Migration Letters
Volume: 20, No: S9(2023), pp. 612-628
ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)
www.migrationletters.com

Heavy Metal Risks in Water and Reduction Strategies for the Pelileo - Ambato Irrigation Canal, Ecuador

Belén Vilcacundo[1], María Vallejo[2], Luis Villacís[3], Edgar Vilcacundo[4*]

Abstract
The Pelileo-Ambato irrigation canal, located in Tungurahua province, is supplied by the Ambato River and serves as a source of water for Pelileo canton communities engaged in agricultural activities. However, analysis revealed that the water from the irrigation canal is contaminated with copper, cadmium, and lead with concentrations that exceed the acceptable levels established in the Water Quality Standard Ministerial Agreement No. 097-A created by the Ministry of Environment of Ecuador. This study aims to identify potential sources of contamination and associated risks to the environment and communities utilizing the waterway. The study also proposes effective prevention and mitigation strategies to minimize these risks. Our findings reveal that 24 industries operating near the canal are significant sources of contamination, and community members face a variety of health risks from gastrointestinal diseases to cancer as a result of exposure. Mitigation strategies such as Phytoremediation and Rhizofiltration, along with prevention efforts involving the community, authorities, farmers, and textile industries, are recommended based on the available evidence.

Keywords: *heavy metals, irrigation canal, risk, prevention and management, water contamination, textiles industry, Pelileo.*

1. Introduction

For many rural communities around the world, self-managed irrigation systems are the basis for access to water for agricultural activities as well as a variety of other uses (Hoogesteger et al., 2023). In Ecuador, it is estimated that 5,470,000 hectares of land are under irrigation, most of which are located in the Sierra region and are managed by irrigation farmers. (AQUASTAT - FAO's Global Information System on Water and Agriculture, 2021). Most of the irrigation systems are small-scale and cover an area that, in the mountainous regions, generally does not exceed a few hundred hectares. (Hoogesteger, 2012).

This is the case of the Pelileo-Ambato irrigation canal. The canal was built to provide the surrounding communities of the Pelileo canton with water for both agricultural needs and human consumption. This essential resource has been adversely affected by heavy metal pollution, especially Cd, Cu and Pb, resulting from the same agricultural activities, through the use of fertilizers, and from the textile industries, the latter especially prominent in the Tambo area of the municipality of Pelileo. These two

[1] Programa de Maestría en Prevención y Gestión del Riesgo, Universidad Estatal de Bolívar, Guaranda Ecuador
[2] Programa de Maestría en Prevención y Gestión del Riesgo, Universidad Estatal de Bolívar, Guaranda Ecuador
[3] Programa de Maestría en Prevención y Gestión del Riesgo, Universidad Estatal de Bolívar, Guaranda Ecuador
[4] Programa de Maestría en Prevención y Gestión del Riesgo, Universidad Estatal de Bolívar, Guaranda Ecuador, mvilcacundo@ueb.edu.ec

activities are the main drivers of the local economy. (Cárdenas, 2019; Vallejo Villacís, 2019).

Heavy metals in general have a high density. When they are present in minimal amounts, they are important in biological processes (Afolabi et al., 2022). However, if their concentrations in drinking water and food exceed the permissible limits, they can affect the body due to their toxic nature, their potential for bioaccumulation, their resistance to the body's own cleansing mechanisms, and their alteration of intracellular chemical reactions. (Briffa et al., 2020).

The purpose of the study is to evaluate the risks posed by water contamination in the Pelileo-Ambato irrigation canal, in order to understand in detail, the magnitude of the problem and, from there, to establish reduction strategies based on the data provided by previous research in comparison with the values of acceptable concentration levels according to the Water Quality Standard Ministerial Agreement No. 097-A of Ecuador. The risks to human health and the environment will be evaluated. Based on this, the risks to human health and the environment are assessed, which allows us to understand the current and future consequences of the contamination, as well as to support decision-making regarding this problem. Finally, effective risk management and prevention measures will be proposed to ensure water quality to minimize risks, protect the health of the local population and ensure environmental sustainability. This research aims to provide relevant information to decision makers, water resource managers and farmers, thus contributing to the protection of the environment and the health of the community.

2. Review of literature

2.1 Heavy metals

Heavy metals are characterized as metallic elements with a high density (greater than 4 g/cm3), an atomic mass greater than twenty (20), and a high degree of toxicity, even in trace amounts. Examples include Copper (Cu), Zinc (Zn), Chrome (Cr), Lead (Pb), Iron (Fe), Cobalt (Co), Nickel (Ni), Manganese (Mn), and more. (Liang et al., 2011). These, in turn, are the most common contaminants found in wastewater and are widely distributed, so they are commonly found in water, soil, and solid waste (Yu, Jiang, et al., 2023). Although some of these metals are essential for important biological functions such as hormone production, enzyme function, cell maintenance, and metabolism because they act as micronutrients, they are minimally required by humans because exceeding the limits becomes a health hazard and a threat to the ecosystem (Zamora-Ledezma et al., 2021). This has been demonstrated for cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn) (Sherameti & Varma, 2010).

There are two types of sources of heavy metals: natural sources and anthropogenic sources (Afolabi et al., 2022). Natural sources include emissions of particulate matter into the atmosphere from volcanic activity, airborne transport of continental particles, and the gradual decomposition of metal-rich rocks through weathering. There are rock formations, such as shale and serpentine, that contain heavy metals that are released into soil and water through natural weathering processes (Naveed et al., 2023). Anthropogenic activities include wastewater discharges, agricultural waste disposal (pesticides and fertilizers), mining operations, and industrial waste releases (Burakov et al., 2018; Chen Jiaping Paul, 2013). Another source of soil contamination is the release of metals from heavy road transport, which may contain elements such as lead, cadmium, zinc and nickel, as they are used as additives in fuels to prevent them from exploding (Masindi & Muedi, 2018).

Pollution caused by non-biodegradable toxic heavy metals has emerged as one of the most significant global environmental problems. The need for responsible management of metal waste has increased significantly over the last two decades. This trend is mainly due to the following reasons (Chamani et al., 2023):

1. There has been a growing demand for metals in various applications.
2. An increasing number of studies have shown that the presence of heavy metals in drinking water, in food and in the air is associated with serious health problems.
3. The quest for a better quality of life has become an increasing priority.

It is of importance to note that, unlike most organic pollutants, heavy metals cannot be biologically degraded for removal and transformation into harmless end products. Instead, they tend to accumulate in living organisms over time. (Sánchez-Castro et al., 2023). Over time and with repeated exposure, heavy metals can cause damage to the body's nucleic acids, induce mutations, mimic the action of hormones, which can affect the endocrine and reproductive systems, and ultimately increase the risk of cancer (Oginawati et al., 2022).

2.1.1 Cadmium

Unlike other heavy metals, cadmium does not play an essential role in biological systems, which means that it does not provide any benefit to the ecosystem, and instead only adverse effects have been documented (F. Guo et al., 2018). Although the immediate toxicity of cadmium is limited, this metal is known to have a long biological half-life, ranging from 10 to 30 years, depending on the organ and tissue of the organism (Xu et al., 2022).

Cadmium can enter the environment from a variety of sources. These include the refining of metal ores, the use of cadmium-containing pigments, the manufacture of alloys and electronic components, and the presence of cadmium in phosphate fertilizers, detergents, and refined petroleum products. In addition, rechargeable batteries containing nickel-cadmium compounds are another source of cadmium (H. Chen et al., 2018).

The main routes of intake of cadmium into the body are through the diet and by smoking. For nonsmokers, ingestion of cadmium-contaminated food is the major source of exposure (Qi et al., 2020). In addition, foods such as wheat, rice, green leafy vegetables, potatoes, and tubers may also be important contributors to the exposure of humans to this metal (Rahman & Singh, 2019).

2.1.2 Copper

Copper is an essential trace element that is required in biological systems for the activation of certain enzymes during the process of photosynthesis (Sharafi et al., 2019). At higher concentrations, however, it has detrimental effects on the human organism. In addition, copper is toxic to a variety of aquatic organisms, even at extremely low levels (K. Gupta et al., 2021).

Copper is a heavy metal that is widely used in a variety of applications. It is used in batteries, semiconductor devices, electronic chips, cell phones, catalysts, metalworking products, and in the manufacture of piping for water systems (Mao et al., 2023). Releases of copper to the environment can occur both from the mining of copper and other metals and from facilities that produce or use metallic copper or copper compounds. It can enter the human body through three main routes: dust, food and water (Giri & Singh, 2017).

2.1.3 Lead

Lead is a naturally occurring chemical element in the carbon group and is also produced as a heavy metal industrially. This element is considered the oldest known metal due to its high toxicity to humans (Niu et al., 2023). It is utilized in manufacturing batteries, pigments, and printing. Therefore, lead ions may be present in wastewater produced by these facilities, as well as in the context of mining and metal production. (Oginawati et al., 2023). Continued exposure to lead and its absorption by the human body can harm multiple body systems, such as the nervous system, digestive system, and reproductive system (Meng et al., 2020).

Humans are commonly exposed to lead through ingestion, inhalation, percutaneous, and transplacental pathways. Generally, only 5-15% of ingested lead is absorbed in the gastrointestinal tract, with the remaining lead excreted in feces. Additionally, during early embryonic development, lead can easily penetrate both the blood-placental and blood-brain barriers (Zhou et al., 2022).

3 Irrigation canals

In many regions across the globe, the issue of water scarcity and compromised water quality presents a pressing challenge, thereby endangering water resources. (Abioye et al., 2020). Ensuring the availability and adequate supply of freshwater is crucial for socioeconomic development since it directly affects the health and productivity of individuals. The rise of industrial agriculture worldwide has boosted crop productivity, leading to escalated extraction of surface and groundwater for irrigation purposes (F. Chen et al., 2023).

Irrigation canals are essential for transporting, distributing, and supplying water in arid and semi-arid areas for agricultural purposes on farms. They serve as the primary method of water transportation and distribution (Carlson et al., 2019; Fan et al., 2023).

4 Objectives of the study

1. To assess the risk that water contamination with heavy metals poses to the health of local communities that use this water for human consumption or crop irrigation.
2. To analyze the effects of water contamination on nearby aquatic and terrestrial ecosystems, including risks to biodiversity and ecosystem health.
3. To investigate and evaluate available techniques and strategies to prevent and mitigate heavy metal water pollution, including sustainable agricultural practices, wastewater treatment, and remediation methods.
4. To develop specific recommendations to reduce water pollution in irrigation canals, with an emphasis on pesticide management and textile industries.

5 Method

This research is entirely descriptive and relies on primary data obtained from reputable sources, such as government agencies, non-governmental organizations, academic institutions, and research centers.

The graphical representations presented in this study depict information on agriculture, socio-economic strata, and sources of irrigation canal water contamination, all created in the ArcGIS program utilizing the WGS 1984 UTM Zone 17S coordinate system.

6 Results

6.1 Study area

The Pelileo-Ambato Irrigation Canal has a length of 27 kilometers and is located in the province of Tungurahua. The water supply for this canal comes from the Ambato River, at an altitude of 2940 meters above sea level. The canal's main channel and secondary channels transport water from Ambato to Pelileo. Its cross-sectional shape has a trapezoidal profile and a concrete lining. On average, the upper section of the canal has a width of 1.60 meters. (Chávez Cárdenas, 2019; Piedra Manchay, 2019). The canal serves as a vital water source for the region, playing a fundamental role in supporting agricultural activities. Constructed by the State Government, this canal supplies a diverse range of crops such as strawberries, blackberries, tomatoes, apples, potatoes, corn, and alfalfa. These crops not only contribute significantly to the local economy but also enhance the region's food security and biodiversity.

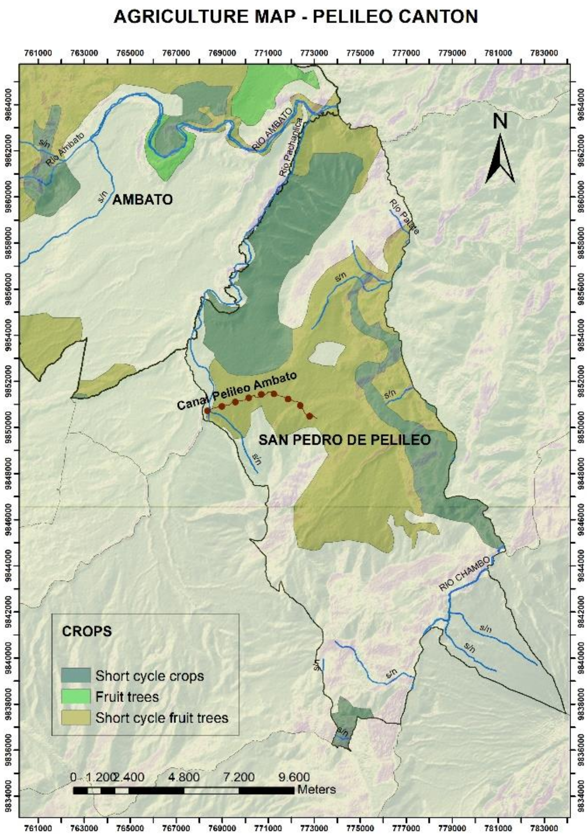

Figure 1. Agriculture Map of Pelileo Canton.

Note: The map displays Pelileo's crop types, with short-cycle trees dominating the area surrounding the irrigation canal.

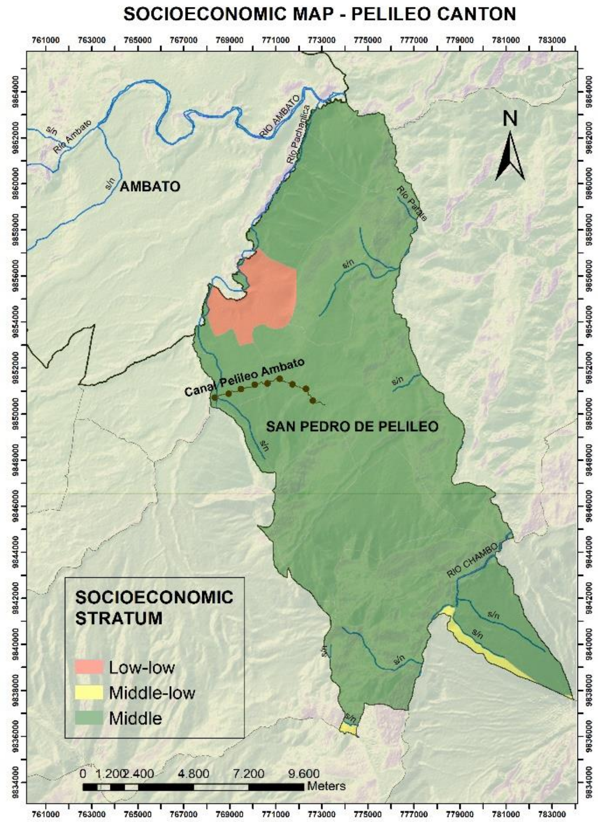

Figure 2. Socioeconomic Map of Pelileo Canton.

Note: This map displays the socioeconomic strata distribution in Pelileo canton, with the middle stratum being the dominant group.

In 2015, the primary sector had the highest share of the economically active population (EAP), followed by the tertiary and secondary sectors. While all three sectors of the economy experienced significant development, the secondary sector experienced notable growth due to the textile industry in Pelileo (Vallejo Villacís, 2019). In the Tambo sector of Pelileo canton, 22 textile industries and two car washers were identified operating in close proximity to an irrigation canal. These industries act as sources of contamination, discharging untreated wastewater and sewage into nearby bodies of water. (Google Maps, n.d.; Vallejo Villacís, 2019).

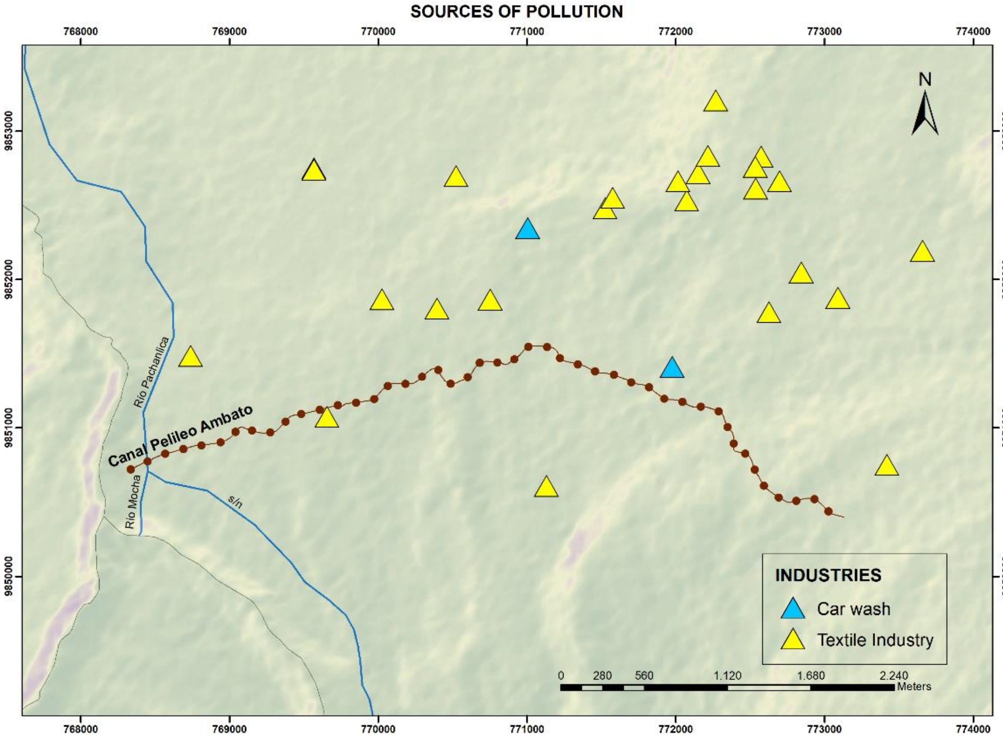

Figure 3. Map of sources of contamination of the Pelileo-Ambato Irrigation Canal

Note: This map indicates the points where the industries that act as a source of contamination of the irrigation canal are located.

6.2 Water quality criteria

The Ecuadorian Ministry of Environment outlines standards for water quality to ensure its appropriateness for agricultural, livestock, and related purposes:

Table 1. Water quality criteria.

Parameter	For agricultural irrigation (mg/l)	For human consumption (mg/l)	For livestock use (mg/l)
Copper	0,5	2	2
Lead	5	0,01	0,05
Cadmium	0,05	0,02	0,05

Note: This table sets forth the permitted amounts of copper, lead, and cadmium for activities (Ministry of Environment of Ecuador, 2015).

6.3 Water análisis

During sampling, the water appeared darker and contained pollutants like soil sediments, animal hair, biological residues, and oil residues. (Chávez Cárdenas, 2019).

The following table presents the amount of total solids present in the water samples:

Table 2. Amount of solids present in water samples.

	Monday (non-industry)		Monday (industry)		Friday (non-industry)		Friday (industry)	
Replica	TSS (%)	Solids present (mg/l)	TSS (%)	Solids present (mg/l)	TSS (%)	Solids present (mg/l)	TSS (%)	Solids present (mg/l)
1	0,55	5524,00	1,02	10210,00	0,39	3870,00	0,86	8586,00
2	0,46	4578,00	1,14	11428,00	0,79	7892,00	1,01	10086,00
3	0,67	6716,00	1,42	14150,00	0,60	5972,00	0,61	6064,00
Average	0,56	5606,00	1,19	11929,33	0,59	5911,33	0,82	8245,33

Note: This table shows the range of total suspended solids (TSS) detected in water samples collected in different places during different time periods (Cárdenas, 2019).

The heavy metal concentrations detected in the water samples are displayed below.

Table 3. Concentration of heavy metals.

	Absorbance	Concentration (mg/l)
Monday (non-industry)	71,85	1,21
Monday (industry)	324,55	5,127
Friday (non-industry)	125,91	2,048
Friday (industry)	217,97	3,475

Note: This table shows the variation of heavy metal concentrations in water samples collected on different days and in different areas (Cárdenas, 2019).

6.4 Risks

Based on the previous findings, a risk assessment was conducted to identify potential hazards to the residents in the area. The table below outlines the potential impacts of total soluble solids and heavy metals (Cd, Pb, and Cu) on both the environment and human health. It is important to note that all information presented is objective and unbiased.

Table 4. Risks of heavy metals Cd, Pb and Cu and presence of total soluble solids.

Parameters	Risks		
	Environment	People	References
Copper	- Removes flora and fauna components.	- Prolonged exposure causes Wilson's	(Ameh & Sayes, 2019;

Parameters	Risks		
	Environment	People	References
	- Causes death or slowing of plant growth. - Causes death or slowing of plant growth. - It affects copper-sensitive animal species such as sheep. - Compromises ecosystem functions - Is absorbed by plants entering the food chain	disease by damaging cells. - Consumption of contaminated food or water causes gastrointestinal diseases. - The immune system is affected by consuming water with high amounts of copper. - In women it affects the ovaries diminishing the quality of the oocytes. - It accumulates in tissues, mainly the liver. - Mucosal irritation - Hemolysis, anemia, jaundice and hemoglobinuria.	Forte et al., 2009; Giri & Singh, 2017; Gupta, 2021; Kumar et al., 2019; Shen et al., 2022; Wang et al., 2023; Yiqin et al., 2022)
Lead	- Is absorbed by plants entering the food chain. - It tends to bioaccumulate in most plant organs: leaves, stems, fruits, roots. - Causes harm to crops during germination and reduces yield during formation. - Delays carbon metabolism in plants.	- Most of the lead ingested accumulates in the kidneys as compared to other organs (heart, liver, brain, etc.). - It displaces other metals and interferes with proteins that control gene expression and alter the nervous system. - It causes headaches, attention problems, irritable behavior, memory loss, among others. - Produces hepatic hyperplasia.	(Ahmad et al., 2011; Akhtar et al., 2022; Begum et al., 2011; Cherfi et al., 2014; Forte et al., 2009; Gonzalez-Martin et al., 2023; X. Guo et al., 2022; A. Gupta, 2021; Meng et al., 2020; O'Connor et al., 2018; Rai et al., 2019; Yu, Xiong, et

Parameters	Risks		
	Environment	People	References
	- It has been investigated that the use of lead had an inhibitory effect on the initial seedling development of crops such as corn, tomato, lettuce and legumes. - It causes a decrease in photosynthesis, stomatal conductance and biomass.	- Decline in intelligence (minus 4.6 IQ points). - Alters blood pressure in hemoglobin biosynthesis and anemia, spontaneous abortion and subtle miscarriage. - Joint discomfort. - It produces affections to the fetus through the placenta. - Decreases fertility in men. - During the gestation period, lead, even in low concentrations, poses a significant risk due to its toxic effects on the fetus, which may include miscarriages, reduced duration of pregnancy and low birth weight in newborns.	al., 2023; Zulfiqar et al., 2019)
Cadmium	- Toxic to animals even in minute quantities - Adheres to plant shoots. - It produces an increase in total chlorophyll content and a decrease in total biomass in the case of tomato.	- Causes DNA damage and affects protein synthesis. - They are substances that can cause cancer in humans, including lung cancer. - It accumulates in the kidneys and liver over time, leading to renal dysfunction. - Even in low concentrations it is the most toxic element. - They act as weak mutagens and are	(Arshad & Martin, 2002; Bandara et al., 2010; Corguinha et al., 2015; Fan et al., 2017; Okhovat & Mousavi, 2012; Ormaza-González et al., 2020)

Parameters	Risks		
	Environment	People	References
		cytotoxic. - It causes osteomalacia - Causes pregnancy loss	
Total Soluble Solids (TSS)	Impacts on biogeochemical processes and biodiversity in floodplains within reservoir systems.	They can carry organic material and microorganisms that affect health by causing diarrhea, nausea, headaches, etc., so the water should not be directly ingested.	(Anjum et al., 2023; W. Chen et al., 2021; Gadd, 2010)

6.5 Pollution reduction strategies

Table 5. Prevention strategies.

Strategy	Technique
Maintenance and cleaning of canals	Regularly clean and maintain the irrigation canal to remove sediment and other accumulated debris.
Implementing good agricultural practices	Promote the adoption of integrated pest management to reduce the use of chemical pesticides by reducing the release of heavy metals in fields.
	Use biological pesticides that are less toxic and are pest specific.
Wastewater treatment and disposal	Implement wastewater treatment systems to remove or reduce heavy metals before releasing the water into the irrigation canal.
	Promote the recycling of treated water in the textile industries.
Education and awareness	Train farmers in the safe and proper use of pesticides to encourage the use of sustainable agricultural practices.
	Educate textile industries on the importance of responsible waste management and adoption of treatment technologies.
Research and continuous monitoring	Encourage research on remediation techniques and specific treatment methods for the elimination of the heavy metals found that are low cost and can be implemented.
	Establish regular monitoring programs where water quality is evaluated from time to time to detect any increase in the levels of heavy metals.

Collaboration between sectors	Government authorities (provincial and cantonal GADs) should implement stricter regulations to supervise pesticide management practices and industrial waste disposal.
	Encourage collaboration and cooperation between textile industries and farmers to find solutions and reduce pollution.

Table 6. Mitigation strategies (Abdullah et al., 2019; Bolisetty et al., 2019; Chinmayee et al., 2012; A. Gupta & Joia, 2016; Naveed et al., 2023; Touceda-González et al., 2017)

Strategy	Technique
Implementation of green barriers	Plant trees and shrubs along the irrigation canal that help act as a natural barrier, filtering and reducing the entry of heavy metals into the water.
Phytoremediation and Rhizofiltration	Use specific aquatic and terrestrial vascular plants capable of absorbing, storing and recycling heavy metals and metalloids (phytoremediation) as well as plant roots to capture surface water pollutants (rhizofiltration) found in the irrigation canal (Pb, Cd, Cu). Examples are Amaranthusspinosus L. and Brassicajuncea.
Phytostabilization	Use plants that reduce the mobility and bioavailability of heavy metals so that they are not transported in the soil.
Application of membrane Technologies	Implementing membrane technologies for removal of suspended solids and organic and inorganic contaminants, such as RO membranes capable of removing Cd and Cu, can be applied in wastewater and other types of water.

7. Conclusions

The Canton of Pelileo has experienced significant growth in the secondary economic sector thanks to the textile industry. Unfortunately, this expansion has resulted in water contamination in the Tambo area, where 22 textile factories and 2 car washes discharge wastewater into water bodies, making them sources of pollution.

Water contamination, particularly by heavy metals, presents significant risks to the water quality of the Pelileo-Ambato irrigation canal and, consequently, to both food safety and public health in the surrounding community. The presence of cadmium, lead, and copper has been identified as impacting both the environment and the health of humans and animals as they enter the food chain.

Copper, for example, can have adverse effects on flora and fauna as well as human health when consumed in high concentrations. Lead, on the other hand, tends to accumulate in various plant organs and can adversely affect germination processes and crop yields, as well as posing a threat to human health with effects ranging from headaches to severe neurological problems and blood pressure. Cadmium, known to be toxic even at low levels, poses a risk to animals and humans because it tends to accumulate in the kidneys and liver, and over time can cause kidney dysfunction and carcinogenesis, including lung cancer in humans.

The proposed reduction strategies for both preventing and mitigating heavy metal risks in the waters of the Pelileo-Ambato Irrigation Canal offer a comprehensive approach. Each strategy addresses specific aspects of the contamination, contributing to the protection of water quality and the health of the local community. This work requires collaboration and action from government entities like the Cantonal GAD, Municipal GAD, Environmental Management Directors, as well as the general public, community leaders, farmers, and the textile industry.

References

Abdullah, N., Yusof, N., Lau, W. J., Jaafar, J., & Ismail, A. F. (2019). Recent trends of heavy metal removal from water/wastewater by membrane technologies. Journal of Industrial and Engineering Chemistry, 76, 17–38. https://doi.org/10.1016/J.JIEC.2019.03.029

Abioye, E. A., Abidin, M. S. Z., Mahmud, M. S. A., Buyamin, S., Ishak, M. H. I., Rahman, M. K. I. A., Otuoze, A. O., Onotu, P., & Ramli, M. S. A. (2020). A review on monitoring and advanced control strategies for precision irrigation. Computers and Electronics in Agriculture, 173. https://doi.org/10.1016/j.compag.2020.105441

Afolabi, T. A., Ejeromedoghene, O., Olorunlana, G. E., Afolabi, T. A., & Alli, Y. A. (2022). A selective and efficient chemosensor for the rapid detection of arsenic ions in aqueous medium. Research on Chemical Intermediates, 48(4), 1747–1761. https://doi.org/10.1007/S11164-022-04665-1/METRICS

Ahmad, M. S. A., Ashraf, M., Tabassam, Q., Hussain, M., & Firdous, H. (2011). Lead (Pb)-induced regulation of growth, photosynthesis, and mineral nutrition in maize (zea mays L.) plants at early growth stages. Biological Trace Element Research, 144(1–3), 1229–1239. https://doi.org/10.1007/S12011-011-9099-5

Akhtar, S., Khan, Z. I., Ahmad, K., Nadeem, M., Ejaz, A., Hussain, M. I., & Ashraf, M. A. (2022). Assessment of lead toxicity in diverse irrigation regimes and potential health implications of agriculturally grown crops in Pakistan. Agricultural Water Management, 271, 107743. https://doi.org/10.1016/J.AGWAT.2022.107743

Ameh, T., & Sayes, C. M. (2019). The potential exposure and hazards of copper nanoparticles: A review. Environmental Toxicology and Pharmacology, 71, 103220. https://doi.org/10.1016/J.ETAP.2019.103220

Anjum, R., Ali, S. A., Siddiqui, M. A., Parvin, F., Khan, Z., Khan, N., Khanam, Z., & Nafees, M. (2023). Hydro-geochemical assessment of ground water for drinking and agricultural purposes and potential human health risk in Aligarh city, India. Chemical Engineering Journal Advances, 16, 100547. https://doi.org/10.1016/J.CEJA.2023.100547

AQUASTAT - FAO’s Global Information System on Water and Agriculture. (2021). https://www.fao.org/aquastat/en/

Arshad, M. A., & Martin, S. (2002). Identifying critical limits for soil quality indicators in agro-ecosystems. Agriculture, Ecosystems and Environment, 88(2), 153–160. https://doi.org/10.1016/S0167-8809(01)00252-3

Bandara, J. M. R. S., Wijewardena, H. V. P., & Seneviratne, H. M. M. S. (2010). Remediation of cadmium contaminated irrigation and drinking water: A large scale approach. Toxicology Letters, 198(1), 89–92. https://doi.org/10.1016/J.TOXLET.2010.04.030

Begum, P., Ikhtiari, R., & Fugetsu, B. (2011). Graphene phytotoxicity in the seedling stage of cabbage, tomato, red spinach, and lettuce. Carbon, 49(12), 3907–3919. https://doi.org/10.1016/J.CARBON.2011.05.029

Bolisetty, S., Peydayesh, M., & Mezzenga, R. (2019). Sustainable technologies for water purification from heavy metals: review and analysis. Chemical Society Reviews, 48(2), 463–487. https://doi.org/10.1039/C8CS00493E

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon, 6(9), e04691. https://doi.org/10.1016/j.heliyon.2020.e04691

Burakov, A. E., Galunin, E. V., Burakova, I. V., Kucherova, A. E., Agarwal, S., Tkachev, A. G., & Gupta, V. K. (2018). Adsorption of heavy metals on conventional and nanostructured materials for wastewater treatment purposes: A review. Ecotoxicology and Environmental Safety, 148, 702–712. https://doi.org/10.1016/J.ECOENV.2017.11.034

Cárdenas, A. B. C. (2019). Evaluation of Heavy Metals in the Ambato - Pelileo Irrigation Canal in Ambato City, Tungurahua Province. 72. files/42/Cárdenas - Se autoriza la reproducción total o parcial, con f.pdf

Carlson, E. A., Cooper, D. J., Merritt, D. M., Kondratieff, B. C., & Waskom, R. M. (2019). Irrigation canals are newly created streams of semi-arid agricultural regions. Science of The Total Environment, 646, 770–781. https://doi.org/10.1016/J.SCITOTENV.2018.07.246

Chamani, S., Mobasheri, L., Rostami, Z., Zare, I., Naghizadeh, A., & Mostafavi, E. (2023). Heavy metals in contact dermatitis: A review. Journal of Trace Elements in Medicine and Biology, 79, 127240. https://doi.org/10.1016/J.JTEMB.2023.127240

Chávez Cárdenas, A. B. (2019). Evaluación de Metales Pesados en el Canal de Riego Ambato-Pelileo e la ciudad de Ambato, Provincia de Tungurahua.

Chen, F., Zhao, H., Roberts, D., Van de Voorde, T., Batelaan, O., Fan, T., & Xu, W. (2023). Mapping center pivot irrigation systems in global arid regions using instance segmentation and analyzing their spatial relationship with freshwater resources. Remote Sensing of Environment, 297, 113760. https://doi.org/10.1016/J.RSE.2023.113760

Chen, H., Yang, X., Wang, P., Wang, Z., Li, M., & Zhao, F. J. (2018). Dietary cadmium intake from rice and vegetables and potential health risk: A case study in Xiangtan, southern China. Science of the Total Environment, 639, 271–277. https://doi.org/10.1016/J.SCITOTENV.2018.05.050

Chen Jiaping Paul. (2013). Decontamination of heavy metals, processes, mechanisms, and applications. CRC Press. files/38/(Advances in industrial and hazardous wastes treatment series) Jiaping Paul Chen - Decontamination of heavy metals _ processes, mechanisms, and applications-CRC Press_Taylor & Francis (2013).pdf

Chen, W., Wang, J., Cao, X., Ran, H., Teng, D., Chen, J., He, X., & Zheng, X. (2021). Possibility of using multiscale normalized difference vegetation index data for the assessment of total suspended solids (TSS) concentrations in surface water: A specific case of scale issues in remote sensing. Environmental Research, 194, 110636. https://doi.org/10.1016/J.ENVRES.2020.110636

Cherfi, A., Abdoun, S., & Gaci, O. (2014). Food survey: Levels and potential health risks of chromium, lead, zinc and copper content in fruits and vegetables consumed in Algeria. Food and Chemical Toxicology, 70, 48–53. https://doi.org/10.1016/J.FCT.2014.04.044

Chinmayee, M. D., Mahesh, B., Pradesh, S., Mini, I., & Swapna, T. S. (2012). The assessment of phytoremediation potential of invasive weed Amaranthus spinosus L. Applied Biochemistry and Biotechnology, 167(6), 1550–1559. https://doi.org/10.1007/S12010-012-9657-0/METRICS

Corguinha, A. P. B., Souza, G. A. de, Gonçalves, V. C., Carvalho, C. de A., Lima, W. E. A. de, Martins, F. A. D., Yamanaka, C. H., Francisco, E. A. B., & Guilherme, L. R. G. (2015). Assessing arsenic, cadmium, and lead contents in major crops in Brazil for food safety purposes. Journal of Food Composition and Analysis, 37, 143–150. https://doi.org/10.1016/J.JFCA.2014.08.004

Fan, Y., Chen, H., Gao, Z., Fan, Y., Chang, X., Yang, M., & Fang, B. (2023). Water distribution and scheduling model of an irrigation canal system. Computers and Electronics in Agriculture, 209, 107866. https://doi.org/10.1016/J.COMPAG.2023.107866

Fan, Y., Zhu, T., Li, M., He, J., & Huang, R. (2017). Heavy Metal Contamination in Soil and Brown Rice and Human Health Risk Assessment near Three Mining Areas in Central China. Journal of Healthcare Engineering, 2017. https://doi.org/10.1155/2017/4124302

Forte, G., Petrucci, F., Cristaudo, A., & Bocca, B. (2009). Market survey on toxic metals contained in tattoo inks. Science of the Total Environment, 407(23), 5997–6002. https://doi.org/10.1016/j.scitotenv.2009.08.034

Gadd, G. M. (2010). Metals, minerals and microbes: Geomicrobiology and bioremediation. Microbiology, 156(3), 609–643. https://doi.org/10.1099/MIC.0.037143-0

Giri, S., & Singh, A. K. (2017). Human health risk assessment due to dietary intake of heavy metals through rice in the mining areas of Singhbhum Copper Belt, India. Environmental Science and Pollution Research, 24(17), 14945–14956. https://doi.org/10.1007/S11356-017-9039-9

Gonzalez-Martin, R., Grau-Perez, M., Sebastian-Leon, P., Diaz-Gimeno, P., Vidal, C., Tellez-Plaza, M., & Dominguez, F. (2023). Association of blood cadmium and lead levels with self-reported reproductive lifespan and pregnancy loss: The national health and nutrition examination survey 1999–2018. Environmental Research, 233, 116514. https://doi.org/10.1016/J.ENVRES.2023.116514

Google Maps. (n.d.). Retrieved September 4, 2023, from https://www.google.com.ec/maps/@-0.1615789,-78.4845747,19z?hl=es&entry=ttu

Guo, F., Ding, C., Zhou, Z., Huang, G., & Wang, X. (2018). Stability of immobilization remediation of several amendments on cadmium contaminated soils as affected by simulated soil acidification. Ecotoxicology and Environmental Safety, 161, 164–172. https://doi.org/10.1016/J.ECOENV.2018.05.088

Guo, X., Jiang, S., Xu, J., Tian, Y., Ouyang, F., Yu, X., Liu, J., Yan, C., & Zhang, J. (2022). Effects of single and combined exposure to lead and stress during pregnancy on offspring neurodevelopment. Developmental Cognitive Neuroscience, 56, 101124. https://doi.org/10.1016/J.DCN.2022.101124

Gupta, A. (2021). Heavy Metal and Metalloid Contamination of Surface and Underground Water; Environmental, Policy, and Ethical Issues (CPR Press, Ed.).

Gupta, A., & Joia, J. (2016). Microbes as Potential Tool for Remediation of Heavy Metals: A Review. Journal of Microbial & Biochemical Technology, 8(4). https://doi.org/10.4172/1948-5948.1000310

Gupta, K., Joshi, P., Gusain, R., & Khatri, O. P. (2021). Recent advances in adsorptive removal of heavy metal and metalloid ions by metal oxide-based nanomaterials. Coordination Chemistry Reviews, 445. https://doi.org/10.1016/J.CCR.2021.214100

Hoogesteger, J. (2012). Trans-Forming Social Capital Around Water: Water User Organizations, Water Rights, and Nongovernmental Organizations in Cangahua, the Ecuadorian Andes. Https://Doi.Org/10.1080/08941920.2012.689933, 26(1), 60–74. https://doi.org/10.1080/08941920.2012.689933

Hoogesteger, J., Bolding, A., Sanchis-Ibor, C., Veldwisch, G. J., Venot, J. P., Vos, J., & Boelens, R. (2023). Communality in farmer managed irrigation systems: Insights from Spain, Ecuador, Cambodia and Mozambique. Agricultural Systems, 204, 103552. https://doi.org/10.1016/J.AGSY.2022.103552

Kumar, V., Sharma, A., Kaur, P., Singh Sidhu, G. P., Bali, A. S., Bhardwaj, R., Thukral, A. K., & Cerda, A. (2019). Pollution assessment of heavy metals in soils of India and ecological risk assessment: A state-of-the-art. Chemosphere, 216, 449–462. https://doi.org/10.1016/J.CHEMOSPHERE.2018.10.066

Liang, N., Yang, L., Dai, J., & Pang, X. (2011). Heavy Metal Pollution in Surface Water of Linglong Gold Mining Area, China. Procedia Environmental Sciences, 10(PART A), 914–917. https://doi.org/10.1016/J.PROENV.2011.09.146

Mao, X., Sun, J., Shaghaleh, H., Jiang, X., Yu, H., Zhai, S., & Hamoud, Y. A. (2023). Environmental Assessment of Soils and Crops Based on Heavy Metal Risk Analysis in Southeastern China. Agronomy, 13(4). https://doi.org/10.3390/AGRONOMY13041107

Masindi, V., & Muedi, K. L. (2018). Environmental Contamination by Heavy Metals. Heavy Metals. https://doi.org/10.5772/INTECHOPEN.76082

Meng, Y., Tang, C., Yu, J., Meng, S., & Zhang, W. (2020). Exposure to lead increases the risk of meningioma and brain cancer: A meta-analysis. Journal of Trace Elements in Medicine and Biology, 60, 126474. https://doi.org/10.1016/J.JTEMB.2020.126474

Ministry of Environment of Ecuador. (2015). Book VI of the Unified Text of Secondary Legislation of the Ministry of Environment: Environmental Quality Standard and Effluent Discharge to Water Resources. https://www.gob.ec/sites/default/files/regulations/2018-09/Documento_Registro-Oficial-No-387-04-noviembre-2015_0.pdf

Naveed, S., Oladoye, P. O., & Alli, Y. A. (2023). Toxic heavy metals: A bibliographic review of risk assessment, toxicity, and phytoremediation technology. Sustainable Chemistry for the Environment, 2, 100018. https://doi.org/10.1016/j.scenv.2023.100018

Niu, C., Dong, M., & Niu, Y. (2023). Lead toxicity and potential therapeutic effect of plant-derived polyphenols. Phytomedicine, 114, 154789. https://doi.org/10.1016/J.PHYMED.2023.154789

O'Connor, D., Hou, D., Ye, J., Zhang, Y., Ok, Y. S., Song, Y., Coulon, F., Peng, T., & Tian, L. (2018). Lead-based paint remains a major public health concern: A critical review of global production, trade, use, exposure, health risk, and implications. Environment International, 121, 85–101. https://doi.org/10.1016/J.ENVINT.2018.08.052

Oginawati, K., Nathanael, R. J., Chazanah, N., Suharyanto, Prabandari, D., Basuki, M. F., Oclandhi, B., Santoso, M., Febriana, S. A., Nugrahaningsih, D. A., Suhartini, S., Prakoeswa, C. R. S., & Tanziha, I. (2023). Occupational lead exposure health risk assessment and heme biosynthesis: A study on batik artisans in yogyakarta, Indonesia. Heliyon, 9(9), e19994. https://doi.org/10.1016/j.heliyon.2023.e19994

Oginawati, K., Suharyanto, Susetyo, S. H., Sulung, G., Muhayatun, Chazanah, N., Dewi Kusumah, S. W., & Fahimah, N. (2022). Investigation of dermal exposure to heavy metals (Cu, Zn, Ni, Al, Fe and Pb) in traditional batik industry workers. Heliyon, 8(2). https://doi.org/10.1016/j.heliyon.2022.e08914

Okhovat, A., & Mousavi, S. M. (2012). Modeling of arsenic, chromium and cadmium removal by nanofiltration process using genetic programming. Applied Soft Computing Journal, 12(2), 793–799. https://doi.org/10.1016/J.ASOC.2011.10.012

Ormaza-González, F. I., Ponce-Villao, G. E., & Pin-Hidalgo, G. M. (2020). Low mercury, cadmium and lead concentrations in tuna products from the eastern Pacific. Heliyon, 6(7). https://doi.org/10.1016/j.heliyon.2020.e04576

Piedra Manchay, D. A. (2019). Hydraulic Study and Characterization from Oval 21 to Oval 27 of the Ambato-Huachi-Pelileo Irrigation Canal, Canton Pelileo, Province of Tungurahua. https://repositorio.uta.edu.ec/jspui/bitstream/123456789/29308/1/Tesis%201300%20-%20Piedra%20Manchay%20Danny%20Alexander.pdf

Qi, H., Zhao, B., Li, L., Chen, X., An, J., & Liu, X. (2020). Heavy metal contamination and ecological risk assessment of the agricultural soil in Shanxi Province, China: Heavy metals in soil in Shanxi of China. Royal Society Open Science, 7(10). https://doi.org/10.1098/RSOS.200538

Rahman, Z., & Singh, V. P. (2019). The relative impact of toxic heavy metals (THMs) (arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. Environmental Monitoring and Assessment, 191(7). https://doi.org/10.1007/S10661-019-7528-7

Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., & Kim, K. H. (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International, 125, 365–385. https://doi.org/10.1016/J.ENVINT.2019.01.067

Sánchez-Castro, I., Molina, L., Prieto-Fernández, M. Á., & Segura, A. (2023). Past, present and future trends in the remediation of heavy-metal contaminated soil - Remediation techniques applied in real soil-contamination events. Heliyon, 9(6), e16692. https://doi.org/10.1016/J.HELIYON.2023.E16692

Sharafi, K., Yunesian, M., Nodehi, R. N., Hossein Mahvi, A., Pirsaheb, M., & Nazmara, S. (2019). The reduction of toxic metals of various rice types by different preparation and cooking processes – Human health risk assessment in Tehran households, Iran. Food Chemistry, 280, 294–302. https://doi.org/10.1016/j.foodchem.2018.12.060

Shen, X., Dai, M., Yang, J., Sun, L., Tan, X., Peng, C., Ali, I., & Naz, I. (2022). A critical review on the phytoremediation of heavy metals from environment: Performance and challenges. Chemosphere, 291. https://doi.org/10.1016/J.CHEMOSPHERE.2021.132979

Sherameti, I., & Varma, A. (2010). Soil Heavy Metals (Soil Biology).

Touceda-González, M., Álvarez-López, V., Prieto-Fernández, Rodríguez-Garrido, B., Trasar-Cepeda, C., Mench, M., Puschenreiter, M., Quintela-Sabarís, C., Macías-García, F., & Kidd, P. S. (2017). Aided phytostabilisation reduces metal toxicity, improves soil fertility and enhances microbial activity in Cu-rich mine tailings. Journal of Environmental Management, 186, 301–313. https://doi.org/10.1016/J.JENVMAN.2016.09.019

Vallejo Villacis, E. (2019). Pelileo Canton Territorial Management Plan. Gobierno Autónomo Descentralizadodel Cantón San Pedro de Pelileo.

Wang, L., Hu, C., Wang, B., Wang, H., Wang, C., Shu, Y., Gao, C., & Yan, Y. (2023). Chronic environmentally relevant concentration of copper exposure induces intestinal oxidative stress, inflammation, and microbiota disturbance in freshwater grouper (Acrossocheilus fasciatus). Aquatic Toxicology, 263, 106702. https://doi.org/10.1016/J.AQUATOX.2023.106702

Xu, J., Hu, C., Wang, M., Zhao, Z., Zhao, X., Cao, L., Lu, Y., & Cai, X. (2022). Changeable effects of coexisting heavy metals on transfer of cadmium from soils to wheat grains. Journal of Hazardous Materials, 423. https://doi.org/10.1016/J.JHAZMAT.2021.127182

Yiqin, C., Yan, S., Peiwen, W., Yiwei, G., Qi, W., Qian, X., Panglin, W., Sunjie, Y., & Wenxiang, W. (2022). Copper exposure disrupts ovarian steroidogenesis in human ovarian granulosa cells via the FSHR/CYP19A1 pathway and alters methylation patterns on the SF-1 gene promoter. Toxicology Letters, 356, 11–20. https://doi.org/10.1016/J.TOXLET.2021.12.002

Yu, X., Jiang, N., Yang, Y., Liu, H., Gao, X., & Cheng, L. (2023). Heavy metals remediation through bio-solidification: Potential application in environmental geotechnics. Ecotoxicology and Environmental Safety, 263, 115305. https://doi.org/10.1016/J.ECOENV.2023.115305

Yu, X., Xiong, L., Zhao, S., Li, Z., Xiang, S., Cao, Y., Zhou, C., Dong, J., & Qiu, J. (2023). Effect of lead, calcium, iron, zinc, copper and magnesium on anemia in children with BLLs ≥ 100 μg/L. Journal of Trace Elements in Medicine and Biology, 78, 127192. https://doi.org/10.1016/J.JTEMB.2023.127192

Zamora-Ledezma, C., Negrete-Bolagay, D., Figueroa, F., Zamora-Ledezma, E., Ni, M., Alexis, F., & Guerrero, V. H. (2021). Heavy metal water pollution: A fresh look about hazards, novel and conventional remediation methods. Environmental Technology & Innovation, 22, 101504. https://doi.org/10.1016/j.eti.2021.101504

Zhou, C. C., Wang, X. J., Li, Z. C., Lu, W. J., Zhang, Y. T., Shen, F. M., & Li, D. J. (2022). Lead Exposure in Developmental Ages Promotes Aβ Accumulation by Disturbing Aβ Transportation in Blood-Cerebrospinal Fluid Barrier/Blood–Brain Barriers and Impairing Aβ Clearance in the Liver. Biological Trace Element Research, 200(8), 3702–3711. https://doi.org/10.1007/S12011-021-02969-8/METRICS

Zulfiqar, U., Farooq, M., Hussain, S., Maqsood, M., Hussain, M., Ishfaq, M., Ahmad, M., & Anjum, M. Z. (2019). Lead toxicity in plants: Impacts and remediation. Journal of Environmental Management, 250, 109557. https://doi.org/10.1016/J.JENVMAN.2019.109557