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Heavy Metal: a misused term?

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Abstract: The use of the term “heavy metal” is regularly questioned by the scientific community. Here, we followed the evolution (1970-2020) in the number of published papers including this term in their title. Thus, we can evidence a continuous, albeit sometimes stabilizing, increase especially in environmental journals. After several other warning opinions, we propose that it should be replaced in the scientific literature by terms like “metal”, “metalloid”, “trace metal elements” or “potentially toxic element”.

Keywords: Heavy metals; trace metal elements; metal; metalloid; potentially toxic elements

1. History

The chemical elements are now well characterized, and their classification in the so-called “Periodic System” reached its 150-year celebration in 2019 [1]. They are also allocated to various series, according to similarities in their properties or their electronic structure; among them are the so-called “heavy metals”. Initially, the term “heavy metal” was based on categorization by density or molar mass (zinc or copper have relatively low density and molar mass compared to lanthanides and actinides). It is often used as a group name for metals and metalloids (i.e., arsenic) that are associated with contamination and potential toxicity in the environment. The “heavy metals” list is not clearly defined and often mixes metals and metalloids. Ultimately, the pejorative connotation of “heavy” associated with the toxicity of metal induces a kind of fear in society. From a quick perusal of the recent scientific literature, it appears that the (mis)use of the term “heavy metal(s)” seems still to be rampant: therefore we decided to follow it, as described in the present article.

In elementary science classes, one often asks to the children: “Which weighs more—a pound of lead or a pound of feathers?” The seemingly naive answer to the familiar riddle is the pound of lead. The correct answer, of course, is that they weigh the same amount[2]. Unfortunately, our own experience has demonstrated that this confusion remains for a part of college students! Apart this funny side, it seems that it is not as easy to understand what really a “heavy metal” is, and its original definition thus pertains, although several “heavy” metallic elements have somewhat low density.

In 1980, Nieboer and Richardson[3] had already proposed the replacement of this nondescript term by biologically and chemically significant classification. Moreover, according to the International Union of Pure and Applied Chemistry (IUPAC) [4], the term “heavy metal” is considered imprecise at best, and meaningless and misleading at worst. The use of this term is strongly discouraged, especially as there is no standardized

definition of this term. In 2004, Hodson[5] considered it as geochemical Bogeyman; In 2007, Chapman[6] first proposed to keep this term for music not for science. In 2010, Hübner et al.[7] proposed to move on from semantics to pragmatics, whereas Madrid[8] recalled the long-standing and sometimes forgotten controversy. Nikinmaa and Schlenk[9] further insisted on the ill-defined term. In 2011, Bhat and Khan[10] defined them as an ambiguous category of inorganic contaminants, nutrients and toxins. In 2012, Chapman[11] continued to write on “the cacophony not the symphony” around “heavy metals” and Batley et al.[12] further detailed on the usefulness of this term.

However, some authors still proposed their classification; in 2010 Appenroth[13] defined “heavy metals” in Plant Sciences, and Ali and Kahn[14] proposed their own "comprehensive" definition (Figure 1). In some classical textbooks, their authors continue to use the term in their title[15-16]; however, they now discuss the misuse of the term. Some other authors have clearly changed their mind and revised the content of their textbook[17].

hydrogen 1 H 1.0079																	helium 2 He 4.0026																		
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180																		
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948																		
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.38	gallium 31 Ga 69.723	germanium 32 Ge 72.64	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.798																		
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29																		
caesium 55 Cs 132.91	barium 56 Ba 137.33											hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]									
francium 87 Fr [223]	radium 88 Ra [226]											rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [277]	meitnerium 109 Mt [268]	darmstadtium 110 Ds [271]	roentgenium 111 Rg [272]																
																		lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.05	lutetium 71 Lu 174.97			
																		actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]	lawrencium 103 Lr [262]			

Figure 1 Periodic table highlighting “heavy metals”, redrawn from Ali and Kahn [11].

In 2018, Pourret and Bollinger [18] further questioned on the use of the term “heavy metals” : to use or not to use? and Pourret [19] proposed to ban this term from the scientific literature. Eventually, Pourret and Hursthouse[20] and Pourret et al.[21] proposed to replace the term with “potentially toxic elements”. Indeed, due to their persistence and indestructible nature (only changes in their chemical species can occur), most of them are unfortunately able to definitively pollute groundwater [22] or soils [23].

All so-called “heavy metals” and their compounds may have relatively high toxicity: human exposure to lead by the addition of tetraethyl-lead to gasoline as an antiknock agent, or to lead paint is well documented, however lead–acid battery does not pose direct threat to humans although its disposal may generate environmentally hazardous waste.

Nonetheless, metals are not always toxic, and some are in fact essential: depending on the dosage and exposure levels and the receiving organism/population, it may be essential or toxic. Known for its use in the US five-cent coin (thus its nickname), nickel is one of the most versatile metals found on Earth: nickel is essential for life (functional in some proteins) and its deficiency is accompanied by histological and biochemical changes and reduced iron resorption and may lead to anemia[24]. Physical organic chemists refer the isotope effects of any elements other than H as "heavy isotope effects".

2. Current status

The term is increasingly used in the scientific literature (Figure 2), especially in articles pertaining to multidisciplinary environmental issues (see Figure 3 for the year 2019). Despite the repeated calls to stop using the term (including ours), and the apparent regular publication of the articles related to this controversy (Table 1), the use of the term “heavy metal” appears not to have declined in the scientific literature (Figure 2a). Indeed, the use of the term is increasing rather than declining. It should be noted that even if the total number of publications has also simultaneously increased: the proportion of publications using this term have globally increased from 0.074% in 2000 to 0.163% in 2020 (Figure 2b).

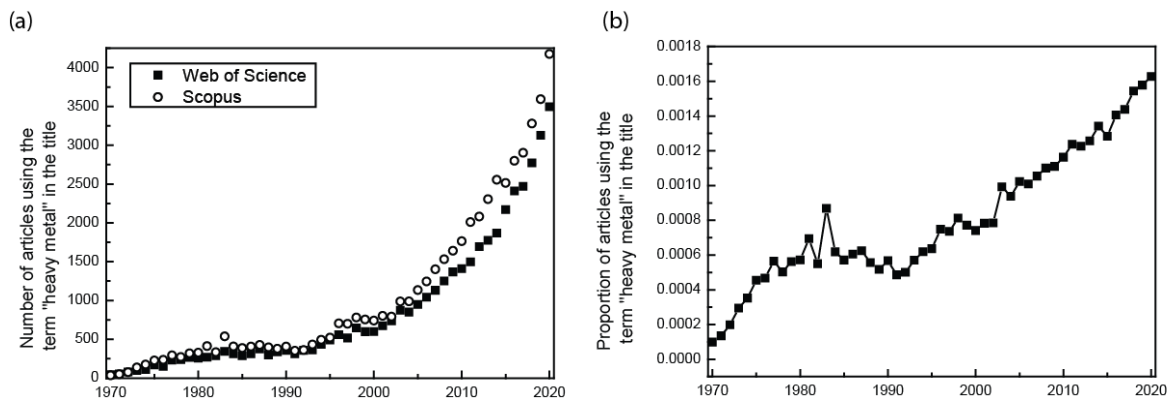


Figure 2 (a) Evolution of the number of publications using the term “heavy metal*” in the title (sourced from Scopus and the Web of Science using the term “heavy metal*”, data accessed 24 February 2021). Modified and updated from [18, 20].

(b) Evolution of publications (number of articles using the term divided by the total number of all articles published that year) using the term “heavy metal” in the title (data from Scopus using “heavy metal*” search, accessed on 24 February 2021).

The term “heavy metal” is a common term used for decades in the sciences, and even more in environmental sciences (Figure 3), particularly in studies of pollution impacts [20]. If we focus on Top journals from the Environmental Science category (selection from Pourret and Bollinger[18]), we can notice a “plateau” or even a small decrease (Figure 4).

Table 1 Type of article and number of citations of papers related to the controversy use of the term “heavy metal” (updated from Pourret and Bollinger [13]; data accessed on 24 February 2021).

Reference	Type of article	Number of citations	
		Scopus	Web of Science
Nieboer and Richardson (1980)[3]	Full paper	864	841
Duffus (2002)[4]	Full paper	617	565
Hodson (2004)[5]	Invited paper	49	40
Chapman (2007)[6]	Letter	9	6
Hübner et al. (2010)[7]	Perspective paper	28	23
Madrid (2010)[8]	Letter	16	15
Appenroth (2010)[13]	Review	45	41
Nikinmaa and Schlenk (2010)[9]	Editorial	5	5
Chapman (2012)[11]	Letter	9	9
Batley (2012)[12]	Letter	9	9
Pourret and Bollinger (2018)[18]	Letter	25	24
Pourret (2018)[19]	Letter	13	11
Ali and Kahn (2018)[14]	Full paper	44	35
Pourret and Hursthouse (2019)[20]	Letter	16	13

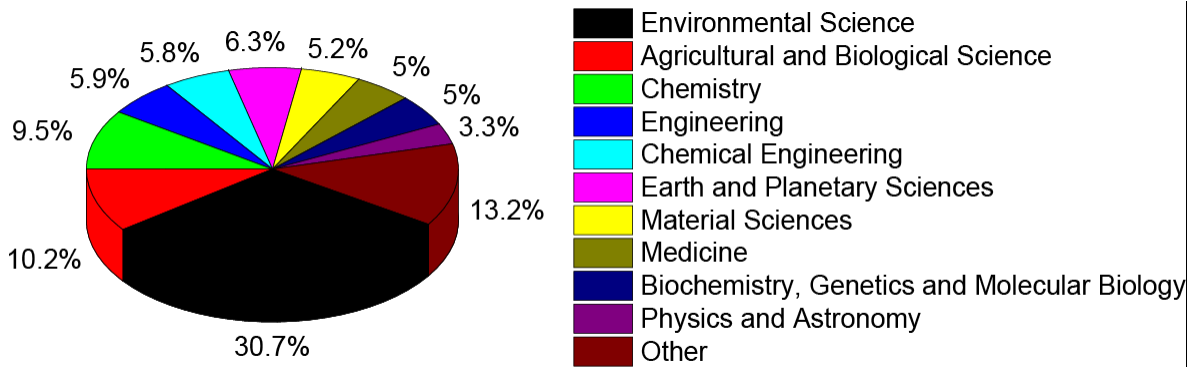


Figure 3 Proportion of publication by research areas in 2020 using the term “heavy metal*” in the title (sourced from Scopus using the term “heavy metal*”, data accessed on 24 February 2021). Modified and updated from [20].

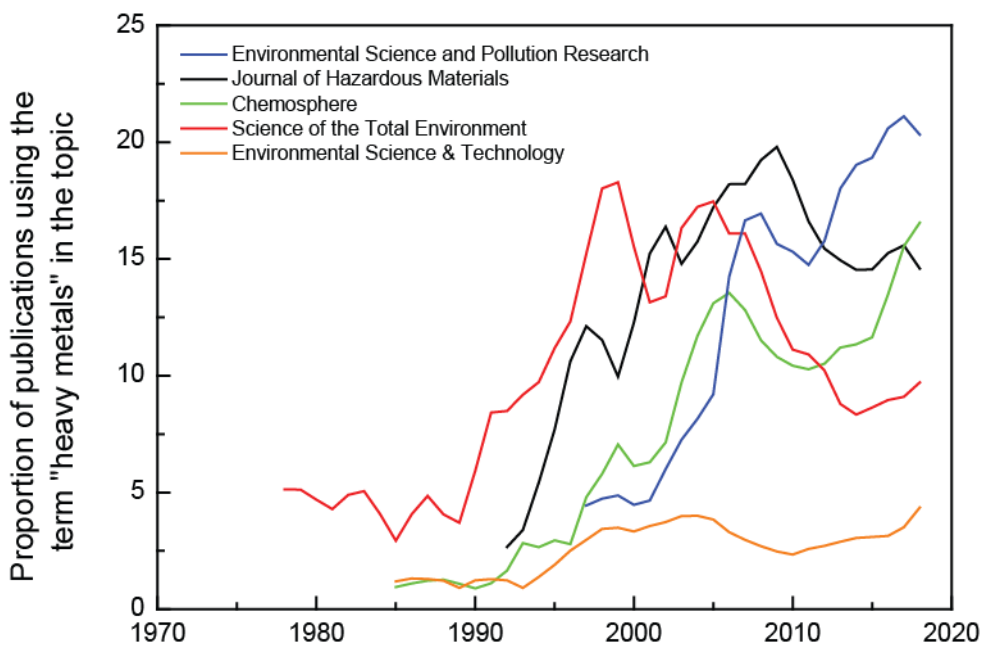


Figure 4 Evolution of publications (number of articles using the term divided by the total number of all articles published that year) using the term “heavy metal” in the topic for journals that highly used “heavy metal” term (data from Web of Science using “heavy metal*” search, plotted using a 3 year span moving average, accessed on 24 February 2021).

Indeed, if we look into this with more detail, and choose four journals, like Pourret and Bollinger[18] did, in which the term “heavy metal” is frequently used (i.e., Journal of Hazardous Materials, Chemosphere, Science of the Total Environment, and Environmental Science and Pollution Research), we notice an exponential increase during the last 30 years, related to the increasing number of articles; however, the proportion of articles using the term “heavy metal” remains stable at around 3% for Environmental Science & Technology (selected as a reference), whereas the use of the term has stabilized in Science of the Total Environment and Chemosphere (between 10% and 15%), and the Journal of Hazardous Materials or Environmental Science and Pollution Research still see high levels of use of this term (up to 20%) (Figure 4). If we further look at the number of articles published in 2019 with the term “heavy metal” in their title (Table 2), Environmental Science and Pollution Research published the higher number of articles with “heavy metal” in their title (102) and up to 7% of article published in Environmental Monitoring and Assessment used this term. In Acta Geochimica, 5% of published article (3/67) used the term “heavy metal” in their title.

Table 2 Number of publications during 2019 using the term “heavy metal” in the title for the ten most common sources and proportion of articles (from Scopus using “heavy metal*” search, data accessed on 24 February 2021).

Journal title	Number of articles	Proportion
Environmental Science And Pollution Research	102	3%
Science Of The Total Environment	95	2%
Ecotoxicology And Environmental Safety	58	4%
Environmental Monitoring And Assessment	55	7%
Chemosphere	52	2%
Environmental Pollution	49	3%
International Journal Of Environmental Research And Public Health	45	1%
Huanjing Kexue Environmental Science	42	6%
Journal Of Hazardous Materials	41	3%
Desalination And Water Treatment	40	3%

In 2019, 34% of those articles were co-authored by researchers from Chinese institutions, 6% from India and 5% from USA (Figure 5), reflecting in part the emergence of intense research activity on widespread environmental issues in the region and as already outlined by Pourret and Hursthouse[20], emerging reports in English language journals, perhaps has enhanced the growth of the term, a result of perpetuating the approach to an established and long-standing practice.

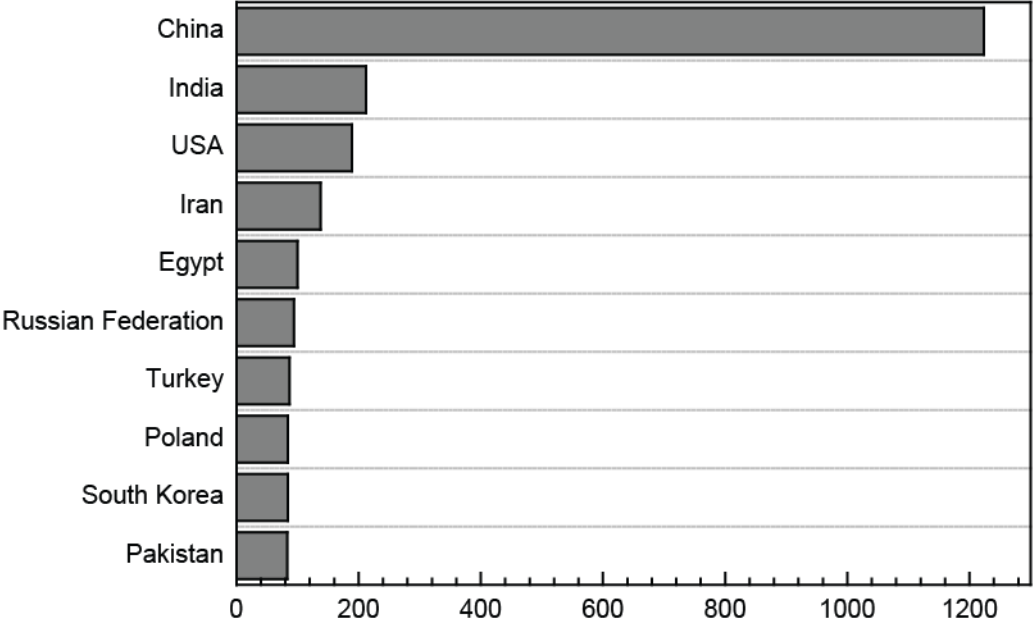


Figure 5 Article distribution by country (top 10) of articles published in 2019 having the term heavy metal* in the title (country based on authors affiliation, several countries may count for the same article).

Thanks to social media, the debate is also relayed to a larger audience (e.g. sketchnote on twitter, Figure 6).

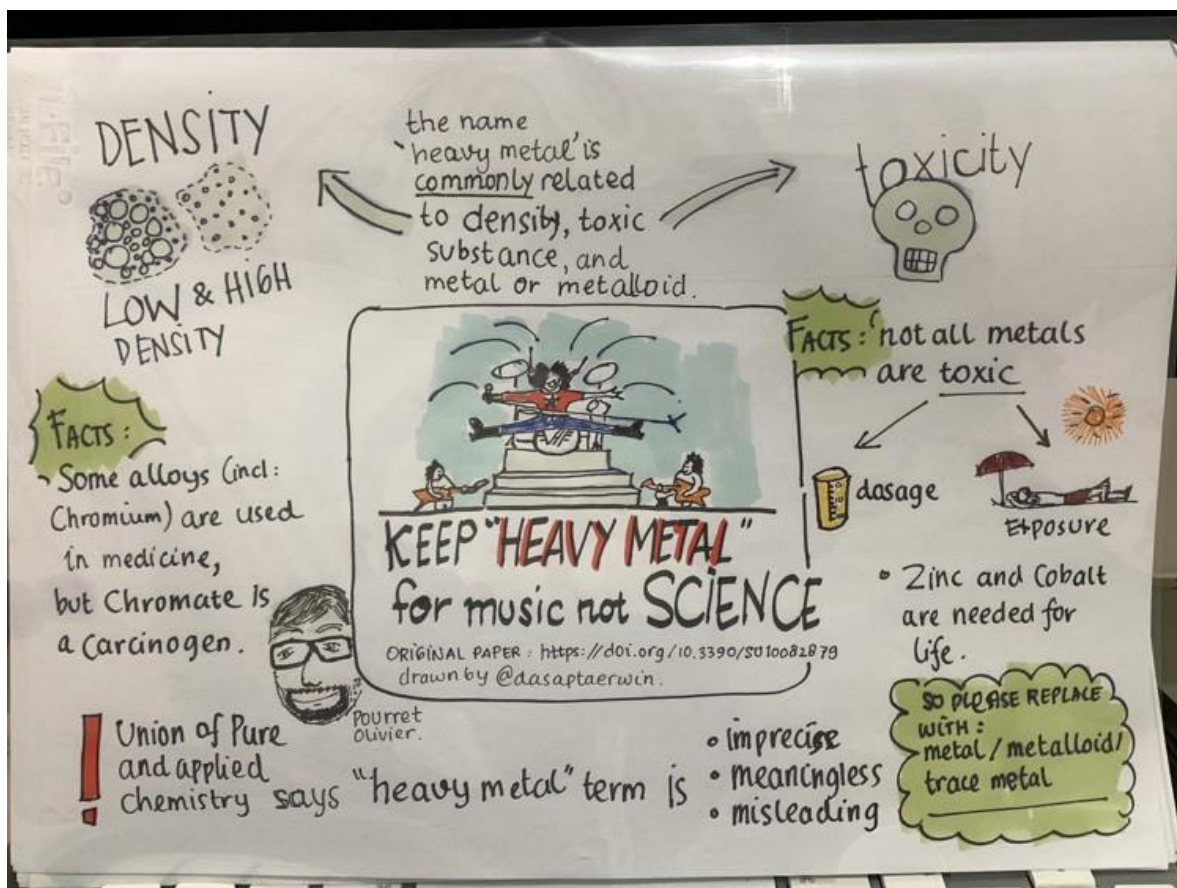


Figure 6 Sketchnote illustrating the misused term "heavy metal" (artwork from Dr. Dasapta Erwin Irawan)[25].

3. Discussion

As already proposed by Hübner et al.[7], solutions exist to deal with the long-standing problem of the imprecise usage of the term "heavy metals" in the scientific literature.

Some authors propose:

(i) Formulating one single scientific definition. This would be an ideal approach, but unlikely to be adopted. A general agreement about a single atomic mass, atomic number, density or another similar criterion will be difficult to achieve. Indeed, Ali and Khan [14] try to but half of the periodic table is considered by this definition (Figure 1).

(ii) Calling the ten elements most commonly considered as "heavy metals", Cr, Co, Ni, Cu, Zn, As, Cd, Sn, Hg, Pb as "heavy metals", all other elements not. It is basic and to a certain degree arbitrary, but at least uniform and based on a mutual understanding[7], though metalloids are still included.

We propose:

(i) Replacement of the term “heavy metals” with a reasonable and scientifically defensible terms like “potentially toxic element”, “trace metal element”, “metal”, “metalloid” in environmental studies[20].

(ii) Avoiding the problem by not using this umbrella term and referring simply to metals or elements. This is a reasonable approach and is probably the only approach that ultimately might successfully suppress the term “heavy metals”[18].

4. Conclusions

To be consistent, researchers should only use well-accepted definitions. In the case of “heavy metal”, this term should be replaced by “metal”, “metalloid” according to the case, or by “trace metal” or “potentially toxic element” when this can be considered. The best way to describe the studied elements is clearly to name them or consider them as a group of elements (metals or metalloids).

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