BB, AD, DF, EM, MK, ST and, TA) participated in searching records/articles/reports from the databases. The published studies were identified through the Web of Science, PubMed, Medline, Embase and Global Health electronic databases, Google Scholar and other methods, including reports using End Note online search. The keywords and MeSH terms with Boolean logic operators (AND, OR) were used individually or in conjunction as the following: (Mercury) AND (Component of Environment: Soil *OR Dust *OR Plant *OR Water [Water-bodies *OR Sea, Lakes *OR Rivers *OR Ocean] OR Animal (Fish *OR Edible Animals *OR Human *OR Blood).

Data Screening

Four reviewers (ST, AB, AD and TA) participated in record screening. They used Microsoft Excel Office 19 (Microsoft Corporation, USA) to screen full articles, titles, and abstracts. Finally, EndNote 20.4.1 (Clarivate, USA) was used to manage the database results, and Zotero software 5.0 (Roy Rosenzweig Center, USA) was used to delete redundant references.

Selection and Quality Assessment

The quality of published studies was appraised using JBI (Joanna Briggs Institute), an appraisal tool which provides the researchers with a standard to assess the methodological quality of the studies (JBI, 2014). Moreover, the funnel plot of Stata also detected the publication bias within the studies.

Data Extraction

Eight reviewers (AB, BB, AD, DF, EM, MK, ST and TA) participated on data extraction. Data were extracted using an extraction spreadsheet in Microsoft Excel office 19 (Microsoft corporation, USA). The extraction spreadsheet included authors, mean and ranges of Hg concentration as well as country of study (Table 1)

Data Analysis

Three reviewers (ST, AD, and AB) analyzed the data using Stata version 17/MP (Stata Corp, Texas, USA). Generic pre-computed effect size with the random-effect model with Restricted Maximum Likelihood methods (Random-Effect REML Model) was used to estimate the pooled mean Hg concentration worldwide. This analysis's outcome or effect size indicated the Methyl mercury concentration in both biotic and abiotic components. Heterogeneity and publication bias were analyzed. The 95% confidence interval with a p-value less than 0.05 was judged statistically significant (CI: 95% two-sided) for all analyses.

Data Processing and Analysis

Four out of eight reviewers (AB, BB, AD and DF) participated on synthesizing the Hg concentration in water bodies, emission and dust. While the remaining four (EM, MK, ST and TA) participated on synthesizing the Hg concentration in soil, dust and blood. For all reviewers, then the overall eligible studies were tabulated, described and synthesized according to the concentration of Hg in the fish, soil, water bodies, plants' leaf, blood, and its emission in sequential order in result as well as discussion sections.

Ethical Consideration

Not applicable

Results

Description of Studies

A total of two hundred and eight (n= 208) studies/records were identified from the databases and other retrieved data and technical reports. Out of these, 33 records were obtained from the PubMed, 39 records from Medline, 37 records from Web of science, 23 records from Embase, 18 records from previous review, 5 records from reports and 53 records through various methods. Finally, a total of 30 studies were included (Fig.1).

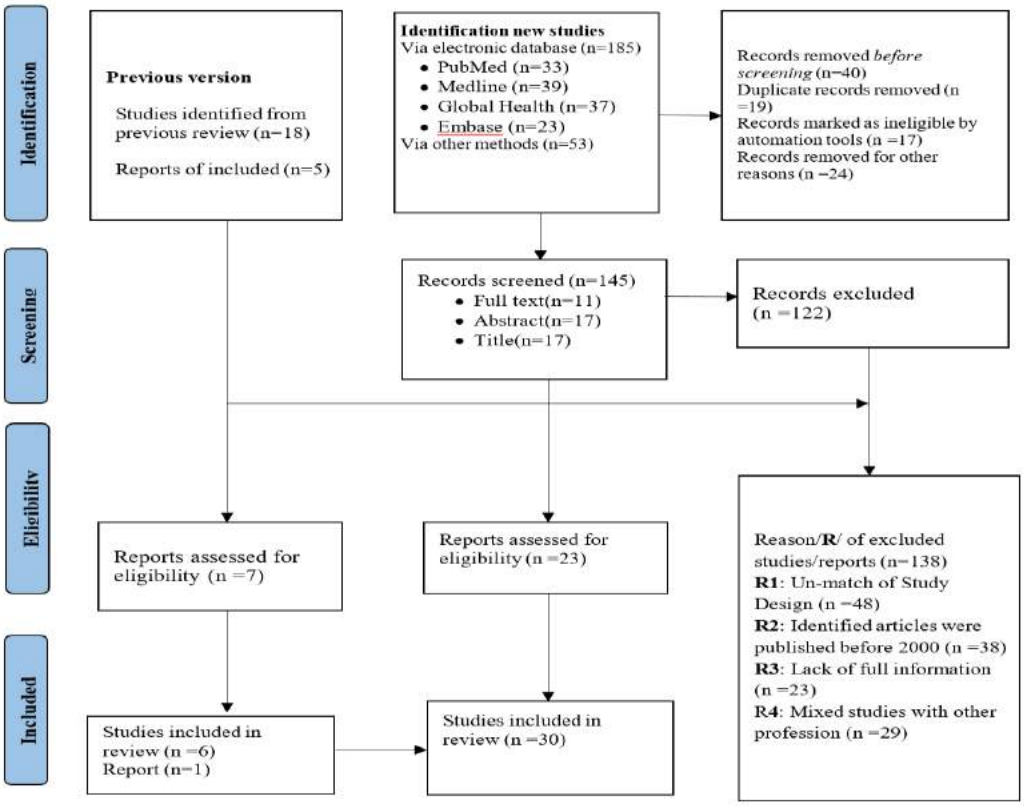

Figure 1 Flow diagram for systematic reviews adopted from PRISMA updated in 2021

Reviewed Studies

The included studies were obtained from Asian countries, Europe, Sub-Sahara, North America, South America, and Australia countries (Table 1). Of these countries, thirty (n=30) studies were eligible for systematic review and meta-analysis on pooled concentration of mercury (Hg) in soil, plant, dust, blood and fish (Table 1). Of these eligible studies, four studies (Ci *et al*., 2011; Jabłońska & Kluska, 2020; Jeong *et al*.,2021; Kim *et al*., 2019) and two studies (Dabeka et al.,2004; Moon *et al*., 2011) were used for Hg quantification from water bodies and type of fish, respectively.Meanwhile, (Becker *et al*., 2002; CDC, 2009; Wong & Lye, 2008; Ye *et al*., 2016) studies were used for quantification mercury concentration in blood. In order to determine the concentration of mercury in the soil component, (Chen *et al*., 2012; Chen *et al*.,2010; Fang *et al*.,2011; Gosar *et al*.,2016; Kelepertzis & Argyraki, 2015; Liu *et al*.,2010; 2019; Perez-Vazquez *et al*., 2015) studies were used. In addition, (Christoforidis & Stamatis, 2009; Coufalík *et al.,* 2014; Hu *et al*., 2011; Liang *et al.,* 2009; Lin *et al*., 2019; Liu *et al*., 2019; Men *et al*., 2018; Zheng *et al*., 2015) (Li qiang *et al.,*2004; Quiñonez-Plaza *et al*., 2017; Xueze *et al*.,2002) and (Dombaiová, 2005; Laacouri *et al*.,2013; Li-qiang *et al*., 2004; 2019; López-Berdonces *et al*., 2014; Xueze *et al*.,2002) studies were used to quantify the concentration of Hg in the dust and leaf of plant, respectively.

The other (Wilson, 2012) study was a technical report but had a lot of information regarding Hg emissions across the world, including Sub-Sahara Africa, which was considered owing to its relevance.

Table 1 Eligible studies for systematic review and meta-analysis on studied items and concentration of mercury (Hg) in worldwide from 2000 to 2023

	Studied items and Concentration of Hg		Type of data	Countries
Reference	Type of Items	Range (Mean)		
(CDC, 2009)	Blood (µg/L)	0.86 (NA)	Serology	US
(Becker *et al*., 2002)	Blood (µg/L)	0.58 (NA)	Serology	Germany
(Wong & Lye, 2008)	Blood (µg/L)	0.76 (NA)	Serology	Canada
(Ye *et al*., 2016)	Blood (µg/L)	2.88-4.28(3.58)	Serology	Korea
(Jabłońska & Kluska, 2020)	Water bodies(µg/dm^3)	0.42-0.50(0.46)	Muchawka	Poland
(Jabłońska & Kluska, 2020)	WB(µg/dm^3)	0.54-0.63(0.59)	Liwie	Poland
(Jabłońska & Kluska, 2020)	WB(µg/dm^3)	0.80-0.89 (0.85)	Bug	Poland
(Jeong *et al*., 2021)	WB(µg/dm^3)	0.01-2.2(1.10)	Yellow Sea	China, Korea
(Kim *et al*., 2019)	WB(µg/dm^3)	0.30-1.64 (0.94)	Japan Sea	East/Japan
(Kim *et al*., 2019)	WB(µg/dm^3)	0.36-0.55 (0.46)	Okhotsk	East/Japan
(Kim *et al*., 2019)	WB(µg/dm^3)	0.62-0.68 (0.65)	Arctic	East/Japan
(Ci *et al*., 2011)	WB(µg/dm^3)	0.13-0.20(0.17)	Yellow Sea	China, Korea
(Dabeka *et al*., 2004)	Fish (µg)	0.40-3.85(1.82)	Swordfish	Canada
(Dabeka *et al*., 2004)	Fish ((µg)	0.34-3.19(1.43)	Marlin	Canada
(Dabeka *et al*., 2004)	Fish ((µg)	0.09-2.73(1.26)	Shark	Canada
(Dabeka *et al*., 2004)	Fish ((µg)	0.02-2.12 (0.35)	Canned	Canada
(Moon *et al*., 2011)	Fish ((µg)	0.04-0.07 (0.06)	Seafood	Korea
(Liu *et al.,* 2019)	Soil (mg/kg)	0.08-1.36(0.36)	Soil	Shanghai, China
(Chen *et al.,* 2010)	Soil (mg/kg)	0.02-9.40(0.30)	Soil	Beijing, China
(Chen *et al*., 2010)	Soil (mg/kg)	0.03-3.32(0.33)	Soil	Guangzhou, China
(Chen *et al*., 2012)	Soil (mg/kg)	0.02-0.02(0.09)	Soil	Shenzhen, China
(Fang *et al*., 2011)	Soil (mg/kg)	0.02-2.84(0.21)	Soil	Wuhan, China
(Gosar *et al*., 2016)	Soil (mg/kg)	0.01-5.29(0.11)	Soil	Slovenia
(Perez-Vazquez *et al*., 2015)	Soil (mg/kg)	NA-2.34(0.45)	Soil	San Luis, México
(Liu *et al.,* 2010)	Soil (mg/kg)	NA-0.22(0.02)	Soil	Carolina, U.S.
(Kelepertzis & Argyraki, 2015)	Soil (mg/kg)	0.01-1.08(0.17)	Soil	Athens, Greece
(Liu *et al*., 2019)	**Road dust** (mg/kg)	0.21-2.18(0.60)	**Dust**	Shanghai, China
(Men *et al*., 2018)	**Road dust**(mg/kg)	0.04-0.78(0.16)	**Dust**	Beijing, China
(Hu *et al*., 2011)	**Road dust**(mg/kg)	00.05-0.34(0.12)	**Dust**	Nanjing, China
(Zheng *et al*., 2015)	**Road dust**(mg/kg)	0.02-0.56(0.16)	**Dust**	Huainan, China
(Lin *et al.,* 2019)	**Road dust**(mg/kg)	0.05-0.80(0.34)	**Dust**	Nanning, China
(Liang *et al.,* 2009)	**Road dust**(mg/kg)	0.034-1.4(0.28)	**Dust**	Xiamen, China
(Coufalík *et al.,* 2014)	**Road dust**(mg/kg)	0.48-2.32(1.11)	**Dust**	Baoji, China
Christoforidis & Stamatis, 2009)	**Road dust**(mg/kg)	0.03-2.67(1.35)	**Dust**	Czech Republic
(Quiñonez-Plaza *et al*., 2017)	**Road dust**(mg/kg)	0.03-0.57(0.13)	**Dust**	Luanda, Angola
(XuezeA *et al*., 2002)	**Road dust**(mg/kg)	NA-3.3(0.13)	**Dust**	Kavala, Greece
(Li-qiang *et al*., 2004)	**Road dust**(mg/kg)	NA-0.3(0.10)	**Dust**	Tijuana, México
(Liu *et al.,* 2019)	**Plant** (mg/kg)	0.26-045(0.09)	**Leaf**	Shanghai, China
(XuezeA *et al*., 2002)	**Plant** (mg/kg)	2.60-22.90(13.64)	**Leaf**	Zhuzhou, China
(Li-qiang *et al.,* 2004)	**Plant** (mg/kg)	0.0-,0.77(0.11)	**Leaf**	Harbin, China
(Laacouri *et al.,* 2013)	**Plant** (mg/kg)	NA-NA (0.04)	**Leaf**	Minnesota, U.S.
(Dombaiová, 2005)	**Plant** (mg/kg)	0.02-0.06 (0.04)	**Leaf**	Slovakia
(López-Berdonces *et al*., 2014)	**Plant** (mg/kg)	46-453(160.6)	**Leaf**	Jódar, Spain
(Wilson, 2012)	**Emission (kg)**	5600-56600(25400)	**TR**	Australia*
(Wilson, 2012)	**Emission (kg)**	21100-73700(42800)	**TR**	Caribbean**
(Wilson, 2012)	**Emission (kg)**	20400-85300(45200)	**TR**	Middle East USA
(Wilson, 2012)	**Emission (kg)**	48400-156300(90000)	**TR**	Americas
(Wilson, 2012)	**Emission (kg)**	101400-335100(215500)	**TR**	South America
(Wilson, 2012)	**Emission (kg)**	51800-233700(123300)	**TR**	***CIS
(Wilson, 2012)	**Emission (kg)**	68000-253400(141600)	**TR**	European Union
(Wilson, 2012)	**Emission (kg)**	478500-1583100(942400)	**TR**	South-East Asia
(Wilson, 2012)	**Emission (kg)**	106000-326500(195900)	**TR**	South Asia
(Wilson, 2012)	**Emission (kg)**	20400-85300(15500)	**TR**	North Africa
(Wilson, 2012)	**Emission (kg)**	131500-364000(225800)	**TR**	Sub Saharan Africa

*NA; Not found, TR; Technical report, *; Australia, +; New Zealand and Oceania, **; Central America and Caribbean, *** CIS; Commonwealth of Independent States and European countries*

Concentration of Mercury in Soil

The pooled mean concentration of Hg in sampled soil was 0.32mg/kg (95% CI: -1.25, 1.90), where the heterogeneity of the study was tau 2=00, I2=0.00 and H2=1.00 (Figure 2).

Concentration of Mercury in Road's Dust

The pooled mean concentration of Hg in sampled road dust was 0.47mg/kg (95%CI: -1.10, 2.04), where the heterogeneity of the study was tau 2=00, I2=0.00 and H2=1.00 (Figure 3).

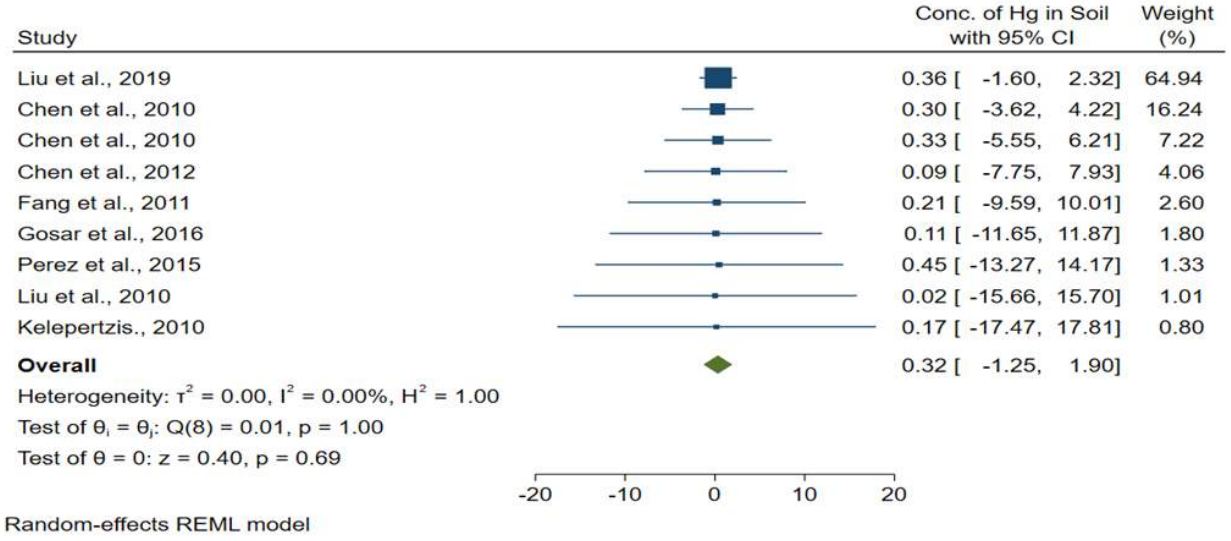

Figure 2: Concentration of Hg in sampled soil and obtained from 2010-2019 published studies

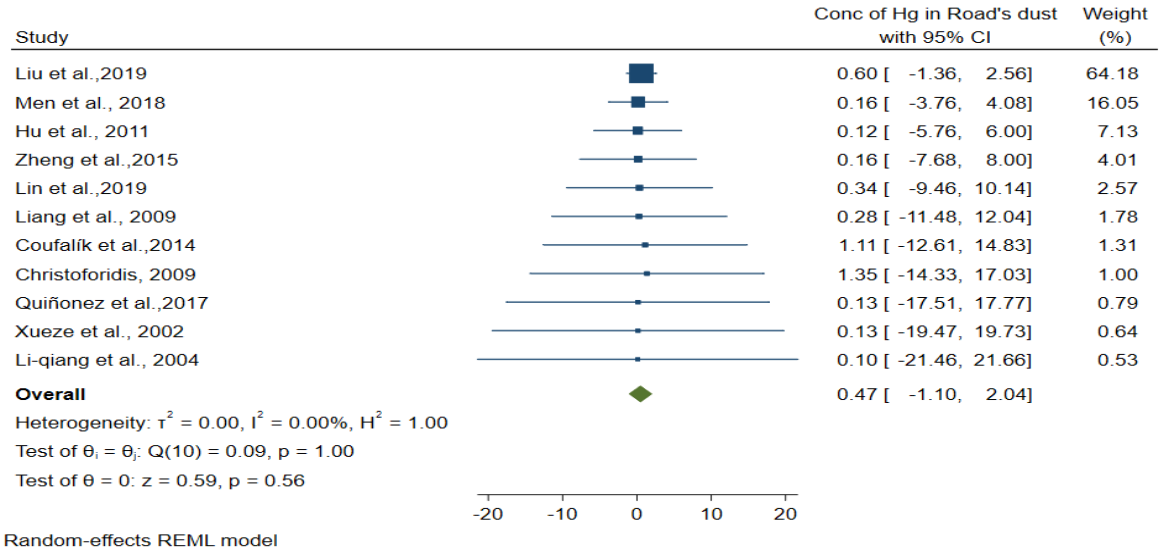

Figure 3: Concentration of Hg in sampled road's dust and obtained from 2004 to 2019 published studies

Concentration of Mercury in Water Bodies

The pooled mean Hg concentration in sampled water bodies particularly seas obtained from different studies was 0.55 µg/dm3 (95% CI: -1.04, 2.13), where the heterogeneity of the study was tau 2=00, I2=0.00 and H2=1.00 (Figure 4).

Concentration of Mercury in Plant

The pooled concentration of Hg in sampled leaf from different plant types obtained from various studies was 28.96 mg/kg (95% CI: -22.57, 80.49), where the heterogeneity of the study was tau 2=4131.74, I2=99.84 and H2=634.38, test for a p-value <0.05(Figure 5).

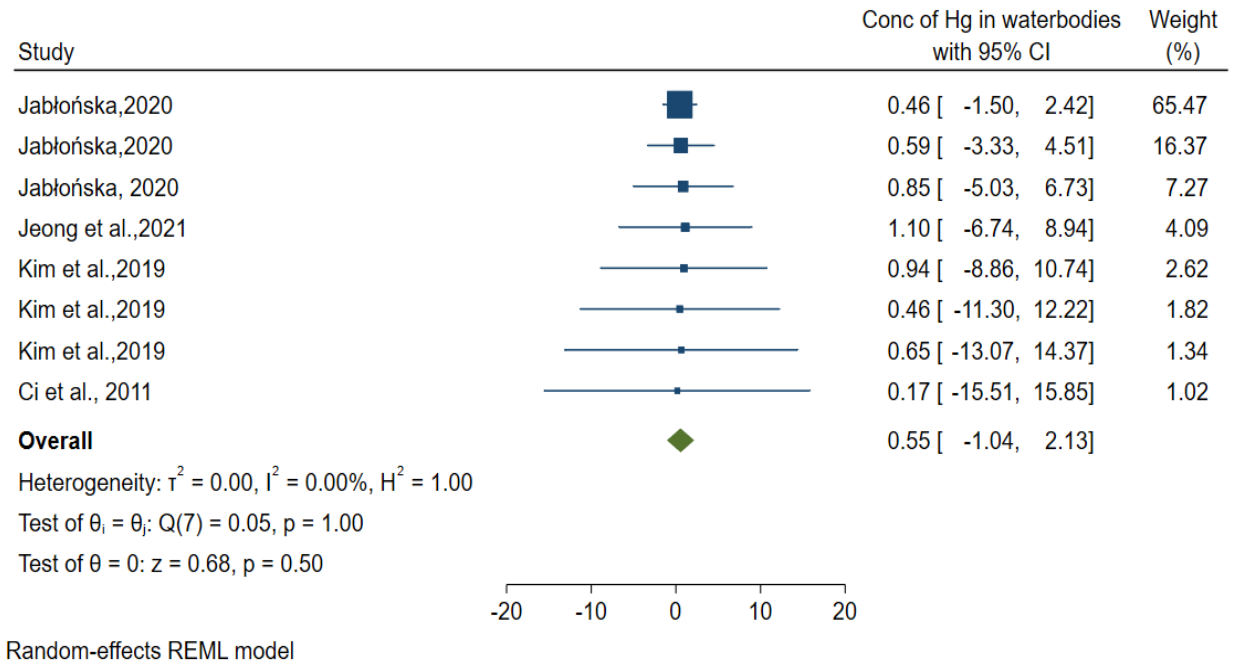

Figure 4: Concentration of Hg in sampled from water bodies obtained from 2011 to 2021 Published studies

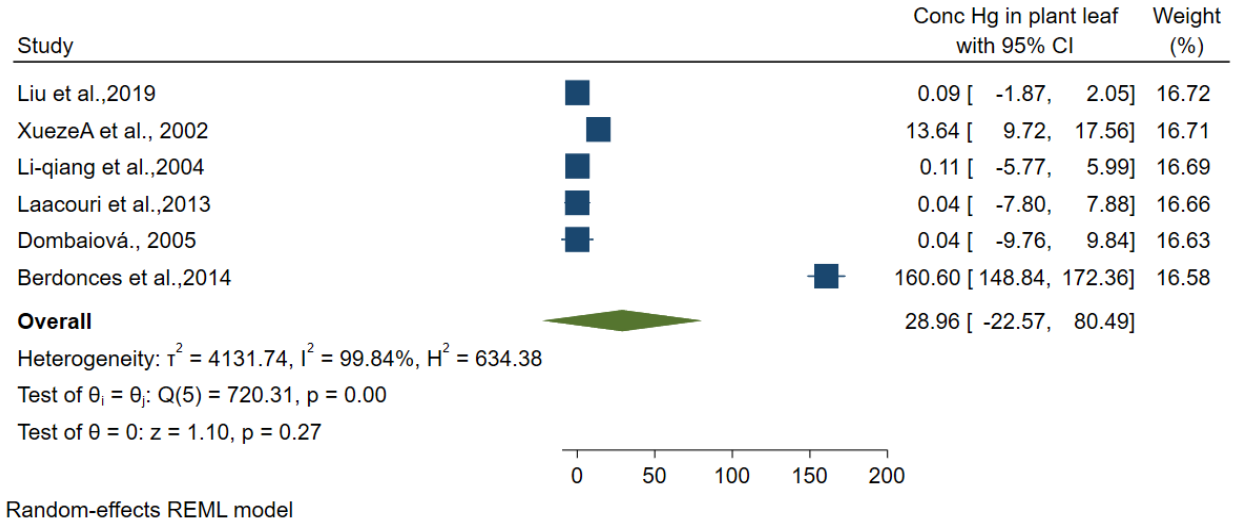

Figure 5: Concentration of Hg in different type plants obtained from 2002 to 2019 Published studies

Concentration of Mercury in Fish

The mean Hg concentration in fish obtained from various studies was 1.60 (µg) (95% CI: -0.02, 3.22), where the heterogeneity of the studies was tau 2=0.00, I2=0.00 (Fig 6).

Concentration of Mercury in Sample Blood

The pooled mercury concentration in sampled blood obtained from four studies was 0.92 µg/L (95%CI: -0.72, 2.57), where the heterogeneity of the study was tau2=0.00, I2=0.00 and H2=1.00 (Fig. 7).

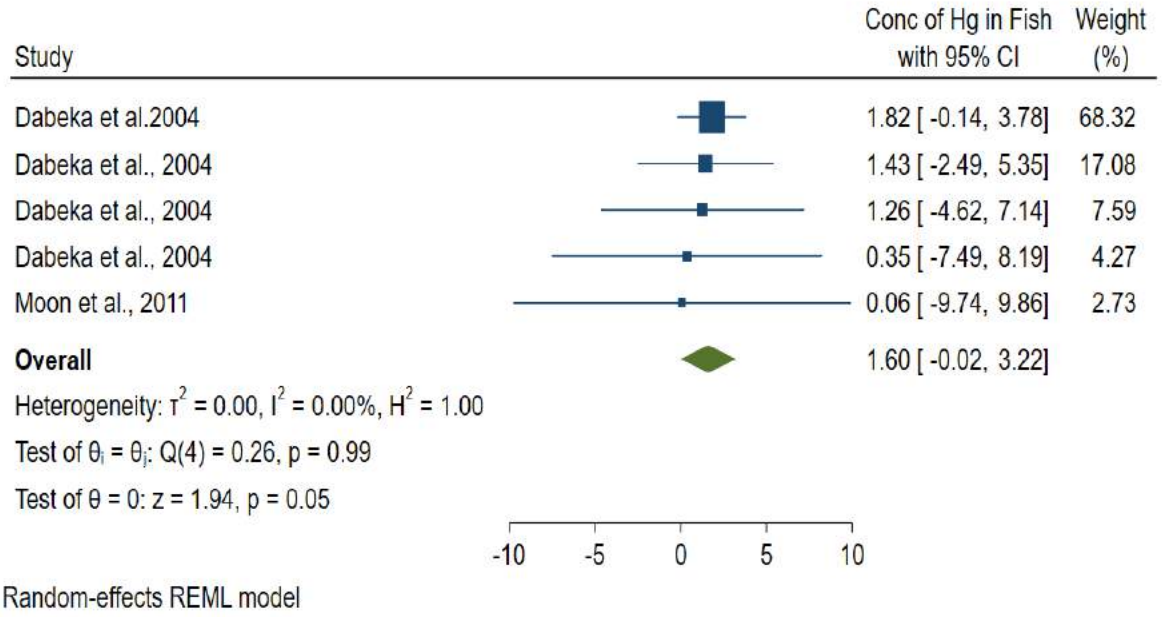

Figure 6: Forest plot depicting the pooled estimate of concentration of Hg in different fish type from published studies from 2004 to 2011

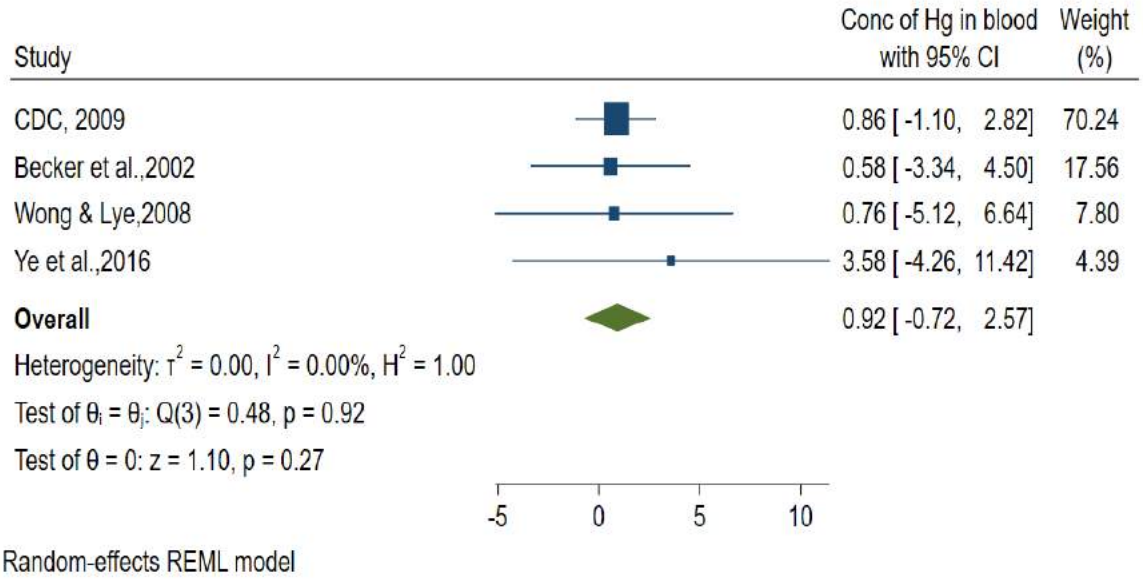

Figure 7: Concentration of mercury in blood sample obtained from studies

Concentration of Mercury Emitted to Atmosphere

According to this evidence, the result of anthropogenically activities, the mean total emission of mercury was 2,063,400kg. The estimated quantity of mercury emissions comes from the following regions: the oceans around Australia, New Zealand, and Oceania; Central and Caribbean America; the Middle East and North Africa; the Americas; South America; the Commonwealth of Independent States and European countries; other European nations; the European Union; East and South-East Asia; South Asia; North Africa; and Sub-Saharan Africa. Of this, the highest amount of Hg emission (i.e., 942,400kg) was originating from the East and Southeast Asia (Figure 8).

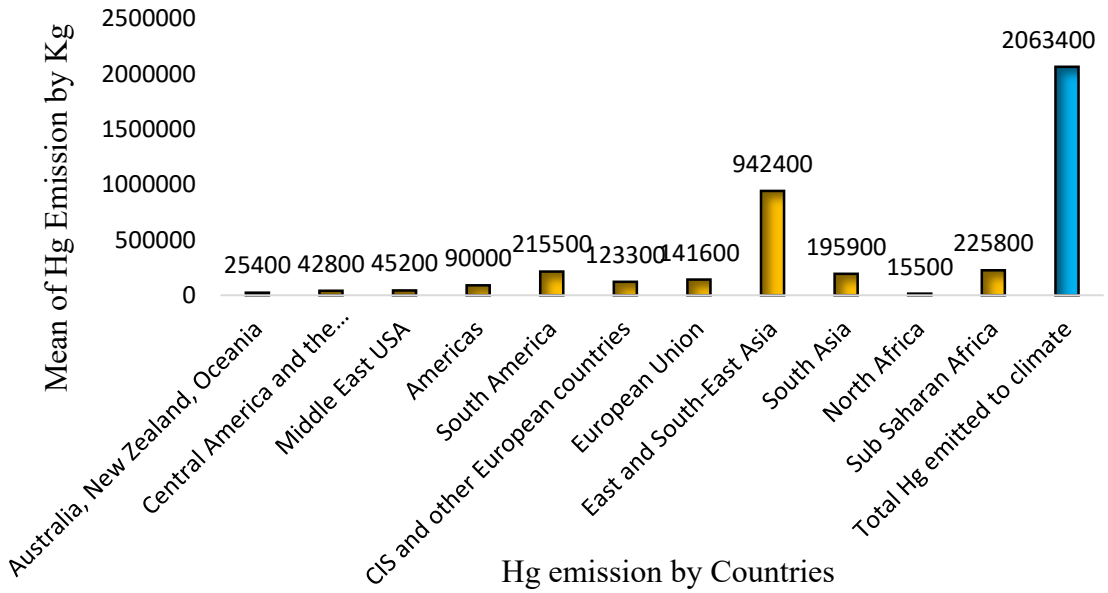

Figure 8: Anthropogenically emission of mercury from different world's countries (Raw data from (Wilson, 2012)

Geo-Spatial Distribution of Mercury Emission to Atmosphere

The Geo-spatial emission of mercury from different world's countries. According to reported data obtained from Wilson (2012), the raw data shows the majority of the countries emitted Hg in the range of 15,951.98 kg to 118,757.76 kg. However, according to reported data obtained a small number of countries, particularly in central and sub-Saharan Africa, emitted Hg in the range of 838,398.22kg to 941,204 (Figure 9).

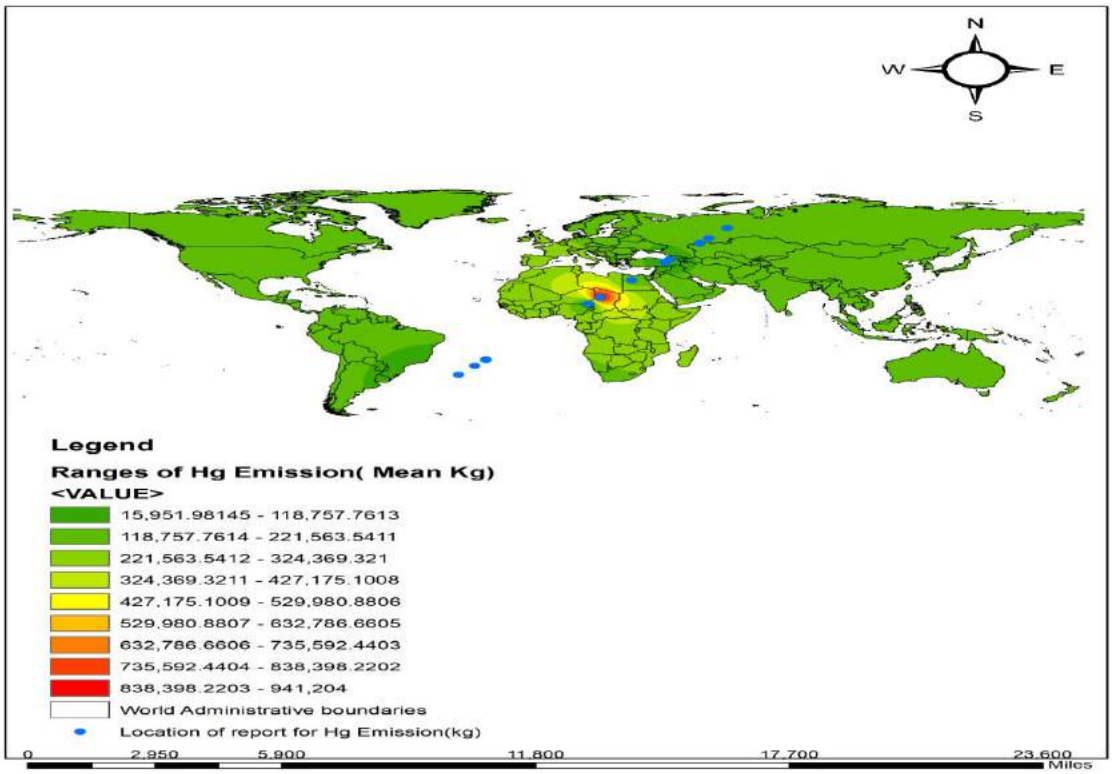

Figure 9: Geo-spatial ranges of Hg emission from different world's countries (Raw data from (Wilson, 2012)

Funnel Plot for Publication Bias

The results of a thorough meta-analysis of funnel statistics can be seen in the scatter plots, which are asymmetrical and have all of the scatters pointing on the vertical line and at the center of the funnel plot (Figure 10).

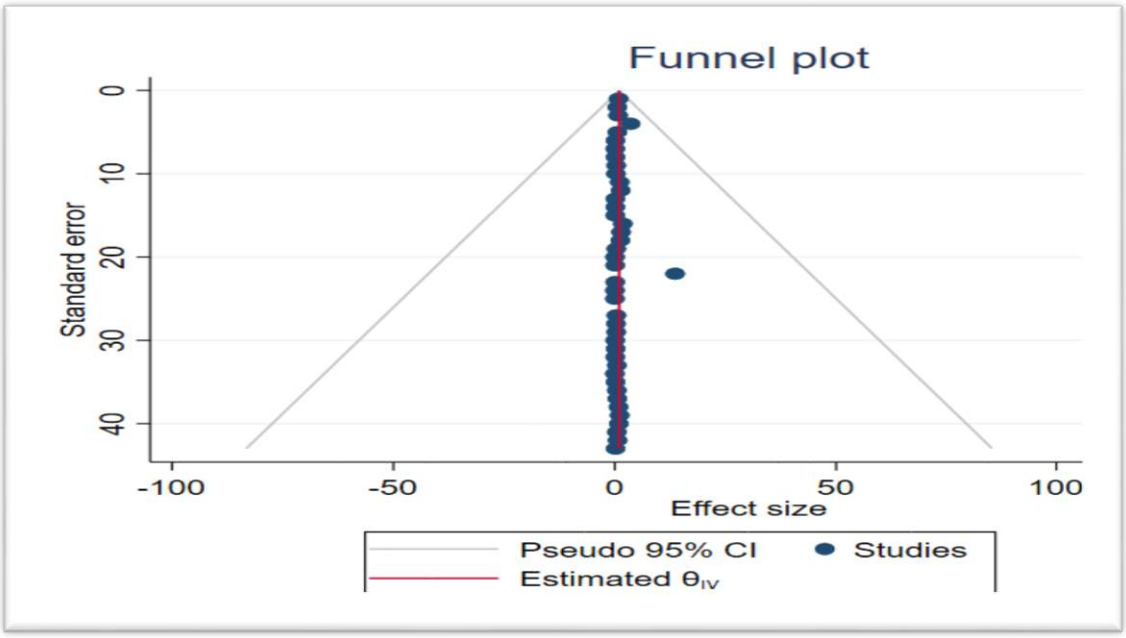

Figure 10: Shows that funnel Plot for Publication bias between components across the Eligible studies

Discussion

Many eligible studies stated that mercury has been used for centuries in multiple capacities, including medicinal and widespread industrial use. This results in widespread chemical exposure and environmental pollutants, which have not been well assessed globally. Therefore, it is essential to understand how to mitigate and rectify biotic and abiotic components. So, that assessing mercury concentration in biotic and abiotic environments is very important to educate the readers about its adverse effects, impact, and prevention methods. Therefore, to quantify mercury concentration in biotic and abiotic environments, a systematic review and meta-analysis were conducted among 30 studies from different countries. Out of eligible studies, four, three, two eight, and five studies or records, were used to quantify Hg concentration in blood, water bodies and type of fish, road dust, dust and leaf of plant, respectively.

Therefore, considering this information, the current systematic review and meta-analysis revealed that the pooled mean concentration of Hg in fish obtained from the various studies was 1.60 (µg). This finding exceeds the maximum permissible limit value of Hg 0.01(EPA, 2004). As the majority of us know, soil, dust, and plants are essential for the growth and development of plants and crops. Considering this, the Hg concentration in the sampled soil, road dust, and plant leaf was assessed. Accordingly, the pooled concentration of Hg in sampled soil, road dust, and plant leaf was 0.32mg/kg, 0.47mg/kg, and 28.96 mg/kg, respectively. According to the characteristics of Hg, because of the bio-concentration, bio-accumulation, and biomagnification properties, such amounts in the ecosystem will increase to much higher levels; considerable increases in soil Hg levels result in relatively small increases in plant Hg levels by direct absorption from soil. Despite plants absorbing little organic and inorganic Hg from the soil, and there is a barrier to Hg transfer from plant roots to crowns (Patra & Sharma, 2000).

The current analysis found that the pooled concentration of Hg in sampled water bodies worldwide was

0.55 µg/dm3. As WHO suggested, naturally occurring levels of Hg in groundwater and surface water should be less than 0.5 µg/L. However, local mineral deposits may produce higher levels in groundwater (WHO, 2003) even if other studies suggested that the concentration of mercury should not be found in water bodies, like oceans, lakes, seas, and rivers (Ye *et al*., 2016). This study found that the Hg exposure limit in the general environment also varies.

The analysis also found that the pooled concentration of mercury in sampled blood among eligible studies was 0.92 µg/L. When compared with the single studies, it is lower than the review from Korea (2.88-4.28ug/L (on average 3.58 ug/L), but it was four to six times higher than that of the U.S. (0.86 ug/L) (CDC, 2009) Germany (0.58 µg/L) (Becker *et al*., 2002), and Canada (0.76 ug/L) (Wong & Lye, 2008). As empirical study indicated, the Hg concentration in whole blood is usually lower than 10 µg/L. However, blood Hg concentrations can reach 35 g/L after prolonged exposure to Hg vapor. (Klaassen & Amdur, 2013). Mercury can cause cardiovascular damage, reproductive and developmental toxicity, neurotoxicity, nephrotoxicity, immunotoxicity, and carcinogenicity (Getchi *et al.,* 2017). However, it serves no beneficial physiological function in man; therefore, a maximum acceptable concentration of 0.001 mg/L (µg/L) in drinking water has been established.

Based on statistics provided by Wilson (2012), most eligible countries released emissions between 15,951.98 kg and 118,757.76 kg. However, a limited number of countries, mainly in central and sub-Saharan Africa, released between 838,398.22 kg and 941,204 kg, according to data that has been reported (Figure 9). Whatever the current status of Hg emission, according to the regulation of mercury emission, even a small amount of Hg could adversely impact the ecosystem, including the food chain (CDC, 2009). This means that a sizable quantity of Hg is being released into the food, soil, water bodies, air, or atmosphere, considerably influencing biotic and abiotic environments, including climate change. Because mercury and many of its derivatives are volatile, the study concluded that mercury is a hazardous, persistent, and mobile contaminant that does not decompose in the environment and thus travels around. Mercury may also travel long distances inside air masses (Pacyna, 2020). In addition, according to one research, Hg is the only element in the periodic table with its environmental treaty, namely the Minamata treaty on Hg, emphasizing the significance of the Hg contamination issue (Bank, 2020). Therefore, this review suggested that the limit of Hg compounds be set to 5 mg/m3 or lower in the air and the components of the environment, according to the findings obtained from (Ye *et al.,* 2016).

The overall heterogeneity (I2) of the studies on the concentration of Hg in fish, soil, road dust, water bodies, and blood was zero percent. I2 may be viewed as the proportion of variability in the point estimates due to tau (τ) rather than within-study error, which was also zero for all studies. This might be because, in this systematic review and meta-analysis, some used more than one for the different effect sizes or outcomes that may lead to a very small percent of I squared, even if zero, across studies. On the other hand, such results could be produced as the reason for overlapping confidence intervals across the eligible studies (Julian & Higgins, 2008). Even though the heterogeneity of the studies obtained for the plants was 99.84 percent, where I2 of the studies ranges between 75% and 100% according to (Higgins, 2011) the cut-off point. This indicates the significant heterogeneity for the unaccounted variability owing to residual heterogeneity in this review and meta-analysis. Moreover, the value of tau (τ) among the studies was 4131.74, representing the absolute value of the actual variance (heterogeneity) between the studies according to the (Higgins, 2011) interpretations.

Moreover, the funnel plot highlighted the area where 95% of the impact size was seen because of publication bias in areas where scatterplots or dots have an uneven distribution at the center. Conventionally, the plot distributions are expected to be on the right and left sides of the vertical line, which is simply symmetrically distributed within triangle of the funnel plot. In addition to this, the vertical axis should divide the scatterplot or dots into equal scatter with accurate distribution, with straight lines denoting 95% confidence intervals, and the vertical line should denote the predicted shape in the absence of bias corresponding to a symmetrical funnel expressed as the standard error (precision of the study) (Thaler *et al.*, 2015). According to (Sterne *et al*., 2000) explanations, the effect size placed at the bottom of the funnel and those close to

the bottom of the funnel indicate low precision of the studies, while dots placed at the top of the funnel in this illustration indicate high precision of the studies.

Strengths and Limitations of the Study

Regardless of the limitations, this review has particular strengthens: Of these, this systematic review and meta-analysis brought the image of studies on Hg concentration across the world. This might be useful for generating evidence about Hg concentration in the various environmental components. This systematic review and meta-analysis also assess the critical environmental components like fish, soil, plants, water bodies, and blood, which brings concrete information to each component for the readers in one published paper. Additionally, the results demonstrate the mean concentration of Hg in both abiotic and biotic environments. Also, regardless of the strengths, systematic review and meta-analysis have limitations. Of these, it was only assessed in a small number of studies or single studies, which may have limited the scope of this systematic review and meta-analysis. The funnel plot for publication bias for all components was not presented or omitted because of the number of scopes within this systematic review and meta-analysis. Furthermore, in the current systematic review and meta-analysis, we used different components; therefore, the result cannot reach a single conclusion about the mean mercury concentration.

Conclusion

In this systematic review and meta-analysis, three-quarters of the eligible studies were from high-income countries. This suggests a paucity of research in low- and middle-income countries, resulting in an unbalanced distribution of research on mercury around the globe. In addition, the included eligible studies demonstrated a high concentration of mercury from human blood, water bodies and types of fish, road dust, dust and leaf of plants. The review also found a small concentration of quantified Hg in biotic and biotic environments. However, it is not modest because mercury possesses bio-concentration, bioaccumulation, and bio-magnification characteristics, and the bio-availability of Hg is shown in both biotic and abiotic. Thus, it has possible adverse effects on the food chain from the low level (producers) to high level (consumers). Therefore, this review advises that the global Hg partnership, policies, and regulations on mercury management in advanced countries be intensified by an Hg phase-out program and Hg control strategies. As a result, in order to maximize regional comparability, future studies should focus on low-middle-income nations, where raw Hg is predicted to be generated in the exact quantities as other industrialized countries.

Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

All authors contributed on data searched and data extraction, information synthesizing and article evaluation. ST, AD and AB contributed on data analysis. BB, DF, EM, MK and TA participated on synthesizing data. All Authors approved this final manuscript.

List of Abbreviations

CIS: Commonwealth of Independent States and European countries, EPA: Environmental Protection Agency, Hg: Mercury, PRISMA: Preferred Reporting Items for Systematic Reviews, JBI: Joanna Briggs Institute, WHO: World Health Organization.

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