|  |  |  |  |
| --- | --- | --- | --- |
| Table 1: Cancer slope factors and reference oral doses for some heavy metals. The acceptable range of the risk limit is 10−6 to 10−4. | | | |
| Heavy metal | Reference doses | Oral slope factors | References |
| Arsenic | 3 × 10-4 | 1.5 | (USEPA, 2012; Kortei et al. 2020) |
| Lead | 4 × 10-3 | 8.5 × 10-3 | (USEPA, 2012; Kortei et al. 2020) |
| Cadmium | 1 × 10-3 | 6.3 | (USEPA, 2012; Kortei et al. 2020) |
| Copper | 4 × 10-2 | **-** | (USEPA, 2012; IRIS 2011; Kortei et al. 2020) |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 2. Comparison of As, Pb, Cd and Cu concentration among stations by season and organism. Boldface numbers indicate statistically significant differences. | | | | | | | | | |
| Heavy metal | Stations | *Gammarus* sp. | | | | Zander | | | |
| Spring  Mean ± SE | Summer  Mean ± SE | Autumn  Mean ± SE | Winter  Mean ± SE | Spring  Mean ± SE | Summer  Mean ± SE | Autumn  Mean ± SE | Winter  Mean ± SE |
| Pb | St1 | 0.51 ± 0.02 | 0.51 ± 0.03 | 0.56 ± 0.02 | 0.49 ± 0.02 | 0.51 ± .02 | 0.72 ± 0.05 | 0.84 ± 0.04 | 0.70 ± 0.03 |
| St2 | 0.51 ± 0.14 | 0.45 ± 0.12 | 0.49 ± 0.12 | 0.50 ± 0.08 | 0.51 ± 0.14 | 0.63 ± 0.14 | 0.75 ± 0.16 | 0.77 ± 0.09 |
| St3 | 0.62 ± 0.98 | 0.66 ± 0.09 | 0.61 ± 0.10 | 0.63 ± 0.13 | 0.62 ± 0.10 | 0.93 ± 0.08 | 0.81 ± 0.07 | 0.89 ± 0.12 |
| St4 | 0.40 ± 0.03 | 0.46 ± 0.04 | 0.50 ± 0.06 | 0.62 ± 0.07 | 0.50 ± 0.07 | 0.65 ± 0.04 | 0.75 ± 0.07 | 0.84 ± 0.06 |
| F (p) | 1.01 (0.421) | 1.53 (0.257) | 0.49 (0.695) | 0.80 (0.518) | 0.37 (0.776) | 2.83 (0.083) | 0.20 (0.895) | 1.03 (0.412) |
| Cd | St1 | 0.59 ± 0.03 | 0.44 ± 0.04 | 0.37 ± 0.03 | 0.35 ± 0.03 | 0.83 ± 0.05 | 0.77 ± 0.04 | 0.64 ± 0.09 | 0.50 ± 0.03 |
| St2 | 0.79 ± 0.02 | 0.84 ± 0.03 | 0.84 ± 0.01 | 0.83 ± 0.01 | 0.93 ± 0.05 | 1.10 ± 0.07 | 1.03 ± 0.06 | 1.02 ± 0.03 |
| St3 | 0.43 ± 0.04 | 0.27 ± 0.02 | 0.49 ± 0.04 | 0.50 ± 0.05 | 0.73 ± 0.05 | 0.42 ± 0.03 | 0.66 ± 0.07 | 0.68 ± 0.05 |
| St4 | 0.42 ± 0.08 | 0.22 ± 0.01 | 0.29 ± 0.04 | 0.37 ± 0.04 | 0.69 ± 0.10 | 0.36 ± 0.03 | 0.44 ± 0.06 | 0.44 ± 0.03 |
| F (p) | **12.17 (0.001)** | **111.05 (<0.0001)** | **48.41 (<0.0001)** | **38.50 (<0.0001)** | 2.68 (0.094) | **53.91 (<0.0001)** | **11.95 (0.001)** | **55.84 (<0.0001)** |
| Cu | St1 | 0.32 ± 0.03 | 0.37 ± 0.06 | 0.34 ± 0.03 | 0.44 ± 0.05 | 0.48 ± 0.04 | 0.61 ± 0.04 | 0.54 ± 0.03 | 0.69 ± 0.05 |
| St2 | 0.51 ± 0.15 | 0.54 ± 0.15 | 0.52 ± 0.17 | 0.63 ± 0.10 | 0.71 ± 0.17 | 0.75 ± 0.14 | 0.69 ± 0.15 | 0.88 ± 0.05 |
| St3 | 0.62 ± 0.09 | 0.67 ± 0.11 | 0.55 ± 0.08 | 0.61 ± 0.10 | 0.87 ± 0.12 | 0.85 ± 0.07 | 0.67 ± 0.07 | 0.78 ± 0.15 |
| St4 | 0.35 ± 0.05 | 0.43 ± 0.03 | 0.37 ± 0.04 | 0.35 ± 0.02 | 0.55 ± 0.04 | 0.64 ± 0.04 | 0.54 ± 0.05 | 0.54 ± 0.01 |
| F (p) | 2.46 (0.113) | 1.74 (0.212) | 1.14 (0.371) | 3.10 (0.067) | 2.68 (0.094) | 1.67 (0.226) | 0.93 (0.454) | 2.92 (0.077) |
| As | St1 | 0.49 ± 0.03 | 0.44 ± 0.04 | 0.40 ± 0.03 | 0.47 ± 0.02 | 0.79 ± 0.06 | 0.64 ± 0.05 | 0.58 ± 0.05 | 0.73 ± 0.06 |
| St2 | 0.71 ± 0.13 | 0.96 ± 0.06 | 0.84 ± 0.10 | 0.74 ± 0.11 | 0.97 ± 0.11 | 1.25 ± 0.23 | 1.10 ± 0.09 | 0.97 ± 0.05 |
| St3 | 0.75 ± 0.11 | 0.54 ± 0.09 | 0.58 ± 0.08 | 0.58 ± 0.05 | 1.16 ± 0.23 | 0.81 ± 0.07 | 0.84 ± 0.09 | 0.78 ± 0.04 |
| St4 | 0.48 ± 0.05 | 0.48 ± 0.04 | 0.47 ± 0.04 | 0.45 ± 0.05 | 0.71 ± 0.06 | 0.69 ± 0.06 | 0.78 ± 0.08 | 0.66 ± 0.05 |
| F (p) | 2.55 (0.105) | **16.25 (<0.0001)** | **7.46 (0.004)** | **3.94 (0.036)** | 2.25 (0.135) | **4.72 (0.021)** | **7.04 (0.006)** | **7.40 (0.005)** |

Table 3. Comparison of Pb, Cd, Cu, and Zn concentrations between fish and *Gammarus* sp. body by season and station. S: significant; NS: not significant.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Heavy metal | Spring | | | | Summer | | | | Autumn | | | | Winter | | | |
| St1 | St2 | St3 | St4 | St1 | St2 | St3 | St4 | St1 | St2 | St3 | St4 | St1 | St2 | St3 | St4 |
| Pb | NS | NS | NS | NS | S | NS | S | S | S | NS | NS | S | S | NS | NS | NS |
| Cd | S | S | S | NS | S | S | S | S | S | S | NS | NS | S | S | S | NS |
| Cu | S | NS | NS | S | S | NS | NS | S | S | NS | NS | S | S | NS | NS | S |
| As | S | NS | NS | S | S | NS | S | S | S | NS | NS | S | S | NS | S | S |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 4. Comparison of Pb, Cd, Cu, and As concentration between *Gammarus* sp. and Zander. | | | | | | | | |
|  | Cd | | Pb | | Cu | | As | |
| *Gammarus* sp. | Zander | *Gammarus* sp. | Zander | *Gammarus* sp. | Zander | *Gammarus* sp. | Zander |
| Mean ± SE | 0.50 ± 0.03 | 0.70 ± 0.03 | 0.53 ± 0.02 | 0.71 ± 0.03 | 0.48 ± 0.02 | 0. 67 ± 0.03 | 0.59 ± 0.03 | 0.84 ± 0.03 |
| Z | -4.395 | | -5.237 | | -5.497 | | -6.040 | |
| p | <0.0005 | | <0.0005 | | <0.0005 | | <0.0005 | |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Table 5. Comparison of heavy metals concentration (μg/g) in muscle of zander in this study with different standards and other studies worldwide. | | | | | | |
| Standards | Fish species | Cd | As | Pb | Cu | References |
| FAO/WHO limits | - | 0.5 |  | 0.5 | 30 | (FAO/WHO 2003) |
| European commission (EC) | - | 0.05 | - | 0.2 | - | (EC 2006) |
| CODEX | - | 0.5 | 0.5 | 1 | - | (CODEX STAN 1995) |
| Kayseri, Turkey | S. lucioperca | 2.52 |  | ˂0.03 |  | (Yildirim et al. 2009) |
| Danube River, Serbia | 0.005 | 0.66 | - | 1.3 | (Subotić et al. 2013) |
| Beyşehir Lake, Turkey | 2.17 | - | 1.62 | 1.38 | (Özparlak et al. 2012) |
| Beyşehir Lake, Turkey | 0.643 | - | 0.678 | - | (Altındağ and Yiğit 2005) |
| Caspian Sea, Iran | 0.09 | - | 0.53 | - | (Alipour and Banagar 2018) |
| Velenjsko jezero, Slovenia | ˂0.01 | - | 0.03 |  | (Mazej et al. 2010) |
| Hirfanlı dam, Turkey | 0.25 | - | 0.4 | 0.65 | (Gül et al. 2011) |
| Sidi Salem, Tunisia | 0.171 | - | 0.046 | - | (Khemis et al. 2017 |
| Rhône, Escault & Seine, France | 0.001 | 0.119 | 0.008 | - | (Noël et al. 2013) |
| Novosibirsk res. & Ob’River, Russia | 0.003–0.01 |  | 0.007–0.42 | 0.23-3.3 | (Popov et al. 2012) |
| Aras river, Iran | 0.7 | 0.838 | 0.71 | 0.67 | Peresnt Study |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 6. Values of target hazard quotient (THQ), total target hazard quotient (TTHQ), and lifetime cancer risk (CR) calculated for zander. Blue highlighted values exceed recommendations. | | | | | | | | |
| Station | THQAs | TRAS | THQPb | TRPb | THQCd | TRcd | THQCu | TTHQ |
| ST1 | **1.17** | **5.2×10-4** | 0.08 | 3.15**×**10-6 | 0.35 | **2.3×10-3** | 0.00 | 1.6 |
| ST2 | **1.83** | **8.2×10-4** | 0.08 | 3.01**×**10-6 | 0.52 | **3.4×10-3** | 0.00 | 2.43 |
| ST3 | **1.52** | **6.8×10-4** | 0.1 | 3.54**×**10-6 | 0.31 | **2.09×10-3** | 0.01 | 1.94 |
| ST4 | **1.21** | **5.4×10-4** | 0.08 | 3.10**×**10-6 | 0.24 | **1.62×10-3** | 0.00 | 1.53 |
| Average | **1.43** | **6.4×10-4** | 0.085 | 3.2**×**10-6 | 0.35 | **2.35×10-3** | 0.002 | 1.87 |