Distribution and assessment of the environmental risk of heavy metals in Aguada Blanca reservoir, Peru

ARTICLES doi:10.4136/ambi-agua.2838

Received: 22 Feb. 2022; Accepted: 06 Jun. 2022

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ABSTRACT

Sediments containing high concentrations of heavy metals in reservoirs, lakes and rivers, can resuspend into aquatic environments and negatively impact water quality. The concentrations of 10 elements were studied in surface sediments and water from the Aguada Blanca Reservoir, Peru, an important water source to 1,080,000 people in the arid province of Arequipa. Sediment and water samples were collected from nine points in 2019. The enrichment, accumulation, ecological risk and distribution of metals in sediment were determined, and the information on heavy metals in water was used to assess the quality of the aquatic system. Spatially, heavy metals showed variations throughout the study area, with an increase for most elements near the deepest part of the reservoir. The average concentration of Cd in sediment was 4 times higher than the natural background. In water, As was the only element that exceeded Peruvian regulations (As > 10 μg L⁻¹). The Enrichment Factor (EF) and Geoaccumulation Index (Igeo) of metals in sediment presented the following order: Cd > As > Pb > Zn > Cu > Ni > Cr, with Ni and Cr being the only elements that did not present enrichment. The most considerable Igeo was Cd (1.21 ± 1.45), presenting a classification of moderately to heavily contaminated. The integrated potential ecological risk (RI) of Cd presented high values in 5 points of the reservoir. The information developed will assist in establishing effective control strategies for the quality of the aquatic system.

Keywords: heavy metals, reservoir, sediments, water quality.
coletadas em nove pontos em 2019. Espacialmente, os metais pesados apresentaram variações ao longo da área de estudo com aumento para a maioria dos elementos próximos à parte mais profunda do reservatório. A concentração média de Cd no sedimento foi 4 vezes maior do que o fundo natural. Na água, o As foi o único elemento que ultrapassou as regulamentações peruanas (As > 10 μg L\(^{-1}\)). O Fator de Enriquecimento (EF) e Índice de Geoacumulação (I\(_{geo}\)) dos metais no sedimento apresentaram a seguinte ordem: Cd > As > Pb > Zn > Cu > Ni > Cr, sendo Ni e Cr os únicos elementos que não apresentaram enriquecimento. O I\(_{geo}\) mais expressivo foi o Cd (1.21 ± 1.45), apresentando uma classificação de moderada a fortemente contaminada. O risco ecológico potencial integrado (RI) do Cd apresentou valores elevados em 5 pontos do reservatório. Os resultados encontrados fornecem informações necessárias para estabelecer estratégias de controle sobre a qualidade do sistema aquático.

**Palavras-chave:** metais pesados, qualidade da água, reservatório, sedimentos.

1. INTRODUCTION

Reservoirs often present problems of heavy metal accumulation due to sediment retention behind reservoirs (Hahn et al., 2018; Kondolf et al., 2014; Vukovic et al., 2014), which results in contamination or reduction of the quality of the water (Varol, 2013). The accumulation of heavy metals in aquatic systems can lead to human health risks and deterioration of aquatic ecology (Hahn et al., 2018; Hou et al., 2013). Therefore, the accumulation of metals in sediments is the subject of environmental studies in much of the world by environmental researchers (Hou et al., 2013; Marziali et al., 2017).

Reservoirs are of great economic importance because they supply water to the population, agricultural and industrial activities, among others (Schleiss et al., 2016; Yasarer and Sturm, 2016). Therefore, water quality must be monitored because heavy metals are non-biodegradable, persistent, bio accumulative elements and with a tendency to enter the food chain (Keshavarzi and Kumar, 2019). The existence of heavy metals in water bodies is the result of anthropogenic activities and natural processes such as rock weathering and volcanic activities, with aquatic environments being the most susceptible to the negative effects of heavy metal pollution (Hahn et al., 2018; Hou et al., 2013; Keshavarzi and Kumar, 2019).

Sediments are important reservoirs of trace elements and could exchange cations with the aquatic environment, and over time contribute pollutants into the water column due to their constant contact (Yahaya et al., 2012). Trace element concentrations in sediments become a problem when they are enriched above natural background levels due to contamination, which may create a threat to the aquatic environment (Olatunde et al., 2014).

Knowing the concentrations and distribution of heavy metals are very useful to determine the degree of contamination of aquatic environments and provide the necessary information for environmental health risk assessment (Li et al., 2019). The indices commonly used to assess heavy metal contamination in sediments are the Enrichment Factor (EF), the Geoaccumulation Index (I\(_{geo}\)) and Integrated Potential Ecological Risk Index (RI) (Barbieri, 2016; Decena et al., 2018).

The present study was carried out in the Aguada Blanca Reservoir, located at 3650 m.a.s.l in the Arequipa region of southern Peru. An important water source to 1,080,000 people in the arid Arequipa province. This reservoir has had sediment removal problems since 1989 due to the inoperability of the discharge gate, promoting sediment accumulation until today (ANA, 2016), which could generate a problem for water quality. This research evaluated the enrichment, geoaccumulation, potential ecological risk, distribution of metals in the reservoir and the relationship between the concentration of metals in sediment and reservoir water.
2. MATERIAL AND METHODS

2.1. Study area

The Aguada Blanca Reservoir is located in the south of the Republic of Peru, in the Arequipa region (Figure 1, A-B), on the slopes of the Misti and Chachani volcanoes about 27 km from the city of Arequipa (19K, 248920 E, 820498 S and 250920 E, 8204980 S). The reservoir is 3.2 km long with an average width of 0.5 km and a maximum depth of 30 m (Figure 1, C-D). The surface of the reservoir is 1.73 km² and accumulates approximately 30 million m³ of water. The function of Aguada Blanca Reservoir is to receive, regulate and distribute the water from six other reservoirs (the Chalchuanca, the Dique de los Españoles, the Bamputañe, the El Pañe, the El Frayle and the Pillones), which feeds the Chili River Basin and supplies water to 1,080,000 people in the city of Arequipa.

Figure 1. Study area: A). Republic of Peru, B) Arequipa Region, C) Aguada Blanca Reservoir with sampling points, D) Depth of the reservoir.

2.2. Sampling collections and analysis

Sediment and water samples were collected at 9 points in the reservoir (water entry zones, middle zone and reservoir zone), in the months of April, July and October 2019, which were averaged. The water samples were taken with a 250 mL Niskin bottle between 0.5 to 1 meter above the sediment (CCME, 2011), then surface sediment sampling was performed using a Lamotte model dredger (Cavanagh et al., 1997). Sampling depth was determined using an Eagle Cuda 168 graphic echo sounder. The water samples were preserved with analytical grade nitric acid (1%) and deposited in bottles (0.25 L) and sediment samples were placed in polyethylene bags (1 Kg) to be transported to the laboratory in a cooler box with ice.

For the determination of heavy metals in sediment, we used the EPA 200.7 method (Inductively Coupled Plasma Optical Emission Spectrometry, ICP-OES, Perkin Elmer) and the EPA 200.8 method in water (Inductively Coupled Plasma Mass Spectrometry; ICP-MS, Agilent) (APHA et al., 2005), for totals metals. Organic matter was determined using the ASTM D 2974-87 method (ASTM International, 2014), and the pH was determined by the APHA 4500-H + B electrometric method (APHA et al., 2005) using an EXO 2 multiparameter probe (Xylem, USA).
2.3. Reagents and standards

All reagents were of analytical grade or Suprapure quality (Merck, Germany). Double deionized water was used for the preparation of all solutions. Standard solutions of elements used for calibration were prepared by diluting stock solutions of 1000 mg L\(^{-1}\) of each element. The stock standard solutions were Merck Certificate standard. All glasswares used were cleaned by soaking in dilute nitric acid for at least 24 hours and were rinsed thoroughly in deionized water before use.

2.4. Quality control

The quality of the analytical data was assured through the application of quality methods and laboratory control. Method precision and quality control were verified by triplicate analysis of proficiency test material. Good agreement was observed between analytical results and certified values, with recovery percentages ranging from 97% (As) to 106% (Cd).

2.5. Sediment contamination assessment

2.5.1. Enrichment factor

The enrichment factor (EF) is used to determine metal enrichment factors in sediments and soils, as well as to assess the presence and intensity of anthropogenic contaminant deposition on the land surface (Barbieri, 2016). The reference values used were those defined by Turekian and Wedopohl (1961), values widely used by different researchers worldwide. The EF calculation reflects the enrichment of metals in sediments in relation to iron (Fe), which was chosen as a stationary reference element to perform this calculation (Ekengele et al., 2017), as seen in Equation 1.

\[
EF = \frac{\left(\frac{M}{Fe}\right)_{sample}}{\left(\frac{M}{Fe}\right)_{Background}}
\]  

(1)

Where \(EF\) = Enrichment Factor; \(\left(\frac{M}{Fe}\right)_{sample}\) is the ratio of metal/Fe in the sample; and \(\left(\frac{M}{Fe}\right)_{Background}\) is the metal/Fe ratio of the reference value. EF values are classified as follows: When EF <1 indicates no enrichment; 1 <EF <3 is low; 3 <EF <5 is moderate; 5 <EF <10 is moderately severe; 10 <EF <25 is severe; 25 <EF <50 is very serious; and EF> 50 is extremely severe (Acevedo-Figueroa et al., 2006; Decena et al., 2018).

2.5.2. Geoaccumulation index (I\(_{geo}\))

The geo-accumulation index (I\(_{geo}\)) was used to assess heavy metal contamination in sediments and is defined as follows (Equation 2) (Li et al., 2019).

\[
I_{geo} = \log_2 \left( \frac{c}{kB} \right)
\]  

(2)

Where: \(C\): is the concentration of the sample; \(B\): is the reference value; \(k\): is the geoaccumulation constant (1.5). The I\(_{geo}\) value of each heavy metal is classified into seven classes, from uncontaminated to extremely contaminated. Classification of heavy metal contamination according to I\(_{geo}\) value: Class 0 (I\(_{geo}\) <0), uncontaminated; Class 1 (0 < I\(_{geo}\) ≤ 1), uncontaminated to moderately contaminated; Class 2 (1 < I\(_{geo}\) ≤ 2), moderately contaminated; Class 3 (2 < I\(_{geo}\) ≤ 3), Moderately to heavily polluted; Class 4 (3 < I\(_{geo}\) ≤ 4), heavily contaminated; Class 5 (4 < I\(_{geo}\) ≤ 5), strong to extremely contaminated; Class 6 (5 < I\(_{geo}\) ≤ 10), extremely contaminated (Li et al., 2019).
2.5.3. Ecological risk index

The potential ecological risk index (RI) is commonly used as a diagnostic tool to determine contamination in sediments, soils and waters due to the presence of metals in the environment. The RI is defined as the sum of the ecological risk index (RE) of each heavy metal, for which Equations 3 and 4 are shown (Hakanson, 1980; Miranzadeh Mahabadi et al., 2020; Sun, 2017).

\[ RE = T_r^i \times C_f^i \]  
\[ RI = \sum_{i=1}^{N} RE = \sum_{i=1}^{N} T_r^i \times C_f^i \]

Where: \( T_r^i \) is the toxic response factor of different heavy metals, the ecological values of Cd, Pb, Cu, Cr and Zn are 30, 5, 5, 2, 1. \( C_f^i = C_i/C_r^i \): is the pollution coefficient of each heavy metal. \( C_r^i \): is the concentration of each heavy metal. \( C_r^i \): is the recommended value for heavy metal concentration in sediments and soils (Sun, 2017), Table 1.

| Level         | Ecological Risk | RI  |
|---------------|-----------------|-----|
| Low           | RE < 40         | RI < 150 |
| Moderate      | 40 < RE ≤ 80    | 150 < RI ≤ 300 |
| Considerable  | 80 < RE ≤ 160   | 300 < RI ≤ 600 |
| High          | 160 < RE ≤ 320  | > 600 |
| Very High     | RE > 320        |     |

Source: Hakanson (1980); Sun (2017).

2.6. Analysis of data

A mean and standard deviation (SD) were determined for the entire reservoir for all parameters analyzed. Statistical analyses were performed with SPSS statistics v24 software; Pearson correlation analysis (p <0.05) was applied to assess the association between the concentration of metals in sediment and water. Spatial distribution graphs were made with the software Surfer Golden 16.

3. RESULTS AND DISCUSSION

3.1. Heavy metals, pH and organic matter

The heavy metal concentrations found for ten elements analyzed in sediments (mg d.w. Kg\(^{-1}\)) are shown in Table 2, where the mean concentration of Cd (1.46 ± 0.94) and the concentrations of As (12.54±5.70) and Pb (16.35±5.59) in some points was higher in relation to values of study by Turekian and Wedepohl (1961), while Cr (7.73 ± 2.16), Sb (1.03 ± 0.92), Ni (7.96 ± 2.86), Cu (35.02 ± 12.36), Zn (45.63 ± 13.60) and Fe (12.984 ± 4.195) presented low values. Cd is characterized by presenting high concentrations in sediments from various parts of the world (Cáceres Choque et al., 2013; El-Radaideh et al., 2017; Vrhovnik et al., 2013; Yahaya et al., 2012), A source of entry of Cd into the environment is anthropogenic; however, the study area is far from the urban area and industrial activities. These high concentrations would be attributed to the geological characteristics of the area (Vargas, 1970), volcanic material and volcanic emissions (Hutton, 1983), since the reservoir is close to two volcanoes (Misti and Chachani). Another source could be atmospheric deposition (Cai et al., 2019). The dynamics of sedimentation and the entry of pollutants is little known for the reservoir.
Table 2. Concentration of heavy metals in sediment (mg d.w. Kg⁻¹), water (µg L⁻¹), pH, organic matter (%) and depth (m) in Aguada Blanca Reservoir, Peru.

| Matrix | Points | As  | Cr  | Cd  | Pb  | Sb  | Ni  | Cu  | Zn  | P   | Fe  | pH  | OM  | Depth |
|--------|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Sediment | SA1 | 20.60 | 11.05 | 1.64 | 22.96 | 2.80 | 12.06 | 48.40 | 58.80 | 1773 | 20000 | 6.22 | 5.30 | 28 |
|         | SA2 | 10.50 | 6.47 | 2.53 | 18.16 | 1.00 | 6.62 | 35.50 | 43.20 | 1016 | 14104 | 5.96 | 6.30 | 24 |
|         | SA3 | 19.50 | 8.67 | 0.33 | 20.76 | 0.30 | 10.14 | 44.30 | 61.40 | 408  | 13289 | 5.95 | 6.27 | 22 |
|         | SA4 | 18.30 | 8.72 | 0.34 | 20.41 | 0.30 | 10.34 | 44.70 | 63.10 | 416  | 12514 | 5.90 | 6.15 | 16 |
|         | SA5 | 13.80 | 10.68 | 1.42 | 18.72 | 2.30 | 10.61 | 46.40 | 49.70 | 1492 | 18255 | 6.47 | 4.75 | 16 |
|         | SA6 | 8.20  | 5.93  | 2.20 | 15.00 | 0.70 | 5.73 | 30.20 | 38.60 | 1008 | 12297 | 6.02 | 5.17 | 10 |
|         | SA7 | 8.80  | 6.21  | 2.16 | 16.28 | 1.00 | 5.93 | 32.50 | 37.70 | 954  | 11275 | 6.01 | 5.54 | 5  |
|         | SA8 | 8.00  | 6.90  | 0.20 | 7.93  | 0.20 | 6.53 | 20.20 | 35.10 | 255  | 7461  | 5.93 | 3.44 | 5  |
|         | SA9 | 5.20  | 4.91  | 2.28 | 6.91  | 0.70 | 3.69 | 13.00 | 23.10 | 287  | 7662  | 5.86 | 1.70 | 4  |

|         | Min | 5.20 | 4.91 | 0.20 | 6.91 | 0.20 | 3.69 | 13.00 | 23.10 | 255  | 7461  | 5.86 | 3.44 | -  |
|         | Max | 20.60 | 11.05 | 2.53 | 22.96 | 2.80 | 12.06 | 48.40 | 63.10 | 1733 | 20000 | 6.47 | 6.30 | -  |
|         | Mean | 12.54 | 7.73 | 1.46 | 16.35 | 1.03 | 7.96 | 35.02 | 45.63 | 841  | 12984 | 6.04 | 5.37 | -  |
|         | SD  | 5.70 | 2.16 | 0.94 | 5.59 | 0.92 | 2.86 | 12.36 | 13.60 | 537  | 4195  | 0.19 | 2.00 | -  |

| Water  | SA1 | 9.44 | 0.30 | 0.03 | 0.20 | 0.20 | 0.56 | 1.70 | 16.65 | -    | 220.80 | 8.41 | -    | 28 |
|        | SA2 | 11.79 | LOD  | 0.03 | 0.20 | 0.20 | 0.70 | 2.00 | 9.67  | -    | 136.10 | 8.23 | -    | 24 |
|        | SA3 | 10.92 | LOD  | LOD  | LOD  | LOD  | 0.39 | 1.90 | 19.83 | -    | 102.90 | 8.36 | -    | 22 |
|        | SA4 | 11.21 | LOD  | LOD  | LOD  | LOD  | 0.43 | 1.80 | 19.12 | -    | 139.30 | 7.96 | -    | 16 |
|        | SA5 | 7.37  | LOD  | LOD  | LOD  | LOD  | LOD  | 1.60 | 15.98 | -    | 302.00 | 8.55 | -    | 16 |
|        | SA6 | 12.42 | LOD  | 0.05 | 0.60 | 0.20 | 0.73 | 2.20 | 9.85  | -    | 121.70 | 8.53 | -    | 10 |
|        | SA7 | 120.70 | LOD  | LOD  | LOD  | LOD  | 0.20 | 0.60 | 1.70  | 212.50 | 115.60 | 8.48 | -    | 5  |
|        | SA8 | 11.30 | LOD  | 0.20 | LOD  | 0.30 | 0.45 | 2.70 | 52.29 | -    | 128.50 | 8.66 | -    | 5  |
|        | SA9 | 138.30 | LOD  | LOD  | LOD  | LOD  | 0.20 | 0.58 | 1.80  | 11.92  | 106.40 | 8.43 | -    | 4  |

|        | Min | 7.37 | 0.20 | 0.03 | 0.20 | 0.20 | 0.39 | 1.60 | 9.67  | -    | 102.90 | 7.96 | -    | -    |
|        | Max | 138.30 | 0.50 | 0.21 | 0.60 | 0.20 | 0.73 | 2.70 | 212.50 | -    | 302.00 | 8.66 | -    | -    |
|        | Mean | 37.05 | 0.33 | 0.08 | 0.33 | 0.20 | 0.55 | 1.93 | 40.87 | -    | 152.60 | 8.40 | -    | -    |
|        | SD  | 52.62 | 0.18 | 0.07 | 0.22 | 0.07 | 0.12 | 0.34 | 65.65 | -    | 66.08 | 0.21 | -    | -    |

LOD: Limit of Detection – in water; LOD₆₅=0.20; LOD₆₇=0.03; LOD₆₉=0.10; LOD₆₁=0.10.
The sediments had a slightly acidic to neutral pH (5.86 to 6.47). This slight acidity would be explained by the geology of the study area, which is composed of volcanic rocks (Vargas, 1970). Low pH values prevent the adsorption of metals, since under acid conditions there are enough H+ ions to bind to the surface of clay and organic matter (Adeniyi et al., 2011), leaving metals available in the water; however, the slightly acidic to neutral pH (5.86 to 6.47) and the basic pH of the deep zone water (7.96 - 8.66) (Table 2), would promote the adsorption of metals.

Other factors influencing heavy metal adsorption are organic matter, anoxic conditions, high Fe and Mn concentrations and low temperatures (Li et al., 2014). The study area presented a considerable percentage of organic matter in the sediments (3.44 - 6.30%), as well as low water temperatures of 7°C to 12°C, which makes these factors reduce the release of metals into water (Li et al., 2014). The adsorption of metals by the sediment is corroborated by the low concentrations found in the water, with the exception of As (Table 2), which presents values above that established in Peruvian regulations, As > 10 μg L⁻¹ (ANA, 2016).

Heavy metal concentrations in water samples (μg L⁻¹) presented the following order: Fe (152 ± 66.08) > Zn (40.87 ± 65.65) > As (37.05 ± 52.62) > Cu (1.93 ± 0.34) > Ni (0.55 ± 0.12) > Pb (0.33 ± 0.22) > Cr (0.33 ± 0.18) > Sb (0.20 ± 0.07) > Cd (0.08 ± 0.07). The results of this study show that the concentrations are high in comparison with the study of two lakes in the central region of Peru where As values were found: 4.2±0.9 μg L⁻¹, for Lake Paca and 4.2±0.9 μg L⁻¹, for Tragadero Lake (Custodio et al., 2021). While in comparison with other international studies, the values of metals were notably high for As, in the case of Cr, Cu, Ni and Pb present low concentrations, while Cd is compatible with other results (see Table 3).

The high concentration of As in the water could be due to the weathering processes of the rocks, which would incorporate As into the aquatic system. This would be reflected in the considerable concentrations of As in the Aguada Blanca Reservoir (Prieto et al., 2016). The concentrations of phosphorus (P) in the sediment would have two effects: it would make As highly available in the aquatic system due to its low adsorption by the sediment (Prieto et al., 2016; Zhang and Selim, 2008), and it would reduce the availability of Cd in the water, as phosphorus works as an adsorption system avoiding its release into the water (Wang and Xing, 2004). This is reflected in the values in Table 2.

Table 4 shows the analyzed data, where a significant positive correlation is observed between the As in the sediment and the other elements in the sediment: Cr, Pb, Ni, Cu, Zn, Sb, and Fe.

The strong correlation of As with the other elements explains its high content in the study area and, consequently, said element would be available in the water. Statistically, no correlation is observed between the concentration of elements in sediment and in the water, possibly the low resuspension of elements in water influences the results.

### 3.2. Evaluation of sediment contamination

#### 3.2.1. Enrichment factor

The EF of each sampling point was calculated to determine the degree of enrichment in the reservoir sediment. The results are shown in Table 5. We observe that the degree of enrichment presents the following order: Cd (18.78 ± 14.89) > As (3.46 ± 1.14) > Pb (2.93 ± 0.58) > Zn (2.49 ± 0.62) > Cu (2.78 ± 0.57) > Ni (0.43 ± 0.11) > Cr (0.32 ± 0.07), where Ni and Cr, are elements that do not present enrichment, Cd presents different degrees of enrichment from moderate to very severe, while As, Pb, Zn and Cu had a low to moderate degree. An EF value between 0.5 – 1.5 (0.5 < EF < 1.5) indicate natural enrichment and values above 1.5 (EF > 1.5) are characterized by an anthropogenic enrichment (Zhang and Liu, 2002). The EF values in our study are low in relation to the EF values found by Cáceres Choque et al. (2013) from Lake Titicaca, which presents the following order Cd (14 - 519) > Pb (32 -233) > Zn (10 - 162) > Co (6 - 71) > Cu (5 - 15) > Mn (3 - 10) > Ni (1 - 18), where we observe the predominance of Cd, Pb, Zn, Cu in presenting the higher enrichment values. The difference between EF values lies in low Fe values in Lake Titicaca in relation to our Fe concentration.
### Table 3. Concentration of heavy metals (μg L⁻¹) in water in other studies.

| Location                             | As  | Cd  | Cr  | Cu  | Fe  | Ni  | Pb  | Zn  | Reference                      |
|--------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-------------------------------|
| **Aguada Blanca Reservoir, Peru**    |     |     |     |     |     |     |     |     |                               |
| Min                                  | 7.37| 0.03| 0.2 | 1.6 | 102.9| 0.39| 0.2 | 9.67| Present study                 |
| Max                                  | 138.3| 0.21| 0.5 | 2.7 | 302 | 0.73| 0.6 | 212.5|                               |
| Mean                                 | 37.05| 0.08| 0.33| 1.93| 152.59| 0.55| 0.33| 40.87|                               |
| **Kralkızı Dam Reservoir**           |     |     |     |     |     |     |     |     |                               |
| Mean                                 | 2.39| 0.036| 20.06| 2.83| 58.63| 15.75| 2.56| 5.02|                               |
| Median                               | 0.70| 0.018| 16.77| nd | 51.28| 9.78 | 0.59| 4.01| (Varol, 2013)                 |
| Max                                  | 22.61| 0.25| 90.12| 9.18| 189.24| 52.12| 26.48| 19.6 |                               |
| **Dicle Dam Reservoir**              |     |     |     |     |     |     |     |     |                               |
| Mean                                 | 1.61| 0.03| 18.58| 2.12| 62.07| 15.86| 1.84| 4.12|                               |
| Median                               | 0.40| 0.014| 14.27| nd | 55.73| 9.99 | 0.34| 2.72|                               |
| Max                                  | 14.14| 0.322| 46.63| 9.63| 251.62| 54.23| 14.73| 19.32| (Varol, 2013)                 |
| **Batman Dam Reservoir**             |     |     |     |     |     |     |     |     |                               |
| Mean                                 | 0.71| 0.044| 16.5 | nd | 57.66| 15.96| 1.56| 4.09|                               |
| Median                               | 0.36| nd | 12.11| nd | 63.11| 12.01| 0.38| 3.45|                               |
| Max                                  | 6.11| 0.428| 40.89| 9.08| 119.12| 36.46| 11.12| 24.57|                               |
| **Atatürk Dam Reservoir, Turkey**    |     |     |     |     |     |     |     |     |                               |
| Tigris River, Turkey                 | -   | nd | -   | 25  | 62  | 15.4 | nd | 64  | (Karade and Ünlü, 2000)       |
| Danjiangkou Reservoir, China         | 12.32| nd | 48.58| 4.52| 159.46| 17.32| 22.03| 3.62| (Varol, 2013)                 |
| Alzate Reservoir, Mexico             | 11.08| 1.17| 6.29| 13.32| 19.14| 1.73| 10.59| 2.02| (Li et al., 2008)             |
| Reference values                     | 13  | 0.3 | 90  | 45  | 46700| 68  | 20  | 95  | (Turekian and Wedepohl, 1961)  |

nd: not detected.
Table 4. Pearson correlation coefficients for elements in sediment and water in Aguada Blanca Reservoir, Peru.

| Elements / matrix | As_S | As_W | Cr_S | Cr_W | Cd_S | Cd_W | Pb_S | Pb_W | Sn_W | Sn_W | Ni_S | Ni_W | Cu_S | Cu_W | Zn_S | Zn_W | Fe_S | Fe_W |
|-------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| As_S              | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| As_W              | -0.572 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Cr_S              | 0.845** | -0.598 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Cr_W              | 0.256 | -0.366 | 0.728* | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Cd_S              | -0.498 | 0.466 | -0.414 | -0.156 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Cd_W              | 0.073 | -0.316 | 0.504 | 0.786* | 0.133 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |
| Pb_S              | 0.864** | -0.522 | 0.734* | 0.181 | -0.112 | 0.225 | 1    |      |      |      |      |      |      |      |      |      |      |      |
| Pb_W              | -0.425 | -0.151 | -0.002 | 0.513 | 0.37 | 0.725* | -0.217 | 1    |      |      |      |      |      |      |      |      |      |
| Sn_S              | 0.344 | -0.141 | 0.663 | 0.741* | 0.348 | 0.604 | 0.464 | 0.364 | 1    |      |      |      |      |      |      |      |      |
| Sn_W              | -0.379 | 0.184 | -0.172 | 0.227 | 0.447 | 0.196 | -0.272 | 0.438 | 0.300 | 1    |      |      |      |      |      |      |      |
| Ni_S              | 0.945** | -0.654 | 0.968* | 0.541 | -0.5 | 0.339 | 0.826** | -0.177 | 0.512 | -0.312 | 1    |      |      |      |      |      |      |
| Ni_W              | -0.522 | 0.175 | -0.411 | -0.126 | 0.915** | 0.196 | -0.104 | 0.569 | 0.269 | 0.401 | -0.482 | 1    |      |      |      |      |      |
| Cu_S              | 0.889** | -0.606 | 0.854* | 0.372 | -0.255 | 0.381 | 0.969** | -0.123 | 0.502 | -0.294 | 0.915** | -0.227 | 1    |      |      |      |      |
| Cu_W              | -0.403 | -0.283 | -0.408 | -0.168 | -0.32 | -0.334 | -0.556 | 0.141 | -0.559 | 0.147 | -0.382 | -0.049 | -0.525 | 1    |      |      |      |
| Zn_S              | 0.968** | -0.661 | 0.799* | 0.194 | -0.528 | 0.111 | 0.894** | -0.374 | 0.231 | -0.481 | 0.922** | -0.485 | 0.924** | -0.34 | 1    |      |      |
| Zn_W              | -0.261 | 0.55 | -0.254 | -0.181 | 0.143 | -0.236 | -0.085 | -0.11 | -0.077 | 0.124 | -0.262 | 0.033 | -0.13 | -0.114 | -0.233 | 1    |      |
| Fe_S              | 0.700* | -0.508 | 0.837* | 0.591 | 0.106 | 0.577 | 0.842** | 0.179 | 0.839** | 0.042 | 0.796* | 0.11 | 0.866** | -0.578 | 0.666 | -0.233 | 1    |
| Fe_W              | 0.355 | -0.383 | 0.779* | 0.932* | 0.007 | 0.873** | 0.401 | 0.498 | 0.833** | 0.075 | 0.617 | 0.022 | 0.556 | -0.42 | 0.325 | -0.226 | 0.767* | 1    |

S: Sediment, W: Water.
**. The correlation is significant at the 0.01 level (bilateral); *. The correlation is significant at the 0.05 level (bilateral).

3.2.2. Geoaccumulation index evaluation (I_{geo})

I_{geo} values were calculated to determine contamination in the sediments of Aguada Blanca Reservoir. The results are shown in Table 5, where the Cd value (1.21 ± 1.45) presents values greater than 0 (I_{geo} > 0), and presented a degree of contamination from moderately to heavily contaminated, while As (-0.78 ± 0.69), Pb (-0.98 ± 0.62), Cu (-1.05 ± 0.64), Zn (-1.71 ± 0.47) and Cr (-4.18 ± 0.40) do not present contamination for the reservoir. The high EF and I_{geo} of Cd would be a risk in the reservoir in relation to other evaluated elements, and compared to other studies, our Cd I_{geo} would be slightly higher (Abata, 2013; Ekengele et al., 2017; Li et al., 2018; Marziali et al., 2017; Zhang et al., 2017) and less equal to studies where the concentration of Cd is described as a strong anthropogenic effect (Cáceres Choque et al., 2013; Çevik et al., 2009; Li, 2014; Nowrouzi and Pour Khabbaz, 2014).
3.2.3. Ecological risk index

Table 5 shows the RI values of the sediment samples, and they present the following order of risk: Cd > Cu > Pb > Zn > Cr. The RI value of Points SA3, SA4, and SA8 were less than 150, indicating that these points present a low ecological risk (<150). While Points SA1, SA2, SA5, SA6, SA7, and SA9 presented values higher than 600, which means a high ecological risk due to the presence of heavy metals (see Table 5). The ER value of Cd is the one that most contributes to the ecological risk of the water body; an element that is characterized by increasing the risk in different investigations (Li, 2014; Mohamaden et al., 2017).

3.3. Spatial distribution of metals

The Aguada Blanca Reservoir presents the highest concentrations of As, Sb, Cu, Ni, Zn, Fe, Cr and Pb in the narrow zone of the reservoir (dam - water outlet) and middle zone (Figure 2), zones characterized by greater depths and where the accumulation of sediments is greater. Therefore, there is a higher concentration of heavy metals (Colman et al., 2011). High concentrations of heavy metals would be the result of deposition and low water flow velocities and where fine particles act as sinks (Palanques et al., 2014). Figure 2 shows the spatial distribution of Cd, As, Pb, Cu, Ni, Zn, Cu, Fe and Sb along the Aguada Blanca Reservoir. According to the maps in Figure 2, it is observed that most of the elements present an increase in their concentrations as they approach the narrow zone of the reservoir (dam - water outlet) and the middle zone of the reservoir, with the exception of Cd, which does not present uniformity in its distribution.

![Figure 2. Spatial distribution of heavy metals in sediments of Aguada Blanca Reservoir, Peru.](image-url)
### Table 5. EF, Igeo, RE and RI values in Aguada Blanca Reservoir.

| Points | As  | Cr  | Cd  | Pb  | Ni | Cu  | Zn  | As  | Cr  | Cd  | Pb  | Ni | Cu  | Zn  | Cd  | Cu  | Pb  | Zn  | Cr  |
|--------|-----|-----|-----|-----|----|-----|-----|-----|-----|-----|-----|----|-----|-----|-----|-----|-----|-----|-----|
| SA1    | 3.7 | 0.29| 12.76| 2.68 | 0.41| 2.51| 2.02 | 0.08| -3.61| 1.87| -0.39| -3.08| -0.48| -1.28| 586 | 10.08| 4.45| 0.93| 0.33| 601.5|
| SA2    | 2.72| 0.3 | 12.11| 2.39 | 0.4 | 2.64| 1.87 | -0.89| -4.38| 2.49| -0.72| -3.95| -0.93| -1.72| 904 | 7.4 | 3.52| 0.68| 0.2 | 915.4|
| SA3    | 2.67| 0.24| 27.92| 3.01 | 0.32| 2.61| 2.1 | 0   | -3.96| -0.45| -0.53| -3.33| -0.61| -1.21| 118 | 9.23| 4.02| 0.97| 0.26| 132.3|
| SA4    | 2.4 | 0.25| 27.85| 2.85 | 0.32| 2.55| 2.16| -0.09| -3.95| -0.4 | -0.56| -3.3 | -0.59| -1.18| 121 | 9.31| 3.96| 0.99| 0.26| 136   |
| SA5    | 2.8 | 0.29| 29.82| 3.37 | 0.36| 2.99| 2.3 | -0.5 | -3.66| 1.66 | -0.68| -3.27| -0.54| -1.52| 507 | 9.67| 3.63| 0.78| 0.32| 521.5 |
| SA6    | 2.44| 0.33| 46.32| 2.11 | 0.33| 1.76| 2.07| -1.25| -4.51| 2.29 | -1 | -4.15| -1.16| -1.88| 786 | 6.29| 2.91| 0.61| 0.18| 795.7 |
| SA7    | 5.27| 0.34| 3.87 | 3.65 | 0.52| 3.46| 3.17| -1.15| -4.44| 2.26 | -0.88| -4.1 | -1.05| -1.92| 771 | 6.77| 3.16| 0.59| 0.19| 782.1 |
| SA8    | 5.25| 0.36| 4.23 | 3.81 | 0.57| 3.71| 3.46| -1.29| -4.29| -1.17| -1.92| -3.97| -1.74| -2.02| 50  | 4.21| 1.54| 0.55| 0.21| 56.51 |
| SA9    | 3.85| 0.48| 4.17 | 2.48 | 0.6 | 2.81| 3.23| -1.91| -4.78| 2.34 | -2.12| -4.79| -2.38| -2.62| 814 | 2.71| 1.34| 0.36| 0.15| 818.9 |
| Min    | 2.4 | 0.24| 3.87 | 2.11 | 0.32| 1.76| 1.87| -1.91| -4.78| -1.17| -2.12| -4.79| -2.38| -2.62| 50  | 2.71| 1.34| 0.36| 0.15| 56.51 |
| Max    | 5.27| 0.48| 46.32| 3.81 | 0.6 | 3.71| 3.46| 0.08 | -3.61| 2.49 | -0.39| -3.08| -0.48| -1.18| 904 | 10.08| 4.45| 0.99| 0.33| 915.4 |
| Mean   | 3.46| 0.32| 18.78| 2.93 | 0.43| 2.78| 2.49| -0.78| -4.18| 1.21 | -0.98| -3.77| -1.05| -1.71| 517 | 7.3 | 3.17| 0.72| 0.23| 528.9 |
| SD     | 1.14| 0.07| 14.89| 0.58 | 0.11| 0.57| 0.62| 0.69 | 0.4  | 1.45 | 0.62| 0.56 | 0.64 | 0.47 | 338 | 2.57| 1.08| 0.22| 0.06| 337.1 |
4. CONCLUSIONS

Sediment quality often reflects the current state of aquatic systems. This study used sediment quality indices to characterize the status of the Aguada Blanca Reservoir in relation to heavy metal concentrations.

According to the quality indices, the reservoir sediments are enriched by Cd, As and Pb, which present concentrations higher than background concentrations and the highest concentrations are distributed in the deeper areas of the reservoir. The high EF and $I_{geo}$ values in Cd would make it a promoter of ecological risks for the aquatic system, if appropriate conditions are given for its availability and mobilization within the system, conditions that would not be currently present due to the low concentration of Cd in the water ($0.08 \pm 0.07 \mu g L^{-1}$). As concentrations exceed Peruvian regulations and present high values in relation to other aquatic systems.

The results of this study underline that it is important to carry out further studies on the dynamics of mobilization of Cd and As to determine the possible risks to water quality under environmental and hydrological changes.

5. ACKNOWLEDGMENTS

The authors wish to thank Universidad Nacional de San Agustin de Arequipa. This research was funded by Universidad Nacional de San Agustin de Arequipa. Financing Contract N° TIM-002-2018-UNSA.

6. REFERENCES

ABATA E. O. Assessment of Heavy Metal Contamination and Sediment Quality in the Urban River: A Case Of Ala River in Southwestern – Nigeria. IOSR Journal of Applied Chemistry, v. 4, n. 3, p. 56–63, 2013. https://doi.org/10.9790/5736-0435663

ACEVEDO-FIGUEROA, D.; JIMÉNEZ, B. D.; RODRÍGUEZ-SIERRA, C. J. Trace metals in sediments of two estuarine lagoons from Puerto Rico. Environmental Pollution, v. 141, n. 2, p. 336–342, 2006. https://doi.org/10.1016/j.envpol.2005.08.037

ADENIYI, A. A. et al. Monitoring metals pollution using water and sediments collected from Ebute Ogbo river catchments, Ojo, Lagos, Nigeria. African Journal of Pure and Applied Chemistry, v. 5, n. 8, p. 219-223, 2011.

ANA (Perú). Plan de aprovechamiento de la disponibilidad hídrica en el ámbito del consejo de recursos hídricos de la cuenca Quilca - Chili 2016 - 2017. Lima, 2016. p. 145. https://hdl.handle.net/20.500.12543/4430

APHA; AWWA; WEF. Standard Methods for the Examination of Water and Wastewater. 21. ed. Washington, 2005.

ASTM INTERNATIONAL. ASTM D 2974 - Standard test methods for moisture, ash, and organic matter of peat and other organic soils. West Conshohocken, 2014. p. 1–4.

AVILA-PÉREZ, P.; BALCÁZAR, M.; ZARAZÚA-ORTEGA, G.; BARCELO-QUINTAL, I.; DÍAZ-DELGADO, C. Heavy metal concentrations in water and bottom sediments of a Mexican reservoir. Science of the Total Environment, v. 234, n. 1–3, p. 185–196, 1999. https://doi.org/10.1016/S0048-9697(99)00258-2
BARBIERI, M. The Importance of Enrichment Factor (EF) and Geoaccumulation Index (Igeo) to Evaluate the Soil Contamination. *Journal of Geology & Geophysics*, v. 5, n. 1, p. 1–4, 2016. https://doi.org/10.4172/2381-8719.1000237

CÁCERES CHOQUE, L. F.; RAMOS RAMOS, O. E.; VALDEZ CASTRO, S. N.; CHOQUE ASPIAZU, R. R.; CHOQUE MAMANI, R. G.; FERNÁNDEZ ALCAZAR, S. G. *et al.* Fractionation of heavy metals and assessment of contamination of the sediments of Lake Titicaca. *Environmental Monitoring and Assessment*, v. 185, n. 12, p. 9979–9994, 2013. https://doi.org/10.1007/s10661-013-3306-0

CAI, K.; YU, Y.; ZHANG, M.; KIM, K. Concentration, source, and total health risks of cadmium in multiple media in densely populated areas, China. *International Journal of Environmental Research and Public Health*, v. 16, n. 13, 2019. https://doi.org/10.3390/ijerph16132269

CAVANAGH, N.; NORDIN, R. N.; SWAIN, L. G.; POMMEN, L. W. *Lake and Stream Bottom Sediment Sampling Manual*. Vancouver: BC, [1997].

CCME. *Protocols Manual for Water Quality Sampling in Canada*. Winnipeg – Manitoba, 2011.

ÇEVİK, F.; GÖKSU, M. Z. L.; DERICI, O. B.; FINDIK, Ö. An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. *Environmental Monitoring and Assessment*, v. 152, n. 1–4, p. 309–317, 2009. https://doi.org/10.1007/s10661-008-0317-3

COLMAN, J. A.; MASSEY, A. J.; LEVIN, S. B. *Determination of Dilution Factors for Discharge of Aluminum-Containing Wastes by Public Water-Supply Treatment Facilities into Lakes and Reservoirs in Massachusetts*. Northborough: U.S. Geological Survey, 2011. (Scientific Investigations Report 2011–5136).

CUSTODIO, M.; FOW, A.; CHANAMÉ, F.; ORELLANA-MENDOZA, E.; PEÑALOZA, R.; ALVARADO, J. C. *et al.* Ecological Risk Due to Heavy Metal Contamination in Sediment and Water of Natural Wetlands with Tourist Influence in the Central Region of Peru. *Water*, v. 13, n. 16, 2021. https://doi.org/10.3390/w13162256

DECENA, S. C. P.; ARGUELLES, M. S.; ROBEL, L. L. Assessing heavy metal contamination in surface sediments in an urban river in the Philippines. *Polish Journal of Environmental Studies*, v. 27, n. 5, p. 1983–1995, 2018. https://doi.org/10.15244/pjoes/75204

EKENGELE, L. N.; BLAISE, A.; JUNG, M. C. Accumulation of heavy metals in surface sediments of Lere Lake, Chad. *Geosciences Journal*, v. 21, n. 2, p. 305–315, 2017. https://doi.org/10.1007/s12303-016-0047-4

EL-RADAIDEH, N.; AL-TAANI, A. A.; AL KHATEEB, W. M. Characteristics and quality of reservoir sediments, Mujib Dam, Central Jordan, as a case study. *Environmental Monitoring and Assessment*, v. 189, n. 4, 2017. https://doi.org/10.1007/s10661-017-5836-3

HAHN, J.; OPP, C.; EVGRAFOVA, A.; GROLL, M.; ZITZER, N.; LAUFENBERG, G. Impacts of dam draining on the mobility of heavy metals and arsenic in water and basin bottom sediments of three studied dams in Germany. *Science of the Total Environment*, v. 640–641, p. 1072–1081, 2018. https://doi.org/10.1016/j.scitotenv.2018.05.295
HAKANSON, L. An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research*, v. 14, n. 8, p. 975–1001, 1980. https://doi.org/10.1016/0043-1354(80)90143-8

HOU, D.; HE, J.; LÜ, C.; REN, L.; FAN, Q.; WANG, J. *et al.* Distribution characteristics and potential ecological risk assessment of heavy metals (Cu, Pb, Zn, Cd) in water and sediments from Lake Dalineuer, China. *Ecotoxicology and Environmental Safety*, v. 93, p. 135–144, 2013. https://doi.org/10.1016/j.ecoenv.2013.03.012

HUTTON, M. Sources of cadmium in the environment. *Ecotoxicology and Environmental Safety*, v. 7, n. 1, p. 9–24, 1983. https://doi.org/10.1016/0147-6513(83)90044-1

KARADEDE, H.; ÜNLÜ, E. Concentrations of some heavy metals in water, sediment and fish species from the Ataturk Dam Lake (Euphrates), Turkey. *Chemosphere*, v. 41, n. 9, p. 1371–1376, 2000. https://doi.org/10.1016/s0045-6535(99)00563-9

KESHAVARZI, A.; KUMAR, V. Spatial distribution and potential ecological risk assessment of heavy metals in agricultural soils of Northeastern Iran. *Geology, Ecology, and Landscapes*, v. 4, n. 2, 2019. https://doi.org/10.1080/24749508.2019.1587588

KONDOLF, G. M. *et al.* Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. *Earth’s Future*, v. 2, n. 5, p. 256–280, 2014. https://doi.org/10.1002/2013ef000184

LI, F.; XIAO, M.; ZHANG, J.; LIU, C.; QIU, Z.; CAI, Y. Spatial distribution, chemical fraction and fuzzy comprehensive risk assessment of heavy metals in surface sediments from the Honghu lake, China. *International Journal of Environmental Research and Public Health*, v. 15, n. 2, p. 1–17, 2018. https://doi.org/10.3390/ijerph15020207

LI, J. Risk assessment of heavy metals in surface sediments from the Yanghe River, China. *International Journal of Environmental Research and Public Health*, v. 11, n. 12, p. 12441–12453, 2014. https://doi.org/10.3390/ijerph111212441

LI, S.; XU, Z.; CHENG, X.; ZHANG, Q. Dissolved trace elements and heavy metals in the Danjiangkou Reservoir, China. *Environmental Geology*, v. 55, p. 977–983, 2008. https://doi.org/10.1007/s00254-007-1047-5

LI, X.; SHEN, H.; ZHAO, Y.; CAO, W.;HU, C.; SUN, C. Distribution and potential ecological risk of heavy metals in water, sediments, and aquatic macrophytes: A case study of the junction of four rivers in Linyi City, China. *International Journal of Environmental Research and Public Health*, v. 16, n. 16, 2019. https://doi.org/10.3390/ijerph16162861

MARZIALI, L.; TARTARI, G.; SALERNO, F.; VALSECCHI, L.; BRAVI, C.; LORENZI, E. *et al.* Climate change impacts on sediment quality of Subalpine reservoirs: Implications on management. *Water (Switzerland)*, v. 9, n. 9, p. 1–18, 2017. https://doi.org/10.3390/w9090680

MIRANZADEH MAHABADI, H.; RAMROUDI, M.; ASGHIRPOUR, M. R.; RAHMANI, H. R.; AFYUNI, M. Evaluation of the ecological risk index (Er) of heavy metals (HMs) pollution in urban field soils. *SN Applied Sciences*, v. 2, n. 1420, 2020. https://doi.org/10.1007/s42452-020-03219-7

MOHAMADEN, M. I. I.; KHALIL, M. K.; DRAZ, S. E. O.; HAMODA, A. Z. M. Ecological risk assessment and spatial distribution of some heavy metals in surface sediments of New Valley, Western Desert, Egypt. *Egyptian Journal of Aquatic Research*, v. 43, n. 1, p. 31–43, 2017. https://doi.org/10.1016/j.ejar.2016.12.001
NOWROUZI, M.; POURKHABBAZ, A. Application of geoaccumulation index and enrichment factor for assessing metal contamination in the sediments of Hara Biosphere Reserve, Iran. *Chemical Speciation and Bioavailability*, v. 26, n. 2, p. 99–105, 2014. https://doi.org/10.3184/095422914x13951584546986

OLATUNDE, K. A.; AROWOLO, T. A.; BADA, B. S.; TAIWO, A. M.; OJEKUNLE, Z. O. Distribution and enrichment of metals in sediments of the Ogun River within Abeokuta, south-western Nigeria. *African Journal of Aquatic Science*, v. 39, n. 1, p. 17–22, 2014. https://doi.org/10.2989/16085914.2014.882287

PALANQUES, A.; GRIMALT, J.; BELZUNCES, M.; ESTRADA, F.; PUIG, P.; GUILLÉN, J. Massive accumulation of highly polluted sedimentary deposits by river damming. *Science of the Total Environment*, v. 497–498, p. 369–381, 2014. https://doi.org/10.1016/j.scitotenv.2014.07.091

PRIETO, D. M.; MARTÍN-LIÑARES, V.; PIÑEIRO, V.; BARRAL, M. T. Arsenic Transfer from As-Rich Sediments to River Water in the Presence of Biofilms. *Journal of Chemistry*, v. 2016, 2016. https://doi.org/10.1155/2016/6092047

SCHLEISS, A. J.; FRANCA, M. J.; JUEZ, C.; DE CESARE, G. Reservoir sedimentation. *Journal of Hydraulic Research*, v. 54, n. 6, p. 595–614, 2016. https://doi.org/10.1080/00221686.2016.1225320

SUN, Y. Ecological risk evaluation of heavy metal pollution in soil based on simulation. *Polish Journal of Environmental Studies*, v. 26, n. 4, p. 1693–1699, 2017. https://doi.org/10.15244/pjoes/68889

TUREKIAN, K. K.; WEDEPOHL, K. H. Distribution of the elements in some major units of earth’s crust. *Geological Society of America Bulletin*, v. 72, n. 2, p. 175–192, 1961. https://doi.org/10.1130/0016-7606(1961)72[175:DOTEIS]2.0.CO;2

VARGAS, L. Geologia del cuadrangulo de Arequipa. *Boletín Ingemmet*, n. 24, 1970.

VAROL, M. Dissolved heavy metal concentrations of the kralkizi, dicle and batman dam reservoirs in the tigris river basin, turkey. *Chemosphere*, v. 93, n. 6, p. 954–962, 2013. https://doi.org/10.1016/j.chemosphere.2013.05.061

Vrhovnik, P.; Šmuc, N. R.; Dolenc, T.; Serafimovski, T.; Dolenc, M. An evaluation of trace metal distribution and environmental risk in sediments from Lake Kalimanci (FYR Macedonia). *Environmental Earth Sciences*, v. 70, n. 2, p. 761–775, 2013. https://doi.org/10.1007/s12665-012-2166-1

VukoVic, D.; VukoVic, Z.; StankoVic, S. The impact of the Danube Iron Gate Dam on heavy metal storage and sediment flux within the reservoir. *Catena*, v. 113, p. 18–23, 2014. https://doi.org/10.1016/j.catena.2013.07.012

Wang, K.; Xing, B. Mutual effects of cadmium and phosphate on their adsorption and desorption by goethite. *Environmental Pollution*, v. 127, n. 1, p. 13–20, 2004. https://doi.org/10.1016/s0269-7491(03)00262-8

Yahaya, M. I. et al. Seasonal potential toxic metals contents of Yauri river bottom sediments: North western Nigeria. *Journal of Environmental Chemistry and Ecotoxicology*, v. 4, n. October, p. 212–221, 2012. https://doi.org/10.5897/jece11.080
YASARER, L. M. W.; STURM, B. S. M. Potential impacts of climate change on reservoir services and management approaches. *Lake and Reservoir Management*, v. 32, n. 1, p. 13–26, 2016. https://doi.org/10.1080/10402381.2015.1107665.

ZHANG, H.; SELIM, H. Magdi. Competitive sorption-desorption kinetics of arsenate and phosphate in soils. *Soil Science*, v. 173, n. 1, p. 3–12, 2008. https://doi.org/10.1097/ss.0b013e31815ce750

ZHANG, J.; LIU, C. L. Riverine composition and estuarine geochemistry of particulate metals in China - Weathering features, anthropogenic impact and chemical fluxes. *Estuarine, Coastal and Shelf Science*, v. 54, n. 6, p. 1051–1070, 2002. https://doi.org/10.1006/ecss.2001.0879

ZHANG, Y.; LIU, S.; CHENG, F.; COXIXO, A.; HOU, X.; SHEN, Z. *et al.* Spatial Distribution of Metals and Associated Risks in Surface Sediments Along a Typical Urban River Gradient in the Beijing Region. *Archives of Environmental Contamination and Toxicology*, v. 74, n. 1, p. 80–91, 2017. https://doi.org/10.1007/s00244-017-0462-1