



25 of observations of Arsenic, Lead, and Manganese exceeded their respective WHO Guideline  
26 Values. Additionally, many urban centers and large portions of the region were geographically  
27 underrepresented in the literature. The synthesized data are sufficient to recommend primary  
28 prevention and progressive remediation efforts to prevent and minimize exposure to TMs in  
29 drinking water across East Africa. Nevertheless, substantive literature gaps remain, indicating a  
30 need for further research across much of the region.

31

32 **Introduction:**

33 Toxic metals (TMs) in drinking water cause a variety of adverse health effects in humans,  
34 including organ damage, cancer, neurotoxicity, and cardiovascular damage (1). Lead (Pb),  
35 Manganese (Mn), and Arsenic (As) are among the TMs present in some drinking water that are  
36 hazardous to human health. Due to the toxicity of these metals, the World Health Organization  
37 (WHO) has established guideline values (GVs) of 10 µg/L for both Lead and Arsenic and a  
38 provisional GV of 80 µg/L for Manganese (2). Lead is particularly dangerous to children and has  
39 been found to cause decreased IQ, problems with learning and attention, and behavioral issues  
40 (3–6). No safe limit for lead exposure has been established, with the GV being selected on the  
41 basis of achievability (7). Arsenic can contaminate groundwater sources from natural geogenic  
42 deposits or anthropogenic sources (8). Arsenic is known to cause numerous health issues,  
43 including cancers and organ damage (9–11). Manganese causes neurological damage, memory  
44 and motor skill loss, and reproductive and fetal development issues, and, like arsenic, often arises  
45 from geogenic deposits (12–15). Drinking water is an important exposure route for these TMs,  
46 but occurrence data have not been systematically reported or synthesized for water systems in  
47 many low- and middle-income country (LMIC) settings.

48 Although the occurrence of TMs is well documented in high-income countries (HICs),  
49 published evidence on TMs in East Africa is less extensive and has not been systematically  
50 synthesized. For this work, East Africa is defined according to AMCOW regional groupings as:  
51 Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, South Sudan, Sudan,  
52 the United Republic of Tanzania, and Uganda (16). The total population in East Africa is 422.3  
53 million (17). TM contamination in East Africa is due to both natural and anthropogenic sources:  
54 many in the Great Rift Valley are affected by well-documented geogenic contamination, as in  
55 well water and surface water in Ethiopia (18). Such contamination can impact both improved and

56 unimproved water sources (19). Urbanization in the region and industrial expansion may lead to  
57 anthropogenic contamination.

58 Over 20% of the populations of Kenya and Tanzania rely on unimproved sources of  
59 drinking water, including surface water (20). Roughly 15% of the populations of Ethiopia,  
60 Rwanda, and Uganda, and 5% of the populations of Sudan and Djibouti use unimproved sources  
61 of drinking water (20). These unimproved sources may be more susceptible to anthropogenic  
62 contamination. As of 2024, 69% of East Africa's population lived in rural areas (17). These  
63 populations may lack immediate access to the laboratory equipment necessary for TM analysis.  
64 While studies have demonstrated the presence of TMs in East Africa (21–23), a full review of  
65 current data can provide a more thorough understanding of TM contamination in the region.

66 This paper aims to assess the extent of TM contamination in drinking water in East  
67 Africa by reviewing relevant peer-reviewed literature and summarizing the findings. The TMs of  
68 focus for this paper are Arsenic, Lead, and Manganese. Currently, no meta-analyses of toxic  
69 metals in this region exist on this scale. The primary objective of this paper is to determine the  
70 prevalence of TMs across East Africa and identify where gaps in evidence remain for future  
71 public health analysis.

72

### 73 **Methods:**

74 The data used in this evaluation of TMs in East Africa are obtained from a larger  
75 systematic review of 14 TMs in all low- and middle-income countries (LMICs) worldwide (full  
76 review protocol registered in Prospero [CRD42024566116]) (24,25). Briefly, a search of  
77 PubMed, EBSCO Global Health, and Web of Science was conducted in 2019 with multiple  
78 search updates, the latest in March of 2025. Initially, 58,576 studies were returned by the search  
79 (Fig. 1). These papers were screened using a machine-learning algorithm (DoCTER) to select the

80 most relevant results (26). The algorithm was trained with manually screened papers at the title  
81 and abstract levels. Studies classified as relevant by the algorithm were then uploaded to  
82 Covidence and deduplicated.

83 Studies were eligible for inclusion in the global systematic review if peer-reviewed,  
84 published in English after 1968, and included one or more primary measurements of at least one  
85 TM of interest in drinking water in an LMIC. For this regionally focused study, publications  
86 were included if they reported data on TMs of interest in drinking water in East Africa, as  
87 defined by the African Ministers' Council on Water (AMCOW) (16). The inclusion criteria were  
88 narrowed for analysis to the TMs for which a sufficient number of observations (>2,000) were  
89 available from included studies in the East Africa region: lead (Pb), arsenic (As), and manganese  
90 (Mn). Peer-reviewed literature with relevant toxic-metal data on Lead, Arsenic, and Manganese  
91 was found for Djibouti, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. The full  
92 description of all metals is available in Supplemental Tables 1 and 2, aggregated for the entire  
93 region.

94

#### 95 *Data Extraction*

96 A total of 84 studies reporting As, Pb, and/or Mn concentrations in drinking water in East  
97 African countries were included. Data was extracted from each paper by a trained reviewer.  
98 Quality control was conducted by a second reviewer.

99 As described in the global systematic review, a continuity correction was applied to  
100 enable analysis of datasets reporting nondetects: specifically, values reported as “non-detect”  
101 were replaced with half the analytical limit of detection when calculating descriptive statistics.  
102 Where a lower limit of detection (LLOD) was not reported in the study, indicative published

103 LLOD values corresponding to the method used in the study of interest were used. If geographic  
104 coordinates for sampling locations were not provided in publications, the centroid of the  
105 sampling area described in the study was estimated using online mapping tools and the  
106 administrative unit(s) listed in the study (e.g., town, city, district, state, region, etc.) and/or any  
107 maps provided in the study. Method quality scores were also calculated for each study based on  
108 the extent and suitability of sample collection, analysis, and quality assurance/quality control as  
109 reported. Based on available data, summary statistics and proportions of observations exceeding  
110 WHO GVs were estimated for TMs of interest. Where suitable raw data or summary statistics  
111 were not provided in studies in a manner adequate for obtaining such estimates, the requisite  
112 values and/or parameters were interpolated as described in Fisher et al. 2025 (24,25) using the  
113 methods first published by Hozo et al. 2005 (27) to credibly impute missing statistics needed for  
114 our analyses. Spatial visualization of data was produced using QGIS (cite).

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117 *Fig. 1: PRISMA Flow Chart for the East African Systematic Review*

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## 120 **Results:**

121 Our search identified 111 articles that reported concentration data for a TM of interest in  
122 drinking water in East Africa; collectively, these studies included 28,812 observations. In  
123 addition to Arsenic, Lead, and Manganese, we included studies reporting on Antimony,  
124 Cadmium, Chromium, Copper, Iron, Mercury, Nickel, Selenium, and Uranium. However, the  
125 number of observations for many of these TMs was not sufficient to warrant further analysis, and  
126 the study was narrowed to focus on Arsenic, Lead, and Manganese, as the 84 included studies

127 reporting on these three TMs yielded more than 2,000 usable observations for each. The final set  
128 of 84 studies comprises 8,484 total observations across As, Pb, and Mn. A summary of all  
129 metals, including those with fewer than 2,000 usable observations, is outlined in S3.

130 While evidence on TMs in drinking water in East Africa is not particularly abundant, a  
131 substantial number of studies report on As, Pb, and Mn, with 32, 47, and 60 studies comprising  
132 2,069, 2,957, and 3,687 observations, respectively (Figs. 2 & 3). The number of included studies  
133 and samples from the East Africa region was quite low before 2010, and increased gradually  
134 from 2012 to 2017, then more sharply from 2017 to the present. Of 8,258 total included  
135 observations, 54% were collected in Ethiopia, 18% in Kenya, 14% in Uganda, and 9% in  
136 Tanzania. As seen in Table S2, there were a few observations in unimproved sources and none in  
137 rural sources in Rwanda. Additionally, there was very little data from Sudan and Djibouti

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140 *Fig. 2: Cumulative Observations of Arsenic, Lead, and Manganese in East African Drinking*  
141 *Water*

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144 *Fig. 3: Cumulative Observations of Arsenic, Lead, and Manganese, Separated by the Country of*  
145 *Measurement - East Africa*

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148 As shown in Table 1, 24.1% of Arsenic observations, 17.1% of Lead observations, and  
149 30.6% of Manganese observations exceeded the respective WHO GV for each TM. There were

150 fewer samples from JMP Improved sources compared to JMP Unimproved sources. The level of  
151 Arsenic exceedances above the 10 µg/L limit in JMP Unimproved sources was substantially  
152 higher than in JMP Improved sources. The percentage of exceedances for Mn and Pb was similar  
153 between Improved and Unimproved sources. A subset of papers contained observations with  
154 insufficient data to estimate exceedances.

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156 *Table 1: Summary of Arsenic, Manganese, and Lead by JMP Source Classification in East*

157 *Africa*

Element	Total Observations	Overall Exceedance	JMP Source Status	Observations	Exceedance (%)
As	2069	24.1%	Improved	825	9.6
			Unimproved	1167	34.3
Pb	2957	17.1%	Improved	1130	15.4
			Unimproved	1827	18.1
Mn	3687	30.6%	Improved	1627	31.8
			Unimproved	1999	29.6

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160 There were similar numbers of samples from Urban and Rural settings for Arsenic and  
161 Lead, as shown in Table 2. However, there were more samples in Rural settings for Manganese.  
162 In Urban sources, Arsenic had the greatest percentage of samples exceeding the WHO GV at  
163 41.8%. Lead also had a higher percentage of exceedances of the 10 µg/L limit in Urban settings

164 than in Rural samples. Manganese, however, had a higher percentage of exceedances in Rural  
165 settings compared to Urban settings.

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167 *Table 2: Summary of Arsenic, Manganese, and Lead Data by Urban and Rural Classification in*  
168 *East Africa*

Element	Total Observations	Overall Exceedance	Urban/Rural Designation	Observations	Exceedance (%)
As	2069	24.1%	Urban	1035	41.8
			Rural	945	4.3
Pb	2957	17.1%	Urban	1315	27.8
			Rural	1308	8.9
Mn	3687	30.6%	Urban	1262	28.8
			Rural	1977	37.3

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171 The geographic distribution of Arsenic, Lead, and Manganese exceedances of their  
172 respective WHO GV<sub>s</sub> is shown in Figs. 4, 5, and 6, respectively. As seen for each TM, there is a  
173 concentration of studies around Addis Ababa and Southern Ethiopia. There is much less  
174 characterization of drinking water in other Urban centers, with few observations in Nairobi,  
175 Kampala, or Dar es Salaam. There are also large gaps in rural data, with limited information on  
176 groundwater quality across countries.

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180 *Fig. 4 - Distribution of the percentages of Arsenic exceeding the WHO Guideline Value of 10 µg/L in East*  
181 *African Drinking Water*

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187 *Fig. 5 - Distribution of the percentages of Lead exceeding the WHO Guideline Value of 10 µg/L in East*  
188 *African Drinking Water*

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192 *Fig. 6 - Distribution of the percentages of Manganese exceeding the provisional WHO Guideline Value of*  
193 *80 µg/L in East African Drinking Water*

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198 **Discussion:**

199 Across the region, a high proportion of observations from all three TMs exceeded WHO  
200 GVs. High exceedances were observed across both JMP Improved and Unimproved sources, as  
201 well as in Rural and Urban settings. Manganese had the highest overall exceedance rate in the

202 region, with 30.6% of observations above the WHO GV, while arsenic and lead contamination  
203 also showed 24.1% and 17.1% exceedances across all regional observations, respectively.

204 Arsenic exceeded the WHO GV much more often in urban settings than in rural settings,  
205 and more frequently in unimproved sources than in improved sources. Manganese, another  
206 geogenic contaminant, showed similar exceedance rates for improved and unimproved sources.  
207 There were no major discrepancies in exceedance levels between urban and rural settings and  
208 JMP source types for manganese or lead.

209 The publications in the review noted or identified geogenic contamination of Arsenic and  
210 Manganese in both improved and unimproved sources. This contamination requires careful  
211 testing and siting to avoid elevated concentrations where possible, and potentially advanced  
212 treatment methods to reduce TM concentrations where sources are already installed or where  
213 alternatives are not available (28). Moving from surface water and dug wells to  
214 boreholes/tubewells may not improve, or may even increase, the occurrence of geogenic  
215 contaminants in some settings (29), but our analysis implies benefits. In considering arsenic,  
216 65%, 33%, and 13% of surface water, unimproved groundwater, and improved groundwater  
217 samples exceeded the WHO GV, respectively. This implies that a transition to groundwater, and  
218 then to improved groundwater sources, may be beneficial for protection against Arsenic.  
219 Alternatively, 28%, 9%, and 15% of samples exceeded the WHO GV for lead in surface water,  
220 unimproved groundwater, and improved groundwater, respectively. This implies that some  
221 systemic contamination from improved infrastructure is affecting water quality, including the use  
222 of lead-containing materials (30). The risks of these TM sources should be weighed against the  
223 potential improvements in microbial health, as protected sources may lead to reduced pathogen

224 exposure and anthropogenic contamination, such as pollution and waste runoff. Preventive action  
225 on siting and material restrictions for infrastructure may prove most beneficial.

226 While there is evidence of concerning levels of Arsenic, Lead, and Manganese in  
227 drinking water across East Africa, a large portion of the region lacks representation in the  
228 dataset. The majority of data came from Ethiopia, Kenya, Tanzania, and Uganda, with limited  
229 observations in Djibouti, Rwanda, and Sudan, and no observations from Burundi, Comoros,  
230 Eritrea, Somalia, or South Sudan. While Ethiopian data accounted for 54% of total observations,  
231 the nation comprises just 31.2% of East Africa's population. For Kenya, Uganda, and Tanzania,  
232 observations in these nations accounted for 18%, 14%, and 9% of the available data,  
233 respectively, while their national populations comprised 13.3%, 11.8%, and 16.2% of East  
234 Africa's population (17). The remaining 5% of observations collected represented 27.3% of the  
235 East African population, and 11.7% of the region's population has no national representation in  
236 the data. Even in countries with larger numbers of studies and observations at a national level,  
237 large areas lack peer-reviewed studies. The majority of exceedance observations are concentrated  
238 in the central Rift Valley and around population centers, and rural areas lack data. For Arsenic,  
239 Lead, and Manganese, rural observations comprised 47.7%, 49.9%, and 61.0% of the data,  
240 respectively. However, 69% of the East African population lives in rural areas, indicating that  
241 rural populations are underrepresented in the available data relative to their urban and suburban  
242 counterparts (17). The limited availability of evidence outside population centers underscores the  
243 need for more comprehensive sampling across the region to fill data gaps in characterizing TM  
244 occurrence in East Africa.

245 As seen in Figures 4 and 5, most exceedances of Lead and Arsenic occur in the Rift  
246 Valley, whereas in Figure 6, Manganese exceedances occur in both the Rift Valley and around

247 Lake Victoria. The Rift Valley, a highly geologically active zone, is susceptible to TM  
248 contamination through both geogenic and anthropogenic sources, such as mining and resource  
249 extraction (31). The concentration of data within this area suggests sufficient research, but  
250 insufficient TM prevention and remediation, as TM exceedance of WHO limits is high in this  
251 area for Arsenic, Manganese, and Lead.

252 Areas of East Africa outside the Rift Valley or population centers lack sufficient data to  
253 determine the overall impact of TM contamination across the region. Based on the available data,  
254 Arsenic, Lead, and Manganese are of concern due to exceedances above 10% for each element.  
255 Further determination of the impacts of TM contamination and the appropriate interventions  
256 cannot be made without broader sampling in population centers and across different settings and  
257 source types. Though the data is limited, there is sufficient evidence to highlight the need to  
258 address the occurrence of Arsenic, Lead, and Manganese in East African drinking water.

259 Access to safe water across East Africa remains contingent not only on infrastructure  
260 expansion but on the regulatory frameworks that govern water quality at the point of use. Lead  
261 contamination poses a particular threat as communities transition to improved sources that may  
262 rely on lead-containing infrastructure (30). We reviewed national policies and regulations of East  
263 African countries and noted inconsistent requirements for the materials used in drinking water  
264 infrastructure (32–35). Likewise, there is an apparent absence of standardized water quality  
265 monitoring requirements for lead in drinking systems, with many regulations calling for the use  
266 of Flame Atomic Absorption Spectrometry (36–39). Protections against lead-containing  
267 materials, coupled with requirements for TM integration into drinking water quality monitoring,  
268 would help prevent further contamination of improved systems while identifying areas of high  
269 contamination for future intervention. which may leave these communities understudied in

270 future research. Strengthening both the geographic reach and material specificity of monitoring  
271 requirements must therefore be understood as foundational, not supplementary, to the region's  
272 water goals.

273

#### 274 *Limitations*

275 The search yielded 84 titles across all countries and contaminants. This number includes  
276 only titles that used appropriate instrumentation to measure the three specified TM contaminants  
277 according to EPA-accepted methods. Studies that did not include a clear number of observations  
278 taken were excluded from our calculations. Due to inconsistent reporting of contaminant levels,  
279 we were unable to calculate exceedance percentages for a minority of studies. Among 31 titles  
280 that reported Arsenic observations, 5 included data that could not be used to calculate  
281 exceedance percentages. Of the 61 titles reporting manganese observations, 13 included data that  
282 could not be used to calculate exceedance percentages. Among 47 titles that reported Lead  
283 observations, 7 included data that could not be used to calculate exceedance percentages.  
284 Inconsistent and incomplete reporting methods were observed across the selected studies,  
285 limiting the availability of data for drawing conclusions. In addition to the need for more  
286 research across underrepresented nations, more consistent and accurate methods and reporting  
287 measures are needed for the research to be useful. Expanding reliable TM data may require  
288 expensive methods, such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) systems,  
289 of which only a handful in Ethiopia were reported across the studies. Additionally, our study  
290 focused only on peer-reviewed literature. This may exclude government datasets that could fill  
291 observed geographic gaps in information.

292

293 **Conclusion:**

294           The purpose of conducting this systematic review of toxic metal contamination in  
295 drinking water in East Africa was to identify where existing data were concentrated, to identify  
296 information gaps, and to create a consistent picture of toxic metal contamination across the  
297 region using the available data. The resulting review, created in accordance with PRISMA  
298 guidelines and methodology, determined that large portions of the East Africa region,  
299 representing significant portions of the population, lacked available data on toxic metal  
300 concentrations in drinking water. At the national level, Ethiopia was overrepresented in  
301 observations, and Kenya and Uganda were adequately represented, while Tanzania, Rwanda,  
302 Djibouti, and Sudan were underrepresented. No data was available for Burundi, Comoros,  
303 Eritrea, Somalia, or South Sudan. Rural areas across all nations were consistently  
304 underrepresented. Based on the available data, Arsenic, Manganese, and Lead all showed  
305 significant exceedances of the WHO limits that must be addressed. This exceedance occurred in  
306 both urban and rural settings and in both improved and unimproved water sources. Exceedance is  
307 especially a concern in the Rift Valley, where much data was available, but exceedances were  
308 very high. These findings indicate that sufficient evidence exists to undertake primary prevention  
309 efforts now, as well as targeted and progressive remediation efforts where appropriate and  
310 feasible. Existing policy and monitoring efforts to prevent and track TM occurrence in drinking  
311 water at levels of health concern can be strengthened, harmonized, and consistently implemented  
312 and enforced to achieve more rapid improvements in water safety regarding TMs.

313

314 **Statements and Declarations**

315 The authors have no financial stakes or conflicts of interest in this research.

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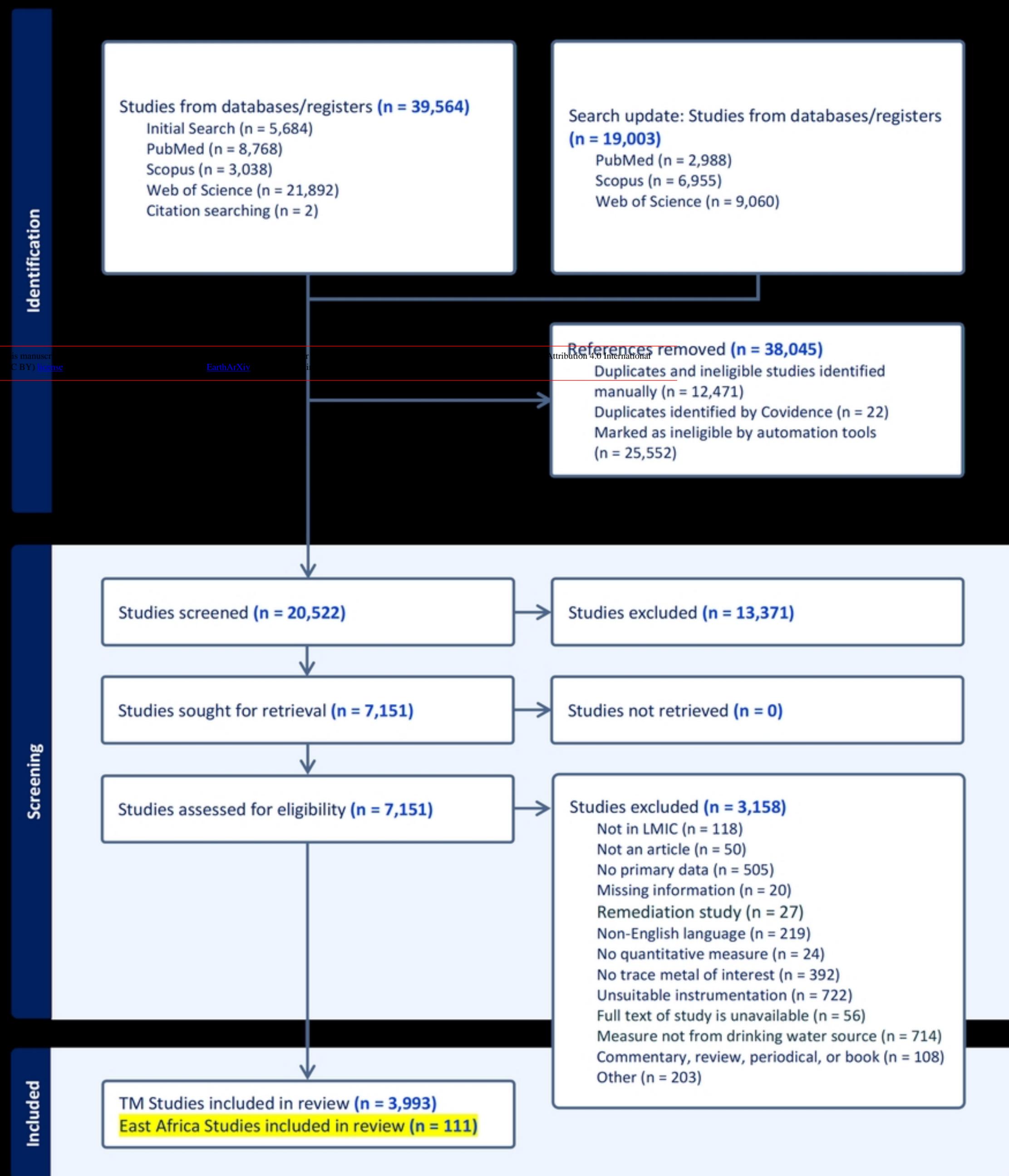


Fig. 1

Cumulative number of observations by contaminant and year

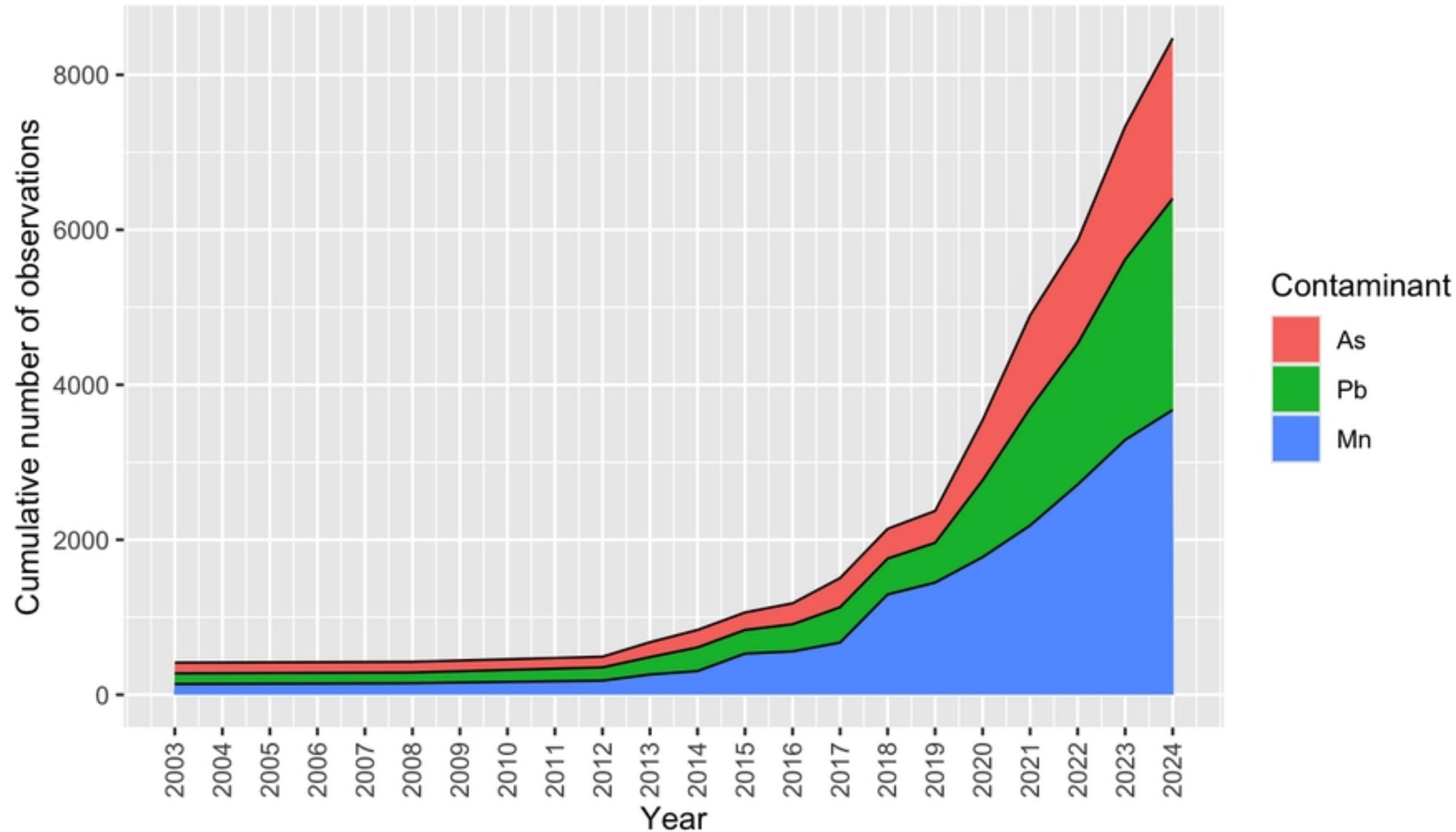


Fig. 2

Cumulative number of observations by country and year

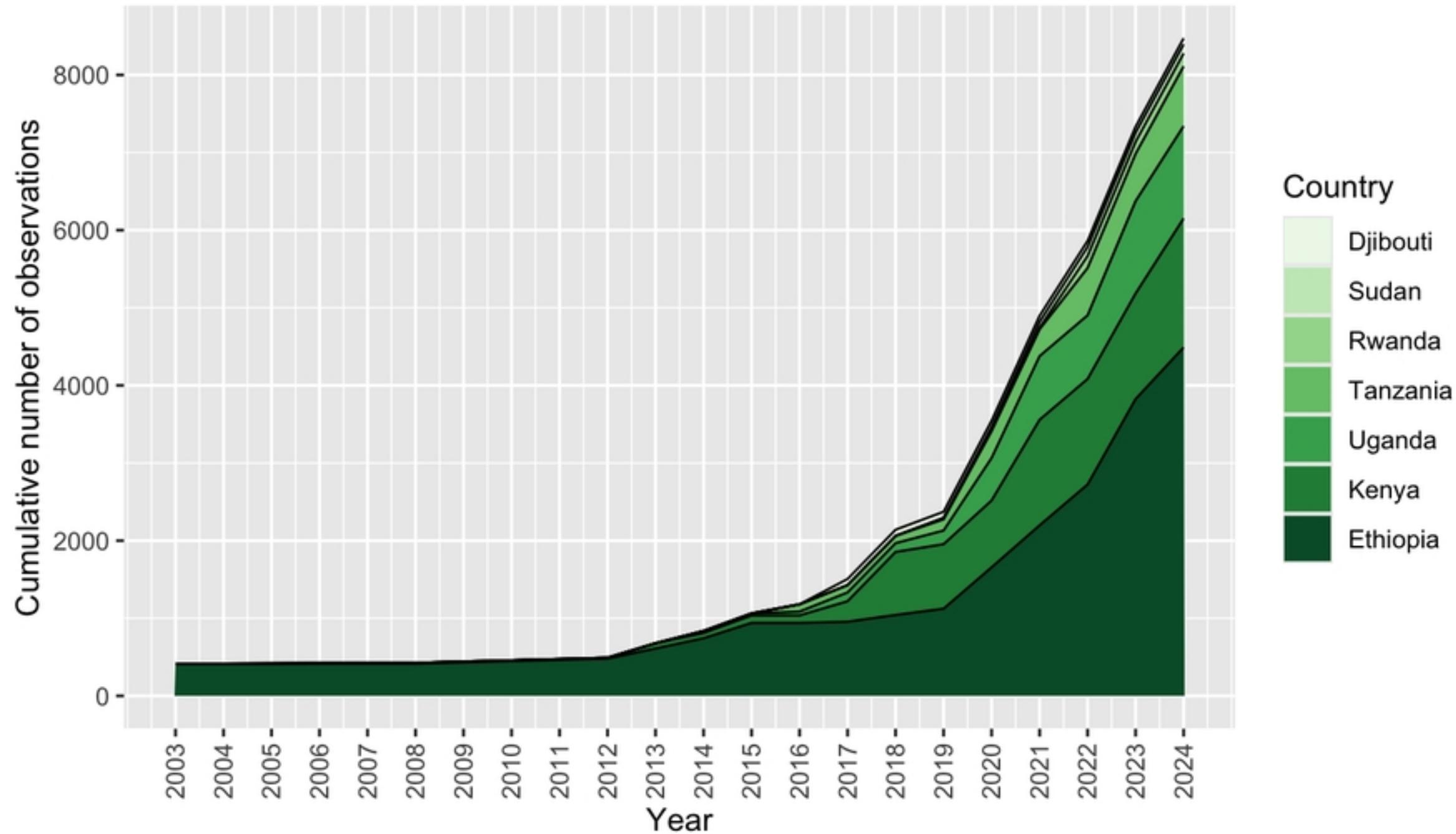


Fig. 3

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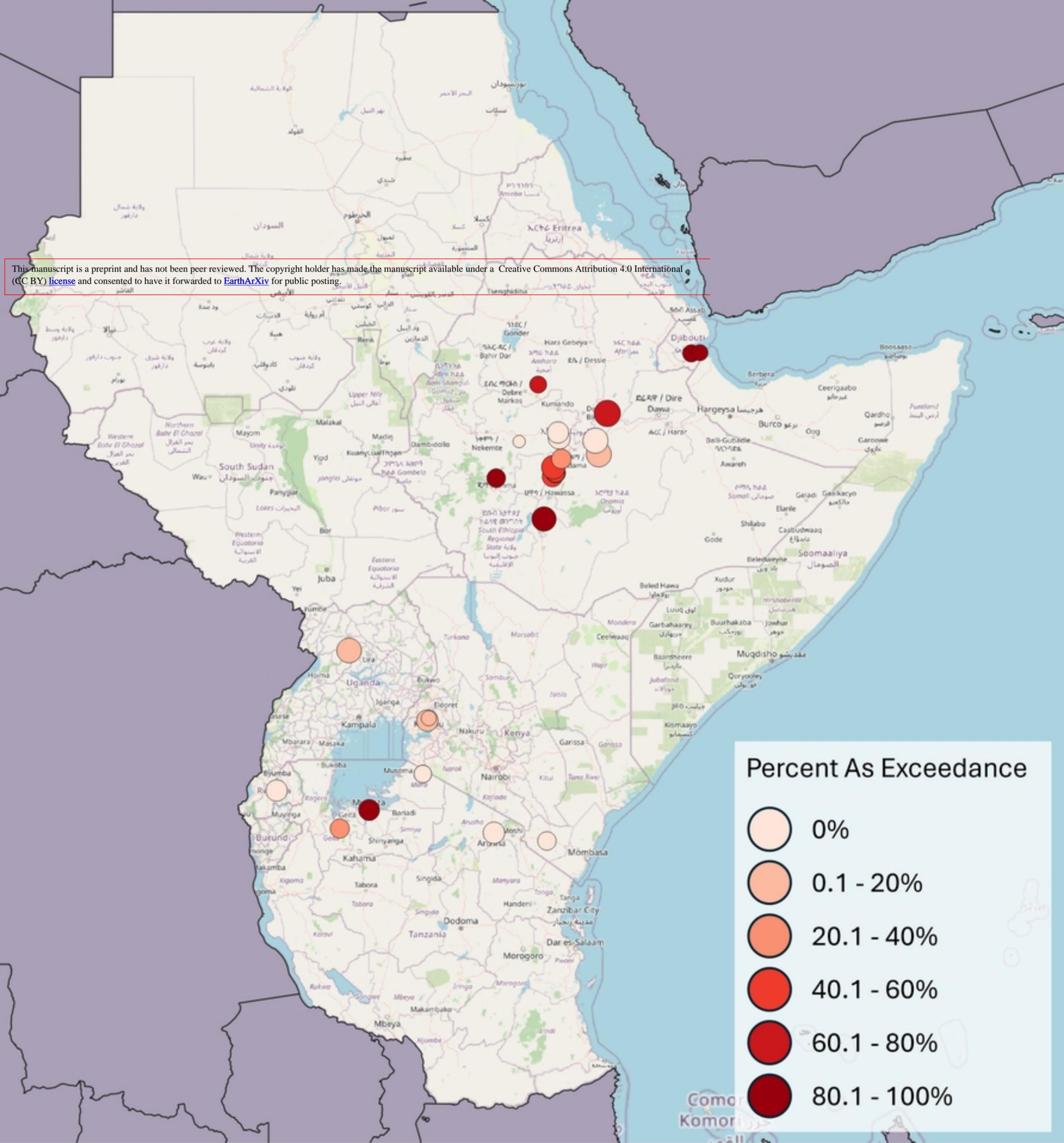


Fig. 4

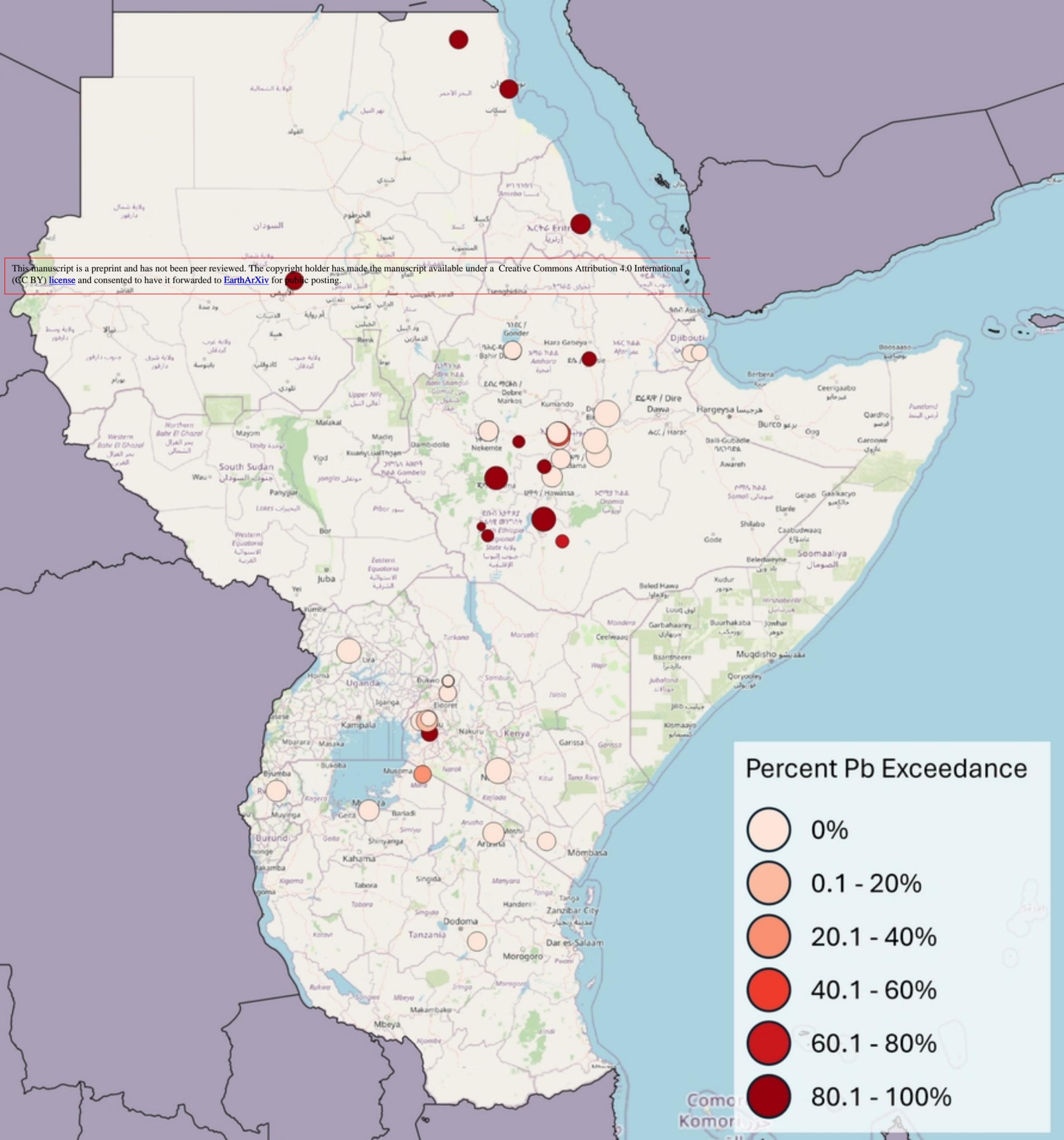


Fig. 5

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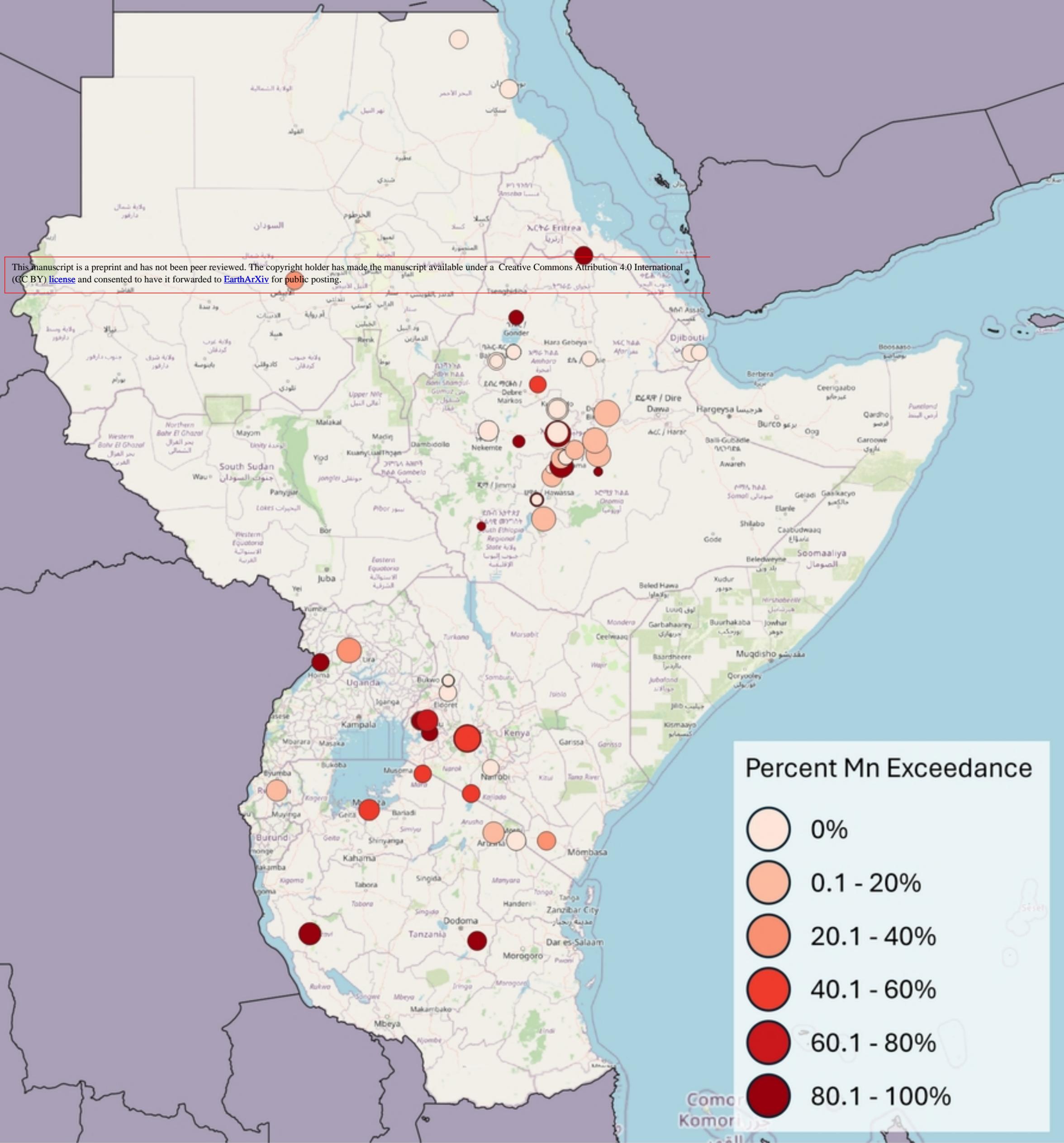


Fig. 6