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中国饮用水中砷的分布特征及基于伤残调整寿命年的健康风险评价

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摘要: 砷的长期暴露可造成多种器官功能性损伤甚至死亡, 掌握其在水中分布特点和潜在风险对防控水源性砷造成人体健康危害有重要意义. 基于2000~2022年已发表数据, 采用文献计量学方法, 在全国尺度范围内系统分析我国饮用水砷污染的地理分布特征, 并以表征疾病负担的伤残调整寿命年(DALYs)为量化指标评价因饮用水中砷暴露导致的健康风险. 结果表明, 我国饮用水中砷的浓度平均值为 $(2.88 \pm 0.33) \mu\text{g} \cdot \text{L}^{-1}$, 低于《生活饮用水卫生标准》(GB 5749-2022)限值($10 \mu\text{g} \cdot \text{L}^{-1}$); 分布表现为北方高于南方, 农村地区高于城市, 个别省份(山西、内蒙古和宁夏)仍存在超标现象. 饮用水砷造成的健康风险大小整体为 1.63×10^{-6} DALYs $\cdot$ (人 $\cdot$ a) $^{-1}$, 高于WHO《饮用水水质准则》推荐的风险参考水平 $[1.0 \times 10^{-6} \text{ DALYs} \cdot (\text{人} \cdot \text{a})^{-1}]$; 在六大地理区域风险大小排序为: 华北 > 东北 > 中南 > 西北 > 西南 > 华东. 水砷暴露导致皮肤癌(2 905.25 DALYs $\cdot$ a $^{-1}$)和肺癌(1 513.96 DALYs $\cdot$ a $^{-1}$)是其产生疾病负担的主要方式(99.4%); 45岁以上中老年人群承受了大部分(78.0%)水砷造成的健康损害, 60岁以上老年人群体健康损失风险更高, 是风险防控中需要特别关注的对象.

关键词: 砷(As); 饮用水; 分布特征; 伤残调整寿命年(DALYs); 健康风险

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Distribution Characteristics of Arsenic in Drinking Water in China and Its Health Risk Based on Disability-adjusted Life Years

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Abstract: Long-term exposure to arsenic can lead to functional damage to many organs and can be life-threatening. It is of great significance to analyze the distribution characteristics of arsenic in water and evaluate its potential risk for preventing and controlling human health hazards caused by water-derived arsenic. Based on the published data from 2000 to 2022, the geographical distribution characteristics of arsenic in drinking water across China were systematically analyzed in detail, and the health risk of arsenic in drinking water was quantitatively assessed using disability-adjusted life years (DALYs), which represent the burden of disease. The results showed that the average concentration of arsenic in drinking water in China was $(2.88 \pm 0.33) \mu\text{g} \cdot \text{L}^{-1}$, which was lower than the limit of $10 \mu\text{g} \cdot \text{L}^{-1}$ set by the standard for drinking water quality (GB 5749-2022). Nevertheless, the arsenic in drinking water in some provinces, including Shanxi, Inner Mongolia, and Ningxia, was still higher than the limit. The arsenic concentration in drinking water in northern China was higher than that in southern China, and that in rural areas was higher than that in cities. The estimated health risk of arsenic in drinking water (1.63×10^{-6} DALYs per person-year) was higher than the acceptable risk level of waterborne exposure of 1.0×10^{-6} DALYs per person-year set by the World Health Organization. The personal health risks related to arsenic in drinking water in the six geographical regions were ranked as follows: North China > Northeast China > Central South China > Northwest China > Southwest China > East China. Almost all (99.4%) of the health burden associated with water arsenic was attributable to skin and lung cancer, which caused 2 905.25 and 1 513.96 DALYs per year, respectively. Most (78.0%) of the health burden was borne by people aged 45 years or older. In addition, given the proportion of each age group in the total population, older persons over the age of 60 bear a higher drinking-water-associated arsenic burden at the individual level than others, and attention should be consequently paid to them when controlling the risk of arsenic in water.

Key words: arsenic(As); drinking water; distribution characteristics; disability-adjusted life years(DALYs); health risk assessment

砷(As)是一种广泛分布于环境中的非金属元素, 存在无机态和有机态两种形式. 一般来说, 无机态As的毒性大于有机态, 三价As的毒性大于六价As. 长期的As污染暴露对人体健康构成严重威胁, 可造成皮肤癌、肺癌、肝癌或膀胱癌等多种器官功能性损伤, 严重者甚至引起死亡^[1]. 人类主要是通过食物和饮水两种途径暴露于环境中的As. 世界卫生组织(WHO)、国际癌症研究中心(IARC)和我国生态环境部先后将As和无机As类化合物列入一级致癌物

清单和有毒有害水污染物名录(第1批)^[2]. 我国最新修订的《生活饮用水卫生标准》(GB 5749-2022)对生活饮用水中As浓度的限值设定为不高于 $10 \mu\text{g} \cdot \text{L}^{-1}$.

饮用水As污染严重威胁水质安全一直受到广泛

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关注. Frost 等^[3]统计美国环保署(US EPA)数据库中有关 As 中毒的数据发现 11 个州 33 个县的饮用水中 As 的平均浓度超过其标准($10 \mu\text{g}\cdot\text{L}^{-1}$). 2000 年, WHO 发布报告指出, 孟加拉国约有 4 000 万人饮用水 As 超标, 约 200 万人表现出 As 中毒症状, 近 30 万人可能因此患癌症而死亡^[4]. 目前, 我国也是饮用水 As 污染严重的发展中国家之一. 北京通州调查发现, 12.88% 的农村饮用水样品中 As 浓度超标^[5]; 内蒙古托克托县某饮水型地方性 As 中毒村采集的 76 份水样全部超标, ρ (无机 As) 为 $56.40 \sim 231.15 \mu\text{g}\cdot\text{L}^{-1}$, 平均值为 $129.92 \mu\text{g}\cdot\text{L}^{-1}$ ^[6]. 另一方面, 新疆的调查其农村饮用水中 As 超标率只有 2.23%, 但在丰水期和枯水期有所差异^[7]; 张秋秋等^[8]在我国重点城市集中供水中 As 浓度均未超标, 但其检出率为 47.8%. 总体上来说, 针对我国饮用水中 As 污染状况已展开了一定的研究, 但大多是针对个别或少数几个地区设置采样点进行的, 监测或检测到的 As 污染情况亦主要是与标准限值进行比较. 目前, 对全国饮用水中 As 的大尺度研究较少, 整体上我国饮用水中 As 的污染分布特征及风险状况仍然不清楚.

本研究借助文献计量学手段, 系统分析了近 22 年我国饮用水 As 浓度水平及区域分布特征, 并以表征疾病负担的伤残调整寿命年(disability adjusted life years, DALYs)作为评价终点, 对饮用水 As 污染造成的健康风险进行评估, 以期为我国饮用水中 As 污染的防控政策制定提供参考, 对防范水源性 As 造成人体健康危害有重要意义.

1 材料与方法

1.1 文献检索与筛选

对公开发表的有关我国饮用水中 As 浓度文献进行系统检索. 时间范围限定在 2000 年 1 月 1 日至 2022 年 12 月 1 日. 中文数据库(CNKI 和万方)检索关键词为“砷”或“重金属”, 主题词为“饮用水”. 英文文献数据库(Web of Science 和 Pubmed)检索术语: WOS: (TS = (arsenic (As)) OR TS = (drinking water) OR TS = (heavy metal)) AND (TS = (water quality detection) OR TS = (health risk assessment)) AND (TS = (China)). 为确保研究准确, 文献筛选标准为: ①有明确 As 的检测方法, 且符合国家标准; ②有明确的采样点、样本大小; ③报告了 As 的浓度. 依据上述原则, 在数据库中检索到相关文献 2 923 篇, 删除重复记录 1 702 篇和不符合要求记录 1 170 篇, 最终纳入 51 篇.

1.2 数据提取与统计处理

从筛选后的文献中进行关键数据提取: 采样时

间、采样地点、样本量、检测方法、检出限以及浓度数据. 通过使用软件 Excel 2019 和 SPSS 26 进行数据统计处理. 其中, 文献中若采样时间未明确标明的, 以发表时间代替; 每篇文献报告的均值和标准差若标明可直接从文献中读取, 不能读取的则根据样本量、中位数、最小值和最大值等统计值间接计算. 然后根据样本量、均值和标准差对整体浓度用分布函数进行拟合, 得到拟合参数和均值^[9].

1.3 健康风险评价

1.3.1 暴露评估

本研究将饮用水中 As 暴露主要考虑饮水摄入和淋浴、洗漱等皮肤接触两种途径. 其中, 经饮水摄入量计算公式为^[10]:

$$\text{CDI}_{\text{oral}} = \frac{\rho(\text{As}) \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (1)$$

式中, CDI_{oral} 为经口摄入日均暴露量 [$\text{mg}\cdot(\text{kg}\cdot\text{d})^{-1}$]; $\rho(\text{As})$ 为饮用水中 As 的浓度 ($\text{mg}\cdot\text{L}^{-1}$); IR 为摄入率 ($\text{L}\cdot\text{d}^{-1}$); EF 为饮水年暴露天数 ($\text{d}\cdot\text{a}^{-1}$); ED 为暴露持续年数 (a); BW 为体重 (kg); AT 为平均终身暴露时间 (d).

经皮肤接触途径暴露量计算公式为^[11]:

$$\text{CDI}_{\text{dermal}} = \frac{\rho(\text{As}) \times \text{SA} \times \text{PC} \times \text{ET} \times \text{EF} \times \text{CF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (2)$$

式中, $\text{CDI}_{\text{dermal}}$ 为皮肤接触日均暴露量 [$\text{mg}\cdot(\text{kg}\cdot\text{d})^{-1}$]; SA 为皮肤接触面积 (cm^2); PC 为化学物质的皮肤渗透常数 ($\text{cm}\cdot\text{h}^{-1}$); ET 为日暴露时间 (淋浴、洗漱等) ($\text{h}\cdot\text{d}^{-1}$); EF 为年暴露天数 (淋浴、洗漱等) ($\text{d}\cdot\text{a}^{-1}$); CF 为转换系数 (10^{-3}).

总暴露量:

$$\text{CDI}_{\text{total}} = \text{CDI}_{\text{oral}} + \text{CDI}_{\text{dermal}} \quad (3)$$

式中, $\text{CDI}_{\text{total}}$ 为每日总暴露量 [$\text{mg}\cdot(\text{kg}\cdot\text{d})^{-1}$].

1.3.2 剂量-效应关系模型

本研究采用 US EPA 建立 As 的暴露浓度与皮肤癌患病率效应关系模型^[11], 采用 Chen 等^[12]和加拿大研究委员会(NRC)^[13]提出的饮用水 As 与内脏癌(肺癌、肝癌和膀胱癌)剂量-效应关系.

$$P(d, t) = 1 - \exp[-(q_1 d + q_2 d^2)(t - m)^k H(t - m)] \quad (4)$$

式中, $P(d, t)$ 为皮肤癌患者比例 (%); t 为年龄 (岁); d 为暴露量 [$\mu\text{g}\cdot(\text{kg}\cdot\text{d})^{-1}$]; H 为 Herveside 函数, 当 $t < m$ 时, $H(t - m) = 0$; 当 $t > m$ 时, $H(t - m) = 1$; q_1 、 q_2 、 k 和 m 值采用张秋秋等^[8]的推荐值.

$$H(c, t) = k(q_1 c + q_2 c^2)(t - m)^{k-1} H(t - m) \quad (5)$$

式中, $H(c, t)$ 为内脏癌的发病率; c 为暴露浓度 ($\mu\text{g}\cdot\text{L}^{-1}$); 其他变量和参数的含义同上.

皮肤癌的患病率转化为发病率公式^[8]:

$$h = \ln \frac{1 - P(x, d)}{1 - P(x + t, d)} \quad (6)$$

式中, h 为年龄段($x, x+t$)皮肤癌的发病率, P 为年龄段($x, x+t$)的患病率。

1.3.3 风险大小

本研究采用人均承受的疾病负担大小来表征风

$$YLDs = \sum_{x,y} n_x P_x \left\{ (1 - S_x) DW_y L_y + S_x [DW_y L_y + P_{seq} DW_{seq} (LE_x - t_c)] \right\} \quad (9)$$

式中, DB 为疾病负担 ($DALYs \cdot a^{-1}$); $YLLs$ 为早死所导致的健康损失 ($DALYs \cdot a^{-1}$); $YLDs$ 为残疾所致的健康损失 ($DALYs \cdot a^{-1}$); x 为年龄段 (按 5 a 间隔分为 19 个年龄组, 即 0 ~ 1 岁、1 ~ 5 岁、5 ~ 10 岁、10 ~ 15 岁, ..., 80 ~ 85 岁, 85 岁以上); y 为疾病的不同阶段; n 为人口数; S 为存活率; LE_x 为标准预期寿命; t_D 为死亡时间; DW 为失效权重; L 为持续时间; P_{seq} 为后遗症患者比例; t_c 为治疗时间。

1.4 相关参数的确定

1.4.1 暴露量参数

本研究中各年龄段人体皮肤接触面积 (SA) 和体重 (BW) 值取自《中国人群暴露参数手册》^[15]。皮肤渗透常数 (PC) 为 $0.0018 \text{ cm} \cdot \text{h}^{-1}$ ^[16], 日暴露时间 (ET) 为 $0.6333 \text{ h} \cdot \text{d}^{-1}$, 年暴露天数 (EF) 为 $365 \text{ d} \cdot \text{a}^{-1}$ ^[17]。男性和女性的暴露持续年数 (ED) 分别为 74 a 和 78 a, 平均终身暴露时间 (AT) 分别为 $74 \text{ a} \times 365 \text{ d}$ 和 $78 \text{ a} \times 365 \text{ d}$ ^[18]。

1.4.2 疾病负担相关参数

各省年龄段人口数 (n) 和标准预期寿命 (LE_x) 均基于《中国统计年鉴 (2020)》^[18]; 参考 Zhang 等^[19] 的研究方法, 皮肤癌、肺癌、肝癌和膀胱癌的死亡时间 (t_D) 中位数分别取值为 2.193、0.83、0.700 和 1.003 a, 其治疗时间 (t_c) 中位数分别为 5.00、6.00、5.00 和 4.00 a。参考张秋秋等^[8] 的研究方法, 确定失效权重 (DW)、后遗症患者比例 (P_{seq}), 以及肺癌与膀胱癌的生存率 (S_x)。皮肤癌 S_x 为 0.900, 肝癌 S_x 为 0.005^[20]。

2 结果与讨论

2.1 饮用水中 As 浓度及分布特征

中国大陆 31 个省 (市区) 饮用水中 $\rho(\text{As})$ 范围在 $0.10 \sim 20.79 \mu\text{g} \cdot \text{L}^{-1}$ (表 1), 对浓度数据进行拟合分布最佳为对数正态分布, 其均值 (标准差) 和中位数分别为 $(2.88 \pm 0.33) \mu\text{g} \cdot \text{L}^{-1}$ 和 $1.06 \mu\text{g} \cdot \text{L}^{-1}$, 均低于《生活饮用水卫生标准》(GB 5749-2022) 限值 ($10 \mu\text{g} \cdot \text{L}^{-1}$)。从地理分布来看, 饮用水 As 浓度在北方要高于南方 (图 1)。其中, 居全国前 3 位的为山西省、内蒙古和宁夏, 其饮用水 $\rho(\text{As})$ 分别为 (20.79 ± 1.12) 、

险大小。疾病负担 (以 $DALYs$ 为单位进行测量) 既考虑了患病导致死亡的健康损失 (years of life lost, $YLLs$), 还考虑了疾病治愈后遗症残疾和治疗时间损失造成的健康损失 (years lived with disability, $YLDs$)^[14]。计算公式如下:

$$DB = YLLs + YLDs \quad (7)$$

$$YLLs = \sum_x n_x P_x (1 - S_x) (LE_x - t_D) \quad (8)$$

(8.85 ± 0.05) 和 $(8.19 \pm 2.06) \mu\text{g} \cdot \text{L}^{-1}$; 福建和安徽的饮用水 $\rho(\text{As})$ 最低, 为 $0.12 \mu\text{g} \cdot \text{L}^{-1}$ 和 $0.10 \mu\text{g} \cdot \text{L}^{-1}$ 。对同一地区城市和农村水 As 数据经皮尔森卡方 (Pearson's chi-squared) 分析发现饮用水 $\rho(\text{As})$ 呈现农村地区高于城市 ($\chi^2 = 61.94, P < 0.01$), 原因可能与农村地区地理位置偏远, 较多使用地下水 (井水) 作为饮用水源有关^[21, 22]。山西大同一项研究发现其盆地周围山地岩石中富含 As^[23], 约为地壳 As 丰度值的 7 倍^[24], 经地下水和沉积物的长期相互作用下, 逐渐从沉积物中释放导致地下水 As 浓度很高。此外, 工业化快速发展也可造成当地饮用水 As 污染。如宁夏自治区的一项监测发现, 饮用水 As 超标现象与当地存在大型工业园区, 同时拥有较多数量的煤炭、钢铁和电镀等企业有关^[25]。

2.2 饮用水 As 的健康风险

2.2.1 总体及区域性健康风险

我国由于饮用水中 As 暴露导致的健康风险为 $1.63 (95\% \text{CI}: 1.06 \sim 2.20) \times 10^{-6} \text{ DALYs} \cdot (\text{人} \cdot \text{a})^{-1}$, 略高于 WHO 推荐的水中有害物质健康风险阈值 [$1.0 \times 10^{-6} \text{ DALYs} \cdot (\text{人} \cdot \text{a})^{-1}$], 但存在明显的地区差异性, 表现为北方地区高于南方, 特别是山西、内蒙古和宁夏为 WHO 推荐阈值的 5 ~ 16 倍 (图 2); 六大地理区域风险大小排序为: 华北 > 东北 > 中南 > 西北 > 西南 > 华东 (表 2)。考虑到各区域人口数量不同, 水 As 导致的总疾病负担大小排序为: 华北 > 中南 > 东北 > 华东 > 西南 > 西北; 华北地区尤为突出 (占全国 45.2%), 其区域性内各省市疾病损失排序为: 山西省 ($581.80 \text{ DALYs} \cdot \text{a}^{-1}$) > 河北省 ($404.29 \text{ DALYs} \cdot \text{a}^{-1}$) > 天津市 ($24.97 \text{ DALYs} \cdot \text{a}^{-1}$) > 北京市 ($9.85 \text{ DALYs} \cdot \text{a}^{-1}$)。分析原因可能有两个方面: 一是当地重工业和能源 (煤炭、重金属) 开采行业发达, 易造成高 As 水环境, 群众长期暴露导致的健康问题 (致病和致癌)^[73]; 另一方面, 不同省份的经济发展和城市化覆盖率存在差异性, 部分农村地区仍存在饮用未经处理的地下水 (井水) 的情况^[75]。山西山阴县和大同市的饮水型 As 中毒区在 2006 ~ 2008 年的水质合格率状况仅为 62.73%, 其中分散式供水的合格率

表 1 我国各地区饮用水中 As 浓度水平

Table 1 Concentration of arsenic in drinking water in different regions of China

区域	省份	样本量	平均值/ $\mu\text{g}\cdot\text{L}^{-1}$	浓度分布拟合 ¹⁾	文献
华北	北京	436	0.53	Log-Norm (-0.778, 0.535)	[26 ~ 28]
	天津	856	2.32	Pareto (0.581, 1.342)	[29, 30]
	河北	246	6.71	Gamma (2.725, 2.462)	[31 ~ 33]
	山西	278	20.79	Norm (20.786, 1.115)	[34]
东北	内蒙古	26459	8.85	Log-Norm (2.07, 0.47)	[22]
	辽宁	232	1.06	Norm (1.055, 0.493)	[35, 36]
	吉林	506	5.90	Norm (5.60, 0.24)	[37]
	黑龙江	85	5.00	—	[38]
华东	上海	189	0.91	Norm (0.91, 0.05)	[39]
	江苏	574	0.93	Gamma (2.74, 0.34)	[40 ~ 45]
	浙江	120	2.00	Uniform (0, 4.00)	[46]
	安徽	451	0.10	—	[47, 48]
	福建	176	0.12	—	[49]
	江西	6	0.99	Norm (0.993, 0.013)	[50]
	山东	1374	0.31	Beta (0.262, 0.577)	[51 ~ 53]
中南	河南	24	0.85	—	[54, 55]
	湖北	293	3.50	—	[56]
	湖南	184	4.82	Log-Logistic (4.82, N/A)	[57]
	广东	14	1.54	—	[58, 59]
	广西	21	1.06	—	[60]
	海南	5	0.30	—	[61]
西南	重庆	98	0.30	Norm (0.30, 0.02)	[62]
	四川	120	0.50	—	[63]
	贵州	38	0.44	Log-Norm (-0.70, 0.57)	[64]
	西藏	60	1.24	Log-Norm (0.184, 0.124)	[65]
	云南	9535	5.45	—	[66]
西北	陕西	8736	0.73	Beta (3.84, 1.44)	[67 ~ 70]
	甘肃	60	1.34	Gamma (41.950, 0.032)	[71]
	青海	17	0.32	—	[72]
	宁夏	112	8.19	Log-Norm (1.92, 0.60)	[73]
	新疆	7874	2.06	Log-Norm (0.645, 0.398)	[7, 74]

1) Norm (μ, σ)表示正态分布;Log-Logistic (μ, σ)表示对数逻辑分布, μ 为均值, σ 为标准差;Log-Norm (x, y)表示对数正态分布, x 为期望均值, y 为对数标准差;Beta (α, β)表示贝塔分布;Gamma (α, β)表示伽马分布, α 为形状参数, β 为尺度参数;Pareto (α, x -minimum)表示帕累托分布, x -minimum为比例参数;Uniform (min, max)为均匀分布,min为最小值,max为最大值;N/A表示相应分布的相应参数不存在;“—”表示数据不充分,不能进行拟合分布

仅为 57.65%,而集中式供水稍高,达到了 80.00%^[23, 76]。随着国家农村安全饮用水工程的实施,在华北地区的饮水 As 的健康风险近 5 年呈现逐年降低趋势,如太原市 2019 年一项调查结果表明其农村

生活饮用水中 $\rho(\text{As})$ 均低于 $1\ \mu\text{g}\cdot\text{L}^{-1}$ ^[77],但保障农村地区的水质安全仍是长期和艰巨的工作。

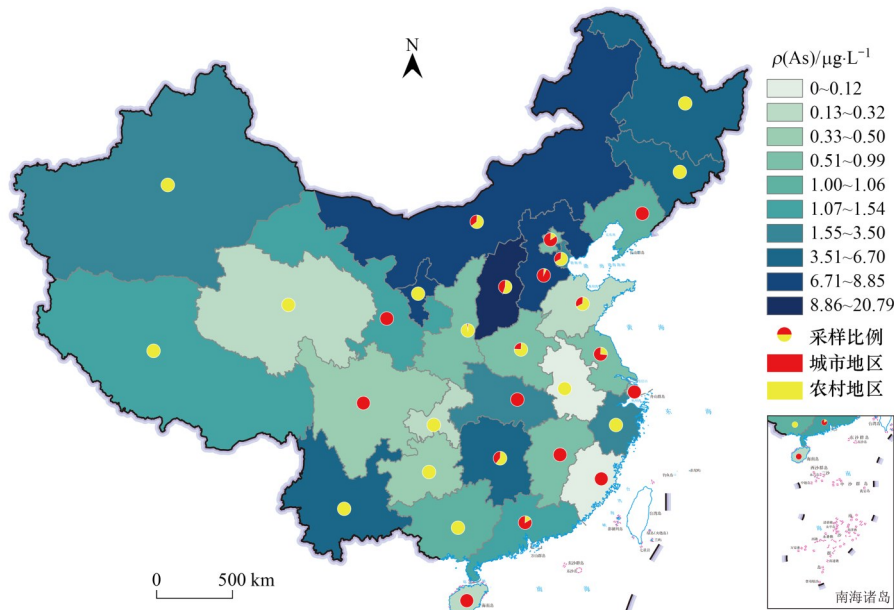
2.2.2 不同健康问题的风险

饮水中 As 暴露所致皮肤癌、肺癌、肝癌和膀胱

表 2 我国六大地理区域饮用水 As 健康风险及导致的疾病负担

Table 2 Health risk and disease burden of arsenic in drinking water in six geographical areas of China

区域	健康风险 $\times 10^{-6}/\text{DALYs}\cdot(\text{人}\cdot\text{a})^{-1}$		总疾病负担/ $\text{DALYs}\cdot\text{a}^{-1}$	
	均值	95%CI	均值	95%CI
华北	7.03	1.25 ~ 10.04	1 020.91	181.61 ~ 1 458.66
东北	2.27	1.02 ~ 4.70	278.12	125.02 ~ 576.05
华东	0.41	0.26 ~ 0.63	173.53	110.10 ~ 266.79
中南	1.23	0.64 ~ 1.73	505.54	262.26 ~ 708.93
西南	0.77	0.29 ~ 1.84	158.51	59.49 ~ 377.47
西北	1.15	0.89 ~ 2.37	120.22	92.96 ~ 247.55



基于自然资源部标准地图服务网站下载的审图号为GS(2020)4630号的标准地图制作,香港、澳门和中国台湾地区的As浓度数据暂缺

图1 我国饮用水As浓度地理分布

Fig. 1 Geographical distribution of arsenic concentration in drinking water in China

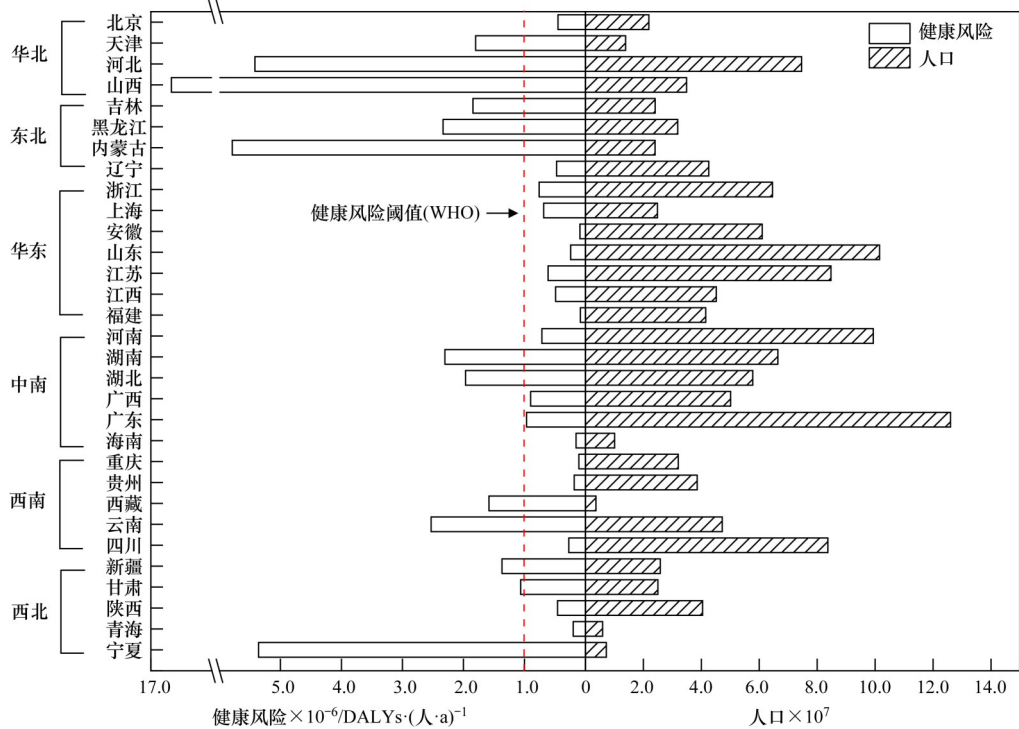


图2 我国不同地区饮用水As健康风险与暴露人口数量

Fig. 2 Health risk of arsenic in drinking water and exposed population in different areas in China

癌的个体终生发病概率分别为 $1.15(95\text{CI}: 0.44 \sim 1.86) \times 10^{-5}$ 、 $1.44(95\text{CI}: 0.48 \sim 2.40) \times 10^{-6}$ 、 $1.45(95\text{CI}: 0.54 \sim 2.36) \times 10^{-8}$ 和 $1.92(95\text{CI}: 1.00 \sim 2.83) \times 10^{-9}$ 。从全人群来看,饮水As暴露导致的癌症患者数量以皮肤癌为主(88.8%),肺癌次之(11.1%),肝癌和膀胱癌仅为0.1%。使用伤残损失寿命年(DALYs)统一度量后,饮水As引起皮肤癌、肺癌、肝

癌和膀胱癌导致的总疾病负担分别为2 905.25、1 513.96、26.04和0.55 DALYs·a⁻¹。其中,肺癌的疾病负担贡献率显著增加到34.1%,与发病贡献率的比值为3.07(34.1%/11.1%);相较于皮肤癌的比值(0.74),可以看出单例肺癌导致的健康损失比皮肤癌更加严重。整体上,皮肤癌和肺癌是饮用水As暴露产生健康损害的主要途径,需要重点关注(图3)。

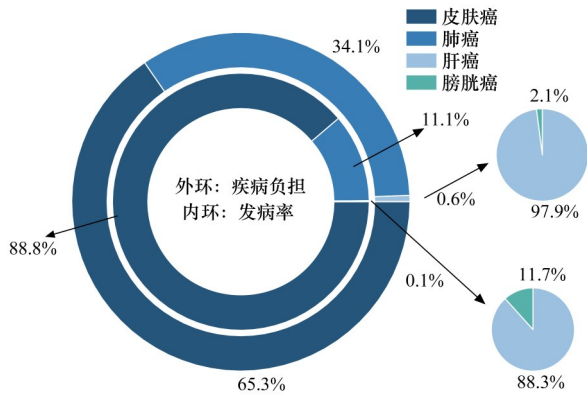


图3 饮水As导致不同癌症的发病率和疾病负担分布情况

Fig. 3 Distribution of incidence (inner ring) and disease burden (outer ring) of cancers attributable to arsenic in drinking water by cancer

2.2.3 不同年龄阶段的健康风险

对不同年龄阶段的人群,饮用水As的暴露导致的健康损害有所不同(图4)。中老年人群(>45岁)承受了78.0%疾病损失;尤其需要关注60岁以上老年人群问题,因为该群体疾病损失占比(40.3%)与其在人口结构中占比(18.7%)的比值高达2.15,说明个体健康损失风险特别高。这可能与饮用水As暴露的长期性和随着年龄增长身体免疫力下降有关^[78]。与土壤重金属健康风险在年龄越小风险越高不同^[79],本研究发现饮用水中As造成的疾病损害在低龄组反而很小,类似于Zhang等^[70]对西安市区域饮用水As的研究结果,原因可能与As致癌需要较长的暴露时间(>20 a)有关。

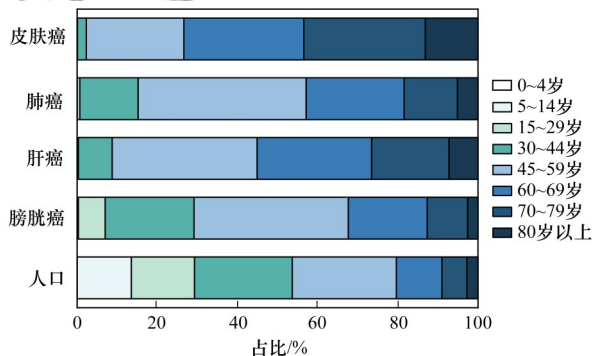


图4 不同年龄阶段下饮水As暴露人群和不同癌症疾病负担比重

Fig. 4 Proportion of the population and the disease burden attributable to arsenic in drinking water by age and by cancer

3 结论

(1)我国饮用水As浓度平均水平低于《生活饮用水卫生标准》(GB5749-2022)限值,但受水文地理状况、经济水平和工业污染等因素制约,呈现出地理区域性差异。山西、内蒙古和宁夏这3个省份的饮用水 $\rho(\text{As})$ 最高,分别为 (20.79 ± 1.12) 、 (8.85 ± 0.05) 和

$(8.19 \pm 2.06) \mu\text{g} \cdot \text{L}^{-1}$ 。饮用水 $\rho(\text{As})$ 呈现农村地区高于城市的分布特征($\chi^2 = 61.94, P < 0.01$)。

(2)我国饮用水As导致的整体健康风险为 $1.63 (95\% \text{CI}: 1.06 \sim 2.20) \times 10^{-6} \text{ DALYs} \cdot (\text{人} \cdot \text{a})^{-1}$,略高于WHO《饮用水水质准则》中规定的风险参考水平,但部分省份如山西、内蒙古和宁夏风险值为参考水平的5~16倍,值得特别关注。

(3)饮用水As暴露导致的皮肤癌和肺癌是其产生疾病负担的主要途径(99.4%);45岁以上中老年人群承受了大部分(87.1%)的健康损害,60岁以上老年人群个体健康损失风险更高,是风险防控中需要特别关注的对象。

参考文献:

- [1] Fatoki J O, Badmus J A. Arsenic as an environmental and human health antagonist: a review of its toxicity and disease initiation[J]. Journal of Hazardous Materials Advances, 2022, 5, doi: 10.1016/j.hazadv.2022.100052.
- [2] Gomez-Camirero A, Howe P D, Hughes M, et al. Arsenic and arsenic compounds [M]. Geneva: World Health Organization, 2001.
- [3] Frost F J, Muller T, Petersen H V, et al. Identifying US populations for the study of health effects related to drinking water arsenic [J]. Journal of Exposure Science & Environmental Epidemiology, 2003, 13(3): 231-239.
- [4] 刘锐平, Mohon S K T, Md R S, 等. 孟加拉国饮用水砷污染控制策略与方向[J]. 环境工程学报, 2020, 14(8): 2075-2080. Liu R P, Mohon S K T, Md R S, et al. Strategy and development direction for arsenic pollution control in drinking water in Bangladesh [J]. Chinese Journal of Environmental Engineering, 2020, 14(8): 2075-2080.
- [5] 周少磊, 刘波, 王鹏, 等. 北京市通州区农村饮用水砷暴露健康风险评估[J]. 预防医学, 2022, 34(7): 705-709. Zhou S L, Liu B, Wang P, et al. Health risk assessment of arsenic exposure in rural drinking water in Tongzhou district, Beijing municipality [J]. Preventive Medicine, 2022, 34(7): 705-709.
- [6] 孔畅, 杨林生, 虞江萍, 等. 内蒙古某地区饮用水砷含量与人体暴露及致癌风险分析[J]. 生态与农村环境学报, 2018, 34(5): 456-462. Kong C, Yang L S, Yu J P, et al. Assessment of arsenic exposure and carcinogenic risk in an endemic arsenism area in Inner Mongolia caused by exposure to arsenic in drinking water [J]. Journal of Ecology and Rural Environment, 2018, 34(5): 456-462.
- [7] 李杰, 张玲, 林勤, 等. 新疆农村饮用水砷分布及改水建议[J]. 疾病预防控制中心通报, 2020, 35(3): 1-3, 13. Li J, Zhang L, Lin Q, et al. Distribution of arsenic in drinking water in rural areas of Xinjiang and suggestion for water improvement [J]. Bulletin of Disease Control & Prevention (China), 2020, 35(3): 1-3, 13.
- [8] 张秋秋, 潘申龄, 刘伟, 等. 我国重点城市饮用水中砷健康累积风险评价[J]. 环境科学, 2017, 38(5): 1835-1841. Zhang Q Q, Pan S L, Liu W, et al. Accumulated health risk assessment of arsenic in drinking water of major cities of China [J]. Environmental Science, 2017, 38(5): 1835-1841.
- [9] WHO. Risk assessment of *Cryptosporidium* in drinking water [M]. Geneva: World Health Organization, 2009.

- [10] U. S. EPA. Risk assessment guidance for superfund, Volume I, human health evaluation manual (part B, development of risk-based preliminary remediation goals) [M]. Washington: Environmental Protection Agency, 1991.
- [11] U. S. EPA. Risk assessment guidance for superfund, Vol. I, human health evaluation manual (part E, supplemental guidance for dermal risk assessment) [M]. Washington: Environmental Protection Agency, 2004.
- [12] Chen C J, Chen C W, Wu M M, *et al.* Cancer potential in liver, lung, bladder and kidney due to ingested inorganic arsenic in drinking water [J]. *British Journal of Cancer*, 1992, **66** (5): 888-892.
- [13] National Research Council. Arsenic in drinking water [M]. Washington: National Academy Press, 2001. 136.
- [14] Pan S L, An W, Li H Y, *et al.* Cancer risk assessment on trihalomethanes and haloacetic acids in drinking water of China using disability-adjusted life years [J]. *Journal of Hazardous Materials*, 2014, **280**: 288-294.
- [15] 环境保护部. 中国人群暴露参数手册[M]. 北京: 中国环境出版社, 2013.
- [16] Gan W H, Guo W H, Mo J M, *et al.* The occurrence of disinfection by-products in municipal drinking water in China's Pearl River Delta and a multipathway cancer risk assessment [J]. *Science of the Total Environment*, 2013, **447**: 108-115.
- [17] Lee S C, Guo H, Lam S M J, *et al.* Multipathway risk assessment on disinfection by-products of drinking water in Hong Kong [J]. *Environmental Research*, 2004, **94**(1): 47-56.
- [18] 中华人民共和国国家统计局. 中国统计年鉴(2020)[M]. 北京: 中国统计出版社, 2020.
- [19] Zhang H, Chang S, Wang L B, *et al.* Estimating and comparing the cancer risks from THMs and low-level arsenic in drinking water based on disability-adjusted life years [J]. *Water Research*, 2018, **145**: 83-93.
- [20] 曹毛毛, 李贺, 孙殿钦, 等. 全球肝癌2020年流行病学现状 [J]. *中华肿瘤防治杂志*, 2022, **29**(5): 322-328.
- [21] Cao M M, Li H, Sun D Q, *et al.* Global epidemiology of liver cancer in 2020 [J]. *Chinese Journal of Cancer Prevention and Treatment*, 2022, **29**(5): 322-328.
- [22] 金银龙, 梁超轲, 何公理, 等. 中国地方性砷中毒分布调查(总报告)[J]. *卫生研究*, 2003, **32**(6): 519-540.
- [23] Jin Y L, Liang C K, He G L, *et al.* Study on distribution of endemic arsenism in China [J]. *Journal of Hygiene Research*, 2003, **32**(6): 519-540.
- [24] 张楠, 闫涛, 徐肖倩, 等. 2014-2018年内蒙古自治区居民生活饮用水砷含量监测[J]. *河南预防医学杂志*, 2021, **32**(6): 429-432.
- [25] Zhang N, Yan T, Xu X Q, *et al.* Monitoring results of arsenic content in drinking water in Inner Mongolia from 2014 to 2018 [J]. *Henan Journal of Preventive Medicine*, 2021, **32**(6): 429-432.
- [26] Yang S, Yang Q C, Ma H Y, *et al.* Health risk assessment of phreatic water based on triangular fuzzy theory in Yinchuan plain [J]. *Ecotoxicology and Environmental Safety*, 2018, **164**: 732-738.
- [27] 李军, 程晓天, 王正辉, 等. 山西大同盆地地方性砷中毒病区饮用水的水砷价态暴露研究[J]. *中国地方病学杂志*, 2006, **25**(1): 64-66.
- [28] Li J, Cheng X T, Wang Z H, *et al.* Studies on exposure status of water-arsenic valence state of inhabitants in endemic arsenism diseased areas of Datong basin of Shanxi [J]. *Chinese Journal of Endemiology*, 2006, **25**(1): 64-66.
- [29] 王敬华. 山阴与应县地区高砷高氟水的形成环境研究[J]. *内蒙古预防医学*, 1997, **22**(4): 145-147.
- [30] 高继军, 张力平, 黄圣彪, 等. 北京市饮用水水源重金属污染物健康风险的初步评价[J]. *环境科学*, 2004, **25**(2): 47-50.
- [31] Gao J J, Zhang L P, Huang S B, *et al.* Preliminary health risk assessment of heavy metals in drinking waters in Beijing [J]. *Environmental Science*, 2004, **25**(2): 47-50.
- [32] Huang S B, Xu P, Lagos G E, *et al.* Winter exposure assessment of copper, zinc and arsenic in drinking water of inhabitants in Beijing, China [J]. *Environment and Pollution*, 2011, **45**(1-3): 197-214.
- [33] 张森, 周志荣, 郑磊, 等. 2016年北京城区生活饮用水34种元素水平[J]. *卫生研究*, 2017, **46**(5): 737-742.
- [34] Zhang M, Zhou Z R, Zheng L, *et al.* Analysis of 34 kinds of elements in drinking water in Beijing city in 2016 [J]. *Journal of Hygiene Research*, 2017, **46**(5): 737-742.
- [35] 罗思, 向文平. 生活饮用水中的金属含量检测分析[J]. *再生资源与循环经济*, 2018, **11**(12): 39-41.
- [36] Luo S, Xiang W P. Analysis of metal elements in domestic drinking water [J]. *Recyclable Resources and Circular Economy*, 2018, **11**(12): 39-41.
- [37] 符刚, 曾强, 赵亮, 等. 基于GIS的天津市饮用水水质健康风险评价[J]. *环境科学*, 2015, **36**(12): 4553-4560.
- [38] Fu G, Zeng Q, Zhao L, *et al.* Health risk assessment of drinking water quality in Tianjin based on GIS [J]. *Environmental Science*, 2015, **36**(12): 4553-4560.
- [39] 梁素理, 吕胜敏, 马景, 等. 河北省饮水砷含量现况调查[J]. *现代预防医学*, 2006, **33**(5): 762-766.
- [40] 侯秀娟, 王玉姣, 周琴, 等. 廊坊市各县区生活饮用水中重金属污染物健康风险评价[J]. *饮料工业*, 2019, **22**(4): 70-73.
- [41] Hou X J, Wang Y J, Zhou Q, *et al.* Health risk assessment of heavy metals in drinking water in Langfang, Hebei [J]. *Beverage Industry*, 2019, **22**(4): 70-73.
- [42] 郭占景, 范尉尉, 陈风格, 等. 石家庄市农村饮用水重金属健康风险评价[J]. *环境卫生学杂志*, 2014, **4**(1): 17-21.
- [43] Guo Z J, Fan W W, Chen F G, *et al.* Health risk assessment for heavy metals in rural drinking water in Shijiazhuang City [J]. *Journal of Environmental Hygiene*, 2014, **4**(1): 17-21.
- [44] 尤龙凤, 丁志强. 太原市饮用水重金属健康风险评价[J]. *山西水利科技*, 2021, (3): 45-47, 50.
- [45] You L F, Ding Z Q. Health risk assessment of heavy metals of drinking water in Taiyuan [J]. *Shanxi Hydrotechnics*, 2021, (3): 45-47, 50.
- [46] 李继芳, 崔仲明, 纪忠义, 等. 铁岭市农村饮用水重金属及其健康风险初步评价[J]. *环境与健康杂志*, 2017, **34**(5): 444-446.
- [47] 温海威, 吕聪, 王天野, 等. 沈阳地区农村地下饮用水中重金属健康风险评价[J]. *中国农学通报*, 2012, **28**(23): 242-247.
- [48] Wen H W, Lv C, Wang T Y, *et al.* Health risk assessment of heavy metal in rural drinking groundwater in Shenyang, China [J]. *Chinese Agricultural Science Bulletin*, 2012, **28**(23): 242-247.
- [49] 隋玉芬. 吉林地区生活饮用水源水中砷的监测分析[J]. *世界最新医学信息文摘*, 2015, **15**(58): 189.
- [50] 张熙遥, 张灿, 史云, 等. 我国北方地区四省份自备井水质卫生学调查风险评价[J]. *中华疾病控制杂志*, 2019, **23**(3): 345-350.
- [51] Zhang X Y, Zhang C, Shi Y, *et al.* Investigation and risk assessment for water quality hygiene in self-supply well water in four northern provinces of China [J]. *Chinese Journal of Disease Control & Prevention*, 2019, **23**(3): 345-350.

- [39] Xu P, Huang S B, Wang Z J, *et al.* Daily intakes of copper, zinc and arsenic in drinking water by population of Shanghai, China [J]. *Science of the Total Environment*, 2006, **362**(1-3): 50-55.
- [40] 赵敏娟, 刘强, 杨海兵, 等. 2017年苏州市生活饮用水重金属污染物的健康风险评估[J]. *职业与健康*, 2018, **34**(14): 1957-1960.
- Zhao M X, Liu Q, Yang H B, *et al.* Health risk assessment of heavy metal pollutants in drinking water in Suzhou city in 2017[J]. *Occupation and Health*, 2018, **34**(14): 1957-1960.
- [41] 周睿婧, 陈敏健, 夏彦恺. 南京市某区中小学生学习饮用水重金属含量及健康风险评估[J]. *南京医科大学学报(自然科学版)*, 2016, **36**(7): 886-892.
- Zhou R J, Chen M J, Xia Y K. Heavy metal contamination and human health risk assessment in drinking water in primary and middle school students from a district of Nanjing city[J]. *Journal of Nanjing Medical University (Natural Sciences)*, 2016, **36**(7): 886-892.
- [42] 陈春静, 张景山, 李峻, 等. 2019年南京市饮用水重金属健康风险评估[J]. *现代预防医学*, 2020, **47**(5): 813-816.
- Chen C J, Zhang J S, Li J, *et al.* Health risk assessment of heavy metals in drinking water, Nanjing, 2019 [J]. *Modern Preventive Medicine*, 2020, **47**(5): 813-816.
- [43] 郑浩, 于洋, 丁震, 等. 江苏省饮用水重金属污染物健康风险评估[J]. *江苏预防医学*, 2012, **23**(4): 5-7.
- Zheng H, Yu Y, Ding Z, *et al.* Health risk assessment of heavy metals in drinking water in Jiangsu province[J]. *Jiangsu Journal of Preventive Medicine*, 2012, **23**(4): 5-7.
- [44] 梁晓军, 施健, 孙强, 等. 昆山市生活饮用水金属污染物的致癌性风险评估[J]. *江苏预防医学*, 2017, **28**(4): 376-378.
- Liang X J, Shi J, Sun Q, *et al.* Carcinogenic risk induced by metal pollutants in drinking water in Kunshan [J]. *Jiangsu Journal of Preventive Medicine*, 2017, **28**(4): 376-378.
- [45] 刘彦凯, 朱鸿儒, 章安帮, 等. 连云港城区2018年末梢水和直饮水中10种金属元素含量对比分析[J]. *江苏预防医学*, 2020, **31**(1): 94-95.
- [46] 周金水, 黄学敏, 朱文明, 等. 浙江省农村居民饮用水中砷含量监测分析[J]. *卫生研究*, 2003, **32**(5): 475-476.
- [47] 汪万芬, 钱东升, 黄润. 六安市城区饮用水源水重金属健康风险评估[J]. *皖西学院学报*, 2010, **26**(2): 140-142.
- Wang W F, Qian D S, Huang R. The health risk assessment of heavy metals in drinking water in Lu'an [J]. *Journal of West Anhui University*, 2010, **26**(2): 140-142.
- [48] 李卫东, 邹铮, 赵立胜, 等. 安徽省地方性砷中毒病区调查[J]. *安徽预防医学杂志*, 2006, **12**(4): 193-196.
- Li W D, Zou Z, Zhao L S, *et al.* Investigation of endemic arsenism in areas Anhui province of China [J]. *Anhui Journal of Preventive Medicine*, 2006, **12**(4): 193-196.
- [49] 叶露欢. 福建省饮用水中的常规重金属元素和稀土元素的调查分析[J]. *中国金属通报*, 2021, (11): 213-214.
- [50] 钟志清, 邱受亮, 钱坤, 等. 声环境、饮用水及地表水中金属离子的调查研究——以江西中医药大学为例[J]. *生物灾害科学*, 2021, **44**(3): 321-326.
- Zhong Z Q, Qiu S L, Qian K, *et al.* Study of acoustic environment as well as metal ions of drinking water and surface water in Jiangxi University of Chinese medicine [J]. *Biological Disaster Science*, 2021, **44**(3): 321-326.
- [51] 彭秀苗, 王雪峰, 公为美, 等. 2016~2020年济南市居民饮用水中8种重金属浓度变化趋势及健康风险特征分析[J]. *山东大学学报(医学版)*, 2021, **59**(12): 24-32.
- Peng X M, Wang X F, Gong W M, *et al.* Concentration changes and health risk of 8 heavy metals in drinking water in Jinan from 2016 to 2020 [J]. *Journal of Shandong University (Health Sciences)*, 2021, **59**(12): 24-32.
- [52] 孟晓琦, 孔伟威, 宣肇菲. 青岛市饮用水源地重金属污染物健康风险初步评价[J]. *干旱环境监测*, 2012, **26**(1): 14-16.
- Meng X Q, Kong W W, Xuan Z F. Preliminary evaluation on drinking water source heavy metals pollutant health risks in Qingdao city [J]. *Arid Environmental Monitoring*, 2012, **26**(1): 14-16.
- [53] 周宇, 范耀龙, 张丹丹, 等. ICP-MS检测济宁某高校师生可饮用水中铬·铅·汞·砷·镉的含量[J]. *安徽农业科学*, 2018, **46**(30): 199-201.
- Zhou Y, Fan Y L, Zhang D D, *et al.* Determination of heavy metals (Cr, Pb, Hg, As, Cd) in potable water for a college in Jining with ICP-MS [J]. *Journal of Anhui Agricultural Sciences*, 2018, **46**(30): 199-201.
- [54] 陈栋, 梁悦, 柳云广. 郑州市饮用水源水中砷含量检测及健康风险评估[J]. *中国给水排水*, 2017, **33**(7): 73-75.
- Chen D, Liang Y, Liu Y G. Detection and health risk assessment of arsenic content of source water in Zhengzhou [J]. *China Water & Wastewater*, 2017, **33**(7): 73-75.
- [55] Cheng Q L, Wu H, Wang W L, *et al.* Health risks of pollutants in the surface water sources of the centralized drinking water supply in Zhengzhou, China [J]. *Water International*, 2012, **37**(3): 253-264.
- [56] 赵淑军, 陈羽明. 仙桃市居民饮用水碘砷氟含量现况调查[J]. *公共卫生与预防医学*, 2017, **28**(1): 107-109.
- [57] 谷传玲, 王俊平, 王硕. 饮用水中重金属的暴露评估[J]. *食品工业科技*, 2011, **32**(11): 374-376, 423.
- Gu C L, Wang J P, Wang S. Exposure assessment for heavy metals in drinking water [J]. *Science and Technology of Food Industry*, 2011, **32**(11): 374-376, 423.
- [58] 郭杏妹, 李宁, 康园, 等. 佛山市农村饮用水中重金属的健康风险评估[J]. *暨南大学学报(自然科学与医学版)*, 2014, **35**(1): 21-25.
- Guo X M, Li N, Kang Y, *et al.* The health risk evaluation of heavy metals via rural surface water source in Foshan [J]. *Journal of Jinan University (Natural Science & Medicine Edition)*, 2014, **35**(1): 21-25.
- [59] 尤汉虎, 庞智锋, 梁雅慧, 等. 佛山市某城区饮用水重金属健康危害风险初步评估[J]. *华南预防医学*, 2011, **37**(3): 32-36.
- You H H, Pang Z F, Liang Y H, *et al.* Health risk assessment of heavy metals in drinking water in a certain district of Foshan city [J]. *South China Journal of Preventive Medicine*, 2011, **37**(3): 32-36.
- [60] 张清华, 韦永著, 曹建华, 等. 柳江流域饮用水源地重金属污染与健康风险评估[J]. *环境科学*, 2018, **39**(4): 1598-1607.
- Zhang Q H, Wei Y Z, Cao J H, *et al.* Heavy metal pollution of the drinking water sources in the Liujiang river basin, and related health risk assessments [J]. *Environmental Science*, 2018, **39**(4): 1598-1607.
- [61] 仝霞, 郭彬. 海口市集中式饮用水源地重金属健康风险评估[J]. *热带农业科学*, 2015, **35**(8): 74-77.
- Tong X, Guo B. Health risk assessment of heavy metals in centralized drinking water sources in Haikou [J]. *Chinese Journal of Tropical Agriculture*, 2015, **35**(8): 74-77.
- [62] Yuan Y Y, Liu Y L, Luo K L, *et al.* Hydrochemical characteristics and a health risk assessment of the use of river water and groundwater as drinking sources in a rural area in Jiangjin

- district, China[J]. *Environmental Earth Sciences*, 2020, **79**(3), doi: 10.1007/s12665-020-8900-1.
- [63] 郑清, 唐春梅, 廖咏梅, 等. 广元市2012~2014年城市饮用水源地中重金属健康风险初步评估[J]. *四川环境*, 2020, **39**(6): 172-178.
- Zheng Q, Tang C M, Liao Y M, *et al.* Preliminary assessment of health risk of heavy metals in urban drinking water source of Guangyuan city from 2012 ~ 2014 [J]. *Sichuan Environment*, 2020, **39**(6): 172-178.
- [64] 张思强, 徐承香, 杨惠瑛, 等. 铜仁矿区农村地下饮用水重金属含量与健康风险评价[J]. *中国农村水利水电*, 2019, (3): 41-49.
- Zhang S Q, Xu C X, Yang H Y, *et al.* Heavy metal content and health risk assessment of underground drinking water in rural areas of Tongren mining area [J]. *China Rural Water and Hydropower*, 2019, (3): 41-49.
- [65] 许川, 陈济安, 舒为群. 川藏沿线兵站饮用水源水中重金属污染物健康风险评价[J]. *解放军预防医学杂志*, 2008, **26**(5): 321-324.
- Xu C, Chen J A, Shu W Q. Preliminary health risk assessment of heavy metals in drinking water from affiliated army service stations along Sichuan-Tibet highway[J]. *Journal of Preventive Medicine of Chinese People's Liberation Army*, 2008, **26**(5): 321-324.
- [66] 杨桂荣, 叶枫, 杨春光, 等. 云南省首次水砷含量筛查结果分析[J]. *中国地方病防治杂志*, 2011, **26**(1): 43-45.
- Yang G R, Ye F, Yang C G, *et al.* The first an analysis for results of water arsenic screening in Yunnan [J]. *Chinese Journal of Control of Endemic Diseases*, 2011, **26**(1): 43-45.
- [67] 雷佩玉, 郑晶利, 贾茹, 等. 2020年陕西省农村饮用水典型类金属及重金属健康风险评估[J]. *卫生研究*, 2022, **51**(1): 45-50.
- Lei P Y, Zheng J L, Jia R, *et al.* Health risk assessment of typical metalloid and heavy metals in rural drinking water in Shaanxi province in 2020 [J]. *Journal of Hygiene Research*, 2022, **51**(1): 45-50.
- [68] 耿雅妮, 董洁, 张军, 等. 宝鸡市区生活饮用水重金属空间分布及风险评价[J]. *环境科学与技术*, 2019, **42**(2): 231-236.
- Geng Y N, Dong J, Zhang J, *et al.* Heavy metal spatial distribution and risk assessment of drinking water in Baoji city [J]. *Environmental Science & Technology*, 2019, **42**(2): 231-236.
- [69] 王彩霞, 刘宇, 郭蓉, 等. 陕西省部分城镇居民生活饮用水中砷含量调查及致癌风险评价[J]. *卫生研究*, 2018, **47**(4): 670-672.
- [70] Zhang H, Wang L B, Wang Y Y, *et al.* Using disability-adjusted life years to estimate the cancer risks of low-level arsenic in drinking water [J]. *Journal of Environmental Science and Health*, 2020, **55**(1): 63-70.
- [71] 陈月芳, 孙善伟, 段小丽, 等. 兰州市西固区儿童饮用水重金属暴露及健康风险精细化评估[J]. *环境科学*, 2020, **41**(1): 262-272.
- Chen Y F, Sun S W, Duan X L, *et al.* Refined assessment of exposure and health risks of heavy metals in water for the children in Xigu district, Lanzhou [J]. *Environmental Science*, 2020, **41**(1): 262-272.
- [72] 杨宁, 廖婉君, 施瑞祥, 等. 青海海西蒙古族藏族自治州农牧区生活饮用水检测结果分析[J]. *医学动物防制*, 2021, **37**(3): 297-299, 302.
- Yang N, Liao W J, Shi R X, *et al.* Analysis of drinking water test results in agricultural and pastoral areas of Haixi Mongolian and Tibetan autonomous prefecture, Qinghai province [J]. *Journal of Medical Pest Control*, 2021, **37**(03): 297-299, 302.
- [73] 朱美霖, 杨晓莉, 赵建明, 等. 宁夏村镇饮用水中重金属暴露健康风险评估及不确定性分析[J]. *生态毒理学报*, 2020, **15**(5): 372-378.
- Zhu M L, Yang X L, Zhao J M, *et al.* Health risk assessment and uncertainty analysis based on heavy metals exposure by drinking water in Ningxia rural areas [J]. *Asian Journal of Ecotoxicology*, 2020, **15**(5): 372-378.
- [74] 刘君, 庾见伟, 戴思芸, 等. 阿克苏地区2018-2020年农村饮用水中砷元素含量及价态的监测分析[J]. *中国地方病防治杂志*, 2021, **36**(4): 367-368.
- [75] 汤洁, 卞建民, 李昭阳, 等. 中国饮水型砷中毒区的水化学环境与砷中毒关系[J]. *生态毒理学报*, 2013, **8**(2): 222-229.
- Tang J, Bian J M, Li Z Y, *et al.* Relationship between hydrochemical environment and arsenism in areas with arsenic poisoning drinking water in China [J]. *Asian Journal of Ecotoxicology*, 2013, **8**(2): 222-229.
- [76] 汪爱华, 赵淑军. 湖北省仙桃市地方性砷中毒病区水砷调查与分析[J]. *中国热带医学*, 2007, **7**(8): 1486-1487.
- Wang A H, Zhao S J. Survey of endemic arsenic poisoning areas in Xiantao city, Hubei province [J]. *China Tropical Medicine*, 2007, **7**(8): 1486-1487.
- [77] 李军, 程晓天, 温新平, 等. 山西省农村饮用水水质卫生状况调查[J]. *环境与健康杂志*, 2008, **25**(2): 130-131.
- Li J, Cheng X T, Wen X P, *et al.* Investigation of drinking water quality in rural areas of Shanxi province [J]. *Journal of Environment and Health*, 2008, **25**(2): 130-131.
- [78] Smith A H, Marshall G, Roh T, *et al.* Lung, bladder, and kidney cancer mortality 40 years after arsenic exposure reduction [J]. *JNCI: Journal of the National Cancer Institute*, 2018, **110**(3): 241-249.
- [79] 余高, 陈芬, 张晓东, 等. 锰矿区周边农田土壤重金属污染特征、来源解析及风险评价[J]. *环境科学*, 2023, **44**(8): 4416-4428.
- Yu G, Chen F, Zhang X D, *et al.* Pollution characteristics, source analysis and risk assessment of heavy metals in the surrounding farmlands of manganese mining area [J]. *Environmental Science*, 2023, **44**(8): 4416-4428.

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