A Systematic Review of Toxic Metals Occurrences through Drinking Water in Ghana

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Abstract

Toxic metals (TMs) are metallic contaminants that cause adverse health effects even at low exposure levels. Arsenic (As), Manganese (Mn), Lead (Pb), and Cadmium (Cd) are among these contaminants of concern, causing irreversible developmental damage to children (Pb), as well as cardiovascular disease (Pb) and cancers (As) in adults. Arsenic and Manganese are primarily geogenic groundwater contaminants that can also be introduced to drinking water systems by localized anthropogenic contamination sources. Corrosion of lead-containing plumbing components contributes to much of the Lead in drinking water, while localized anthropogenic pollution can leach into some otherwise clean water sources as well. Cadmium is often used in fertilizers and can be an indicator of anthropogenic contamination. We reviewed published studies reporting on concentrations of As, Mn, Pb, and Cd in Ghanaian drinking water quality to assess the occurrence and potential health implications of these TMs. As part of a larger systematic review, we searched for peer-reviewed literature from PubMed, EBSCO Global Health, and the Web of Science, between November 2019 and March 17, 2025, to retrieve studies published in English after 1968 that assessed toxic metals levels or contamination in drinking water in Low- and Middle-Income Countries. This generated 20,552 studies from the initial search, which were screened down to 3,993 studies for extraction. We selected the 93 studies that measured a TM in Ghanaian drinking water for full-text review and data extraction. We focused on Arsenic, Manganese, Lead, and Cadmium, for which we had the most data on metals with WHO limits. 79 studies reported concentrations of Arsenic, Manganese, Lead, and/or Cadmium. A quality evaluation was carried out for these studies by assessing the suitability of reported sample collection, analysis, and quality assurance/quality control practices, and by extracting information on the source of drinking water, GPS coordinates, and observed concentrations for each TM. This resulted in the inclusion of 93 studies comprising 82,111 samples, with 8,124, 11,882, 6,079, and 6,679 observations for Arsenic, Manganese, Lead, and Manganese, respectively. We found that 18%, 34%, 17%, and 15% of included Ghanaian drinking water samples exceeded the WHO Guideline Values for Arsenic, Manganese, Lead, and Cadmium, respectively. Data were widespread across Ghana, though we found few studies in the regions north of Kumasi. These findings comprise sufficient evidence to recommend preventative action to eliminate such contamination in new drinking water systems in Ghana, as well as to explore potential interventions to progressively prioritize and remediate the most serious existing exposures to TMs in existing drinking water systems.

Keywords: Toxic Metals, Drinking Water, Ghana, Arsenic, Manganese, Lead, Cadmium

Introduction

Toxic metals (TMs) are metals and semimetals that can cause adverse health effects even at low exposure levels. There is growing evidence that drinking water is an important exposure route for man TMs. A global systematic review found that several TMs occur in drinking water in low- and middle-income countries (LMICs) at levels exceeding World Health Organization Guideline Values (WHO GVs) at frequencies relevant to public health (1,2).

Arsenic (As) is widely known to contaminate groundwater through geogenic deposits and industrial or mining contamination (3–5). It has been linked to numerous cancers and negative long-term health outcomes (6–9). The WHO has set a guideline value of 10 μg/L for As in drinking water (10).

Manganese (Mn) is a trace metal that is essential in humans but can also cause harmful health effects, including neurotoxicity, muscle pain, and fatigue at higher concentrations (11–13). Drinking water contaminated with high manganese concentrations may cause learning and behavioral problems in children and infants (14). There is debate over the allowable exposure to manganese, but when considering child health, WHO has recently adopted a provisional GV of 80 μg/L for Mn in drinking water (10,15). Manganese is typically a geogenic contaminant in drinking water, but it is also linked to anthropogenic contamination from mining, industrial emissions, and fossil fuel combustion (16).

Lead (Pb) is a neurotoxin with no taste or odor in drinking water, for which no safe level of exposure has been determined (17–20). Lead is especially harmful to children, for whom it can cause irreversible learning disabilities and atypical neurological development (21–23). Lead is also linked to cardiovascular disease (17,24,25). The WHO has set a Guideline Value of 10 μg/L Pb for drinking water (10), though other bodies have recommended thresholds as low as 1 μg/L for drinking water in childcare settings (26). Common contamination routes in drinking water include the leaching of Pb from lead-containing infrastructure (27–30) and pollution from industrial waste (17,28,31,32).

Cadmium (Cd) is a typically anthropogenic contaminant linked to agriculture and the use of fertilizers (10,33). Cadmium is a carcinogen that can also cause damage to diverse organ systems (33–37). The WHO has set a GV of 3 μg/L for Cd in drinking water (10).

Ghana has made substantial progress in improving drinking water infrastructure over the past decade. Nevertheless, less than 1% of urban populations in Ghana currently lack access to either Basic or Safely Managed drinking water, down from 8% in 2015 (38). The rural setting has also improved from 68% to 76%, with either Basic or Safely Managed drinking water, from 2015 to 2024 (38). However, the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) estimates that 10.51% of rural Ghanaians still rely on surface water for their drinking source. The World Bank Group estimates that 42% of Ghana's population of 34 million lives in rural settings, implying that at least 1,400,000 individuals may depend on surface water (39).

There has been recent evidence that JMP-Improved drinking water in Ghana has some level of TM contamination (40–42). Ghana has widespread mineral mining across many districts, both at the artisanal and industrial levels, which may negatively affect water quality in the region. This contamination has been noted in both urban and rural Ghana (42,43). Many of these datasets present fragmented evidence on TMs in Ghanaian drinking water. Noting the lack of national data, we aim to synthesize regional studies to develop a more representative evaluation. This study seeks to use evidence from a systematic review to characterize the occurrence and distribution of TMs in Ghanaian drinking water, with a focus on the occurrence of Arsenic, Manganese, Lead, and Cadmium. We seek to evaluate the level of exceedance of these metals in drinking water above their respective guideline values in urban, rural, improved, and unimproved settings.

Methods:

Search Strategy and Screening

This study is part of a larger systematic review of TM occurrence in drinking water in Low- and Middle-Income Countries (LMICs) produced by Fisher et al. (1,2). We therefore use the same methodology, described in the original studies and registered under PROSPERO (CRD42024566116). Briefly, we searched PubMed, EBSCO Global Health, and Web of Science to select relevant studies published in English after 1968 with primary data on TM concentrations in drinking water in an LMIC setting, with the most recent search in March 2025. This generated an initial 20,552 citations for evaluation. In our overall systematic review, a total of 3,993 studies were included in the final data extraction and analysis step. A full description of the search terms and inclusion criteria is provided in S1. For this study, we included studies evaluating water quality data in Ghana. The search summary is shown in Figure 1 below.

Data Extraction and Analysis

We extracted relevant information from 93 studies on Toxic Metals in Ghanaian Drinking Water, following the PRISMA guidelines, as outlined in Figure 1. This extraction included relevant metadata, water-source type, season, metal-concentration measurements, reported source(s) of contamination, as well as sample collection, analysis, and laboratory quality assurance/quality control (QA/QC) practices. A continuity correction was made for results reported as "non-detects," which were replaced with one-half the published limit of detection (of reported) or one-half the indicative limit of detection for the method used, as reported by other sources. A single reviewer extracted data, and a second team member evaluated the extraction sheet for each study. Missing summary statistics and other relevant information were imputed using the methodology outlined in Hozo et al. (44). Using the information provided in each paper and any imputed values, we calculated summary statistics for toxic metals concentrations and used these values to estimate the percentage of samples that exceeded the WHO Guideline Values (GVs) if not reported in the original paper. Using QGIS, we evaluated the percentage of the population within five miles of a study's centroid to identify regions with missing evidence.

Fig. 1 - PRISMA Flowchart of studies included in a systematic review of Arsenic, Manganese, Lead, and Cadmium in drinking water sources in Ghana

Results:

We found 93 papers discussing TMs in Ghanaian drinking water. Of these, 79 papers were included that measured As, Mn, Pb, or Cd, which we discuss in the body of this paper. A summary of all TMs, comprising the additional elements Antimony, Chromium, Copper, Iron, Mercury, Nickel, Selenium, and Uranium, is available in S2.

The total number of observations included in this study is 82,111. There are 8,124 As observations, 11,882 Mn observations, 6,097 Pb observations, and 6,679 Cd observations. A summary of these studies is shown in Fig. 2. There was a noticeable increase in total observations after 2013, in which a single large study produced almost 9,000 observations. According to Table 1, there are fewer observations in urban settings than in rural settings; the proportions of observations from JMP-Improved versus JMP-Unimproved sources are roughly comparable, as shown in Table 2. Many of the studies pulled samples from mixed locations.

Fig. 2 - Characteristics of included studies. (Left) Cumulative studies published on toxic metals in Ghanaian drinking water over time; (Right) Cumulative observations of Arsenic, Lead, and Manganese in Ghanaian drinking water over time.

We observed overall exceedances above their GVs for 18%, 34%, 17%, and 15% of total samples for Arsenic, Manganese, Lead, and Cadmium, respectively. There was a noticeably lower number of observations in urban settings across all contaminants, which did not correspond to the level of urban population, as shown in Table 1. There were more observations in "Mixed" settings than in urban or rural settings for Arsenic, Lead, and Cadmium. This includes a handful of large datasets that had low observed exceedance percentages. Arsenic, Lead, and Cadmium exceedances were higher in Urban settings, while Manganese exceedances were higher in Rural settings by a larger margin. A higher percentage of samples from unimproved vs improved sources exceeded WHO GVs across all toxic metals (Table 2). For Manganese and Lead, improved sources still exceeded 10%.

Table 1: Summary of Data by Urban versus Rural Classification for Arsenic, Manganese, Lead, and Cadmium

Contaminant	Urban/Rural	Total Observations	% Exceedances
As	Urban	389	52.7
	Rural	3610	25.9
	Mixed	4125	6.3
Mn	Urban	1328	19.2
	Rural	6035	52.5
	Mixed	4519	12.1
Pb	Urban	535	38.3
	Rural	1480	33.2
	Mixed	4082	8.6
Cd	Urban	321	35.2
	Rural	2578	32.3
	Mixed	3780	2.3

Table 2: Summary of Data by JMP Improved versus Unimproved Classification for Arsenic, Manganese, Lead, and Cadmium

Contaminant	Improved/Unimproved	Total Observations	% Exceedances
As	Improved	4236	7.7
	Unimproved	3888	27.7
Mn	Improved	5249	18.2
	Unimproved	6633	45.4
Pb	Improved	4063	15.9
	Unimproved	2034	19.8
Cd	Improved	3775	7.7
	Unimproved	2904	25.6

Across all elements, Southern Ghana has a higher number of TM measurements. Few studies have evaluated TM contamination in drinking water in the Volta, Bono, Bono East, Oti, Savannah, Northern, Upper West, North East, and Upper East regions, where around 10.5

million people live. Looking at the sub-administrative units where samples were collected, Manganese, Arsenic, Lead, and Cadmium were sampled, and their data were presented, for 143, 110, 107, and 86 of 260 units, respectively. This accounts for 17.9 million, 14.8 million, 14.1 million, and 11.2 million individuals living in sub-administrative units within 5 miles of a sampling point with reported data, respectively. Arsenic data, shown in Figure 3A, showed high exceedance rates, predominantly in the South. Manganese data, shown in Figure 3B, had high percentages of exceedance concentrated in the South, especially in the Greater Accra, Cape Coast, and Western regions, with additional pockets of exceedance observed in the North. Lead and Cadmium data, shown in Figure 3C-D, showed scattered exceedance percentages across the country, with no discernible geographic trend.

Fig. 3 - Distribution of the percentages of (A) Arsenic, (B) Manganese, (C) Lead, and (D) Cadmium exceeding the WHO Guideline Values of 10, 80 (provisional), 10, and 3 μg/L in Ghanaian Drinking Water, respectively

Discussion:

The cumulative exposure to TMs above Guideline Values is of potential concern to health and should not be overlooked in drinking water quality. From a public health perspective, the lower percent exceedance of each TM in improved sources compared to unimproved settings suggests a potential benefit for chemical water safety as water source infrastructure improves. This is pronounced for Arsenic and Cadmium, though improved settings still resulted in some exceedances for these TMs, suggesting that further investigation and source protection are still necessary. Both Manganese and Lead in improved settings exceeded 15% in terms of exceedance, implying that these sources may still be of public health concern. For Lead contamination, there is little difference between the improved and unimproved sources. This may be caused by systemic use of lead-containing plumbing materials (45). The use of leaded brass and lead-containing galvanized iron/steel can cause Lead to leach into otherwise clean drinking water (46). Therefore, for all elements, a shift to improved drinking water infrastructure does not ensure the elimination of TMs. JMP-Unimproved sources may include sources like unprotected dug wells, unprotected springs, or surface water (47), on which approximately 24% of rural Ghanaians rely. While bottled water and tanker water are used as drinking sources, they have very few total measurements of TMs, so we cannot evaluate their adequacy as alternatives.

In terms of the number of studies conducted in rural and urban communities in Ghana, an overwhelming majority of the studies were conducted in rural settings, despite only accounting for 42% of the country's population. For papers where urban and rural results could be disaggregated, rural samples account for 84% of observations. While there is some representation of urban settings in the handful of "Mixed" setting studies, most of these papers sampled from rural drinking water systems, with a minority of samples in urban settings that could not be disaggregated for analysis. These observations suggest that there is a disproportionate effort on drinking water quality monitoring for TMs in rural areas compared to urban areas in Ghana. While such disproportionate efforts might be justified by the lower improved water source coverage in rural areas than urban areas in Ghana, which necessitates such efforts to improve potable water access in the rural areas, the findings of this study have proven that the occurrence of TMs is pervasive in drinking water in both rural and urban areas in the country. Notably, the exceedance level of As in drinking water samples from urban communities was 2-fold higher than that from rural communities. Alternatively, Mn showed a nearly 3-fold higher exceedance in rural samples than in urban samples.

The synthesized data suggests that the drivers of these TMs in drinking water in Ghana are persistent in both rural and urban areas. While the comparable levels of the Pb and Cd exceedance might suggest concordance in the drivers of these TMs in the rural and urban settings, the conflicting levels in Mn and As are suggestive of differential drivers (in type and/or scale) of Mn and As in rural and urban drinking water in Ghana. Together, these observations not only call for intensified efforts on urban drinking water quality monitoring for TMs in Ghana, but also to understand such disparity in Mn and As occurrences in rural and urban areas in the country.

Of potential concern in designing public health interventions to TM contamination is the lack of data in many communities. Despite accounting for 84% of observations, rural settings across much of Ghana are poorly characterized, highlighting the need for more data. While geogenic contamination from Arsenic and Manganese can be potentially generalized or cross-referenced with mineralogical datasets, water quality evaluations are needed to identify key hotspots. Beyond the already described need for urban evaluations, we have noted a lack of data in many areas of the Volta, Bono, Bono East, Oti, Savannah, Northern, Upper West, North East, and Upper East regions, with some regions having no TM samples. Preventing anthropogenic pollution-induced contamination can be achieved through stricter environmental regulation. Likewise, the prevention of water-system-derived lead can be achieved through the use of lead-free infrastructure (45,46). Geogenic contamination can be prevented through site-specific monitoring and data collection coupled with source substitution (to avoid constructing systems relying on groundwater with elevated As or Mn levels where possible), coupled with applicable treatment where such geogenic contaminants cannot be entirely avoided. For existing systems contaminated with TMs, progressive remediation is often necessary, with a risk-based approach prioritizing systems with higher concentrations, larger user populations, longer design lives, and/or greater opportunities for prevention and remediation. Such progressive remediation can include the use of sorption and/or filtration techniques, corrosion control, oxidation/filtration, and/or other unit processes to remove arsenic and/or manganese from drinking water, and could be progressively implemented in rural, urban, and other communities to mitigate TM exposures through drinking water in Ghana (48).

Limitations

Our analysis has included all peer-reviewed studies on Toxic Metals in Ghana, though some datasets remain missing. We did not include grey literature, and to avoid upward bias, we rejected datasets using inadequate analytical instrumentation. This means that many datasets using Flame Atomic Absorption Spectrometry, whose limits of detection are often around 20 ug/L at best, had to be rejected for Arsenic, Lead, and Cadmium. Conversely, publication bias may lead to over-reporting of water-quality exceedances. However, there is likely still adequate information to recommend preventative measures and more targeted studies in underreported locations.

In calculating statistical significance across distributions between settings and identifying understudied locations, we had to rely on available data. If a dataset did not include sufficient information to impute log-mean data, such as only reporting percent exceedances or minimums and maximums, we were unable to include it in a T-test. Similarly, if a study did not include relevant information beyond percent exceedances, we could not include it in evaluating the population within a sampling point. Despite using the lowest administrative sub-unit available, the distance between a sampling point and the far end of a unit could be up to 50 miles, and therefore, its relevance to public health interventions may be limited. However, it may still be useful for identifying regions where substantial datasets are unavailable.

Conclusion:

The global call of the United Nations' Sustainable Development Goal 6 (SDG6) to improve clean water access has intensified efforts to increase potable water access in Ghana. In line with such efforts, the present study consolidated evidence of the occurrence of toxic metals in drinking water sources in Ghana from several studies to provide a general appraisal of the occurrences of Arsenic, Manganese, Lead, and Cadmium in Ghanaian drinking water sources. We observed exceedances of toxic metals in Ghanaian drinking water sources at levels of potential public health concern. We also noted a lack of data from urban settings and from many regions of Ghana. The findings revealed a source-type divide in the occurrence of TMs between improved and unimproved water sources in Ghana, with disproportionately higher exceedance levels for all the investigated TMs in water samples from unimproved sources relative to those from improved sources.

Statements and Declarations

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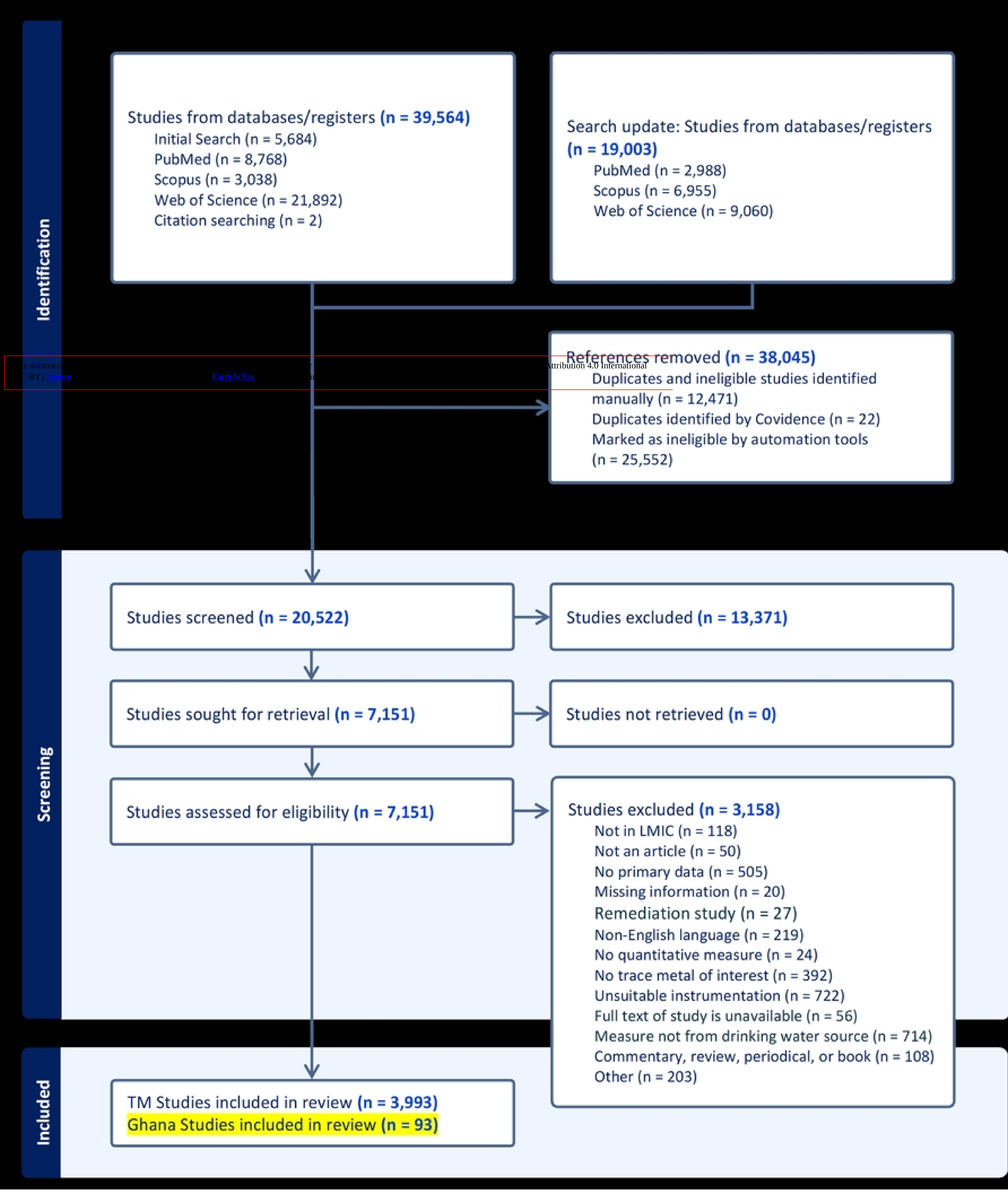
Identification
Studies from databases/registers (n = 39,564)
Initial Search (n = 5,684)
PubMed (n = 8,768)
Scopus (n = 3,038)
Web of Science (n = 21,892)
Citation searching (n = 2)
Search update: Studies from databases/registers (n = 19,003)
PubMed (n = 2,988)
Scopus (n = 6,955)
Web of Science (n = 9,060)
References removed (n = 38,045)
Duplicates and ineligible studies identified manually (n = 12,471)
Duplicates identified by Covidence (n = 22)
Marked as ineligible by automation tools (n = 25,552)
Screening
Studies screened (n = 20,522)
Studies excluded (n = 13,371)
Studies sought for retrieval (n = 7,151)
Studies not retrieved (n = 0)
Studies assessed for eligibility (n = 7,151)
Studies excluded (n = 3,158)
Not in LMIC (n = 118)
Not an article (n = 50)
No primary data (n = 505)
Missing information (n = 20)
Remediation study (n = 27)
Non-English language (n = 219)
No quantitative measure (n = 24)
No trace metal of interest (n = 392)
Unsuitable instrumentation (n = 722)
Full text of study is unavailable (n = 56)
Measure not from drinking water source (n = 714)
Commentary, review, periodical, or book (n = 108)
Other (n = 203)
Included
TM Studies included in review (n = 3,993)
Ghana Studies included in review (n = 93)

Fig. 1

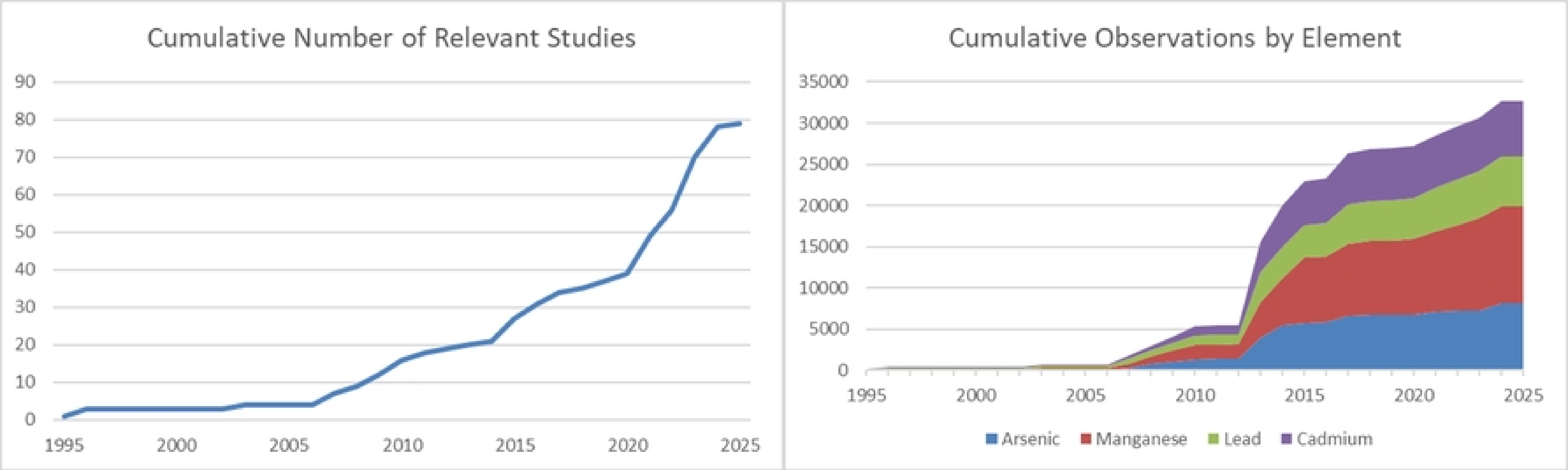
Cumulative Number of Relevant Studies
90
80
70
60
50
40
30
20
10
0
1995
2000
2005
2010
2015
2020
2025
Cumulative Observations by Element
35000
30000
25000
20000
15000
10000
5000
0
1995
2000
2005
2010
2015
2020
2025
Arsenic
Manganese
Lead
Cadmium

Fig. 2

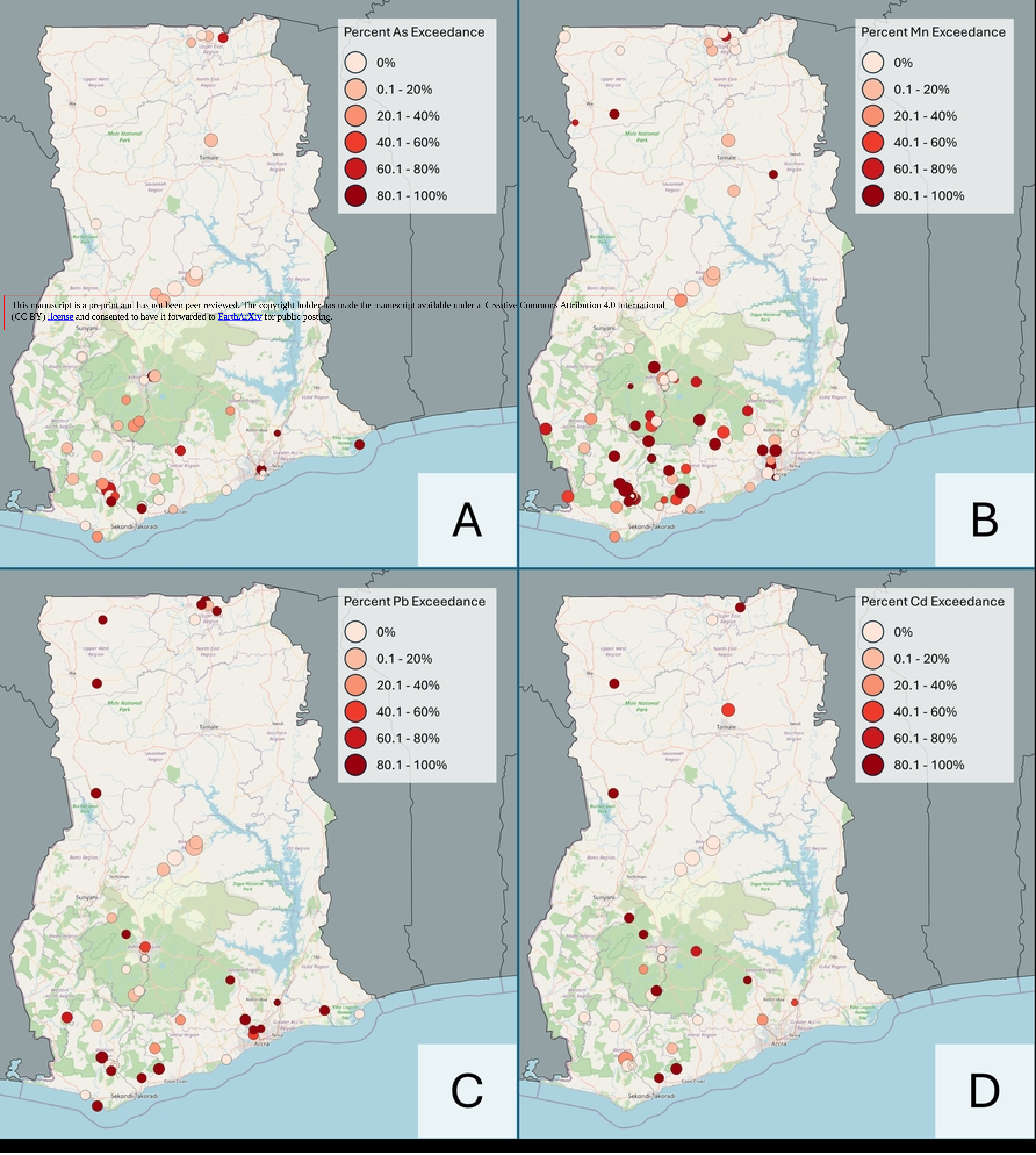
Percent As Exceedance
0%
0.1 - 20%
20.1 - 40%
40.1 - 60%
60.1 - 80%
80.1 - 100%
A
Percent Mn Exceedance
0%
0.1 - 20%
20.1 - 40%
40.1 - 60%
60.1 - 80%
80.1 - 100%
B
Percent Pb Exceedance
0%
0.1 - 20%
20.1 - 40%
40.1 - 60%
60.1 - 80%
80.1 - 100%
C
Percent Cd Exceedance
0%
0.1 - 20%
20.1 - 40%
40.1 - 60%
60.1 - 80%
80.1 - 100%
D

Fig. 3