Heavy Metal Contamination Chan Thnal Reservoir

Subjects: Environmental Sciences
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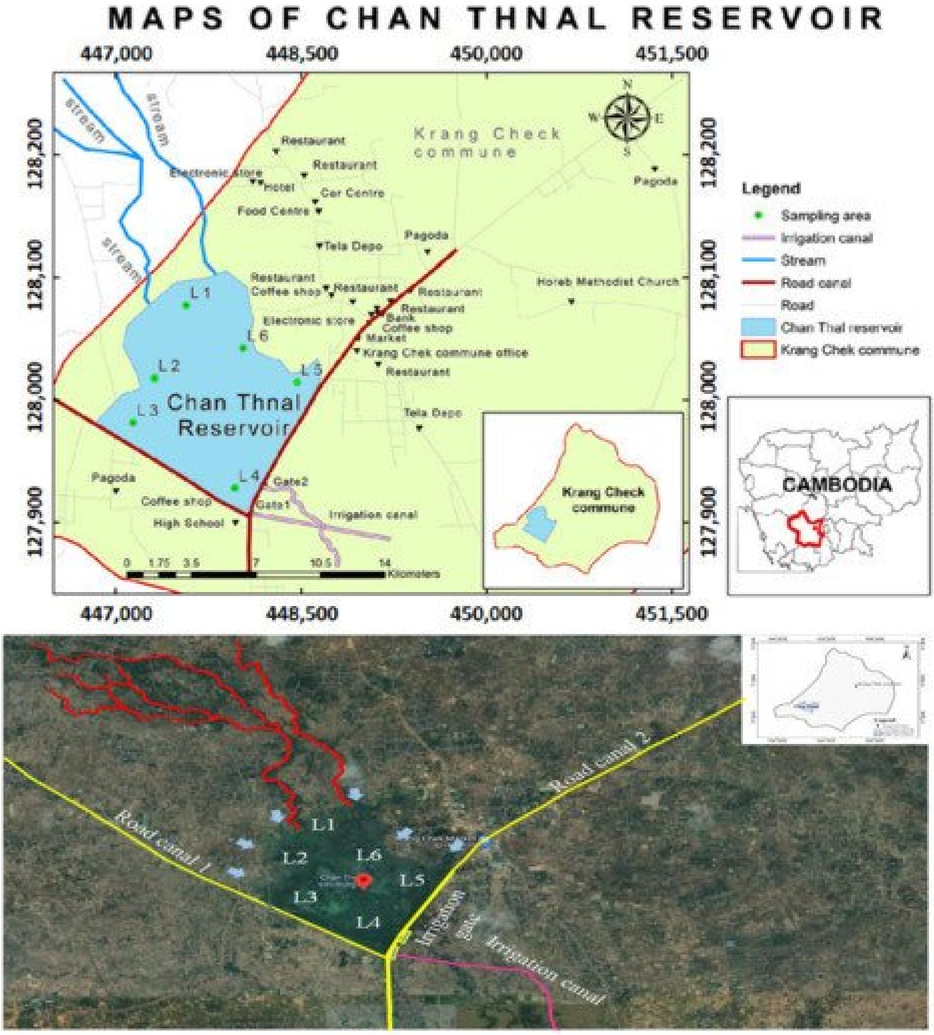
Chan Thnal reservoir, built during the Pol Pot period, is the major water source for the people in Krang Chek commune, Kampong Speu Province, Cambodia. Metal pollution caused by agricultural activities, improper wastewater treatment, and municipal waste disposal poses serious environmental health problems.

heavy metals pollution ecological risk health risk assessment

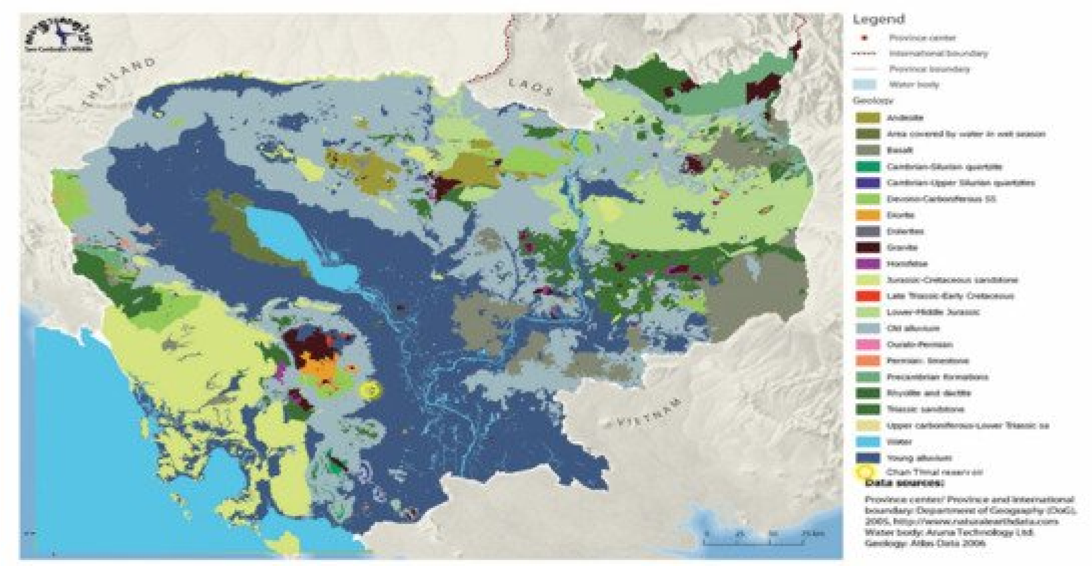
1. Introduction

Rapid growth in the industrial and agricultural sectors is one of the main contributors to environmental deterioration. Environmental pollutants from both anthropogenic and natural sources enter the environment through various processes and cause serious threats to the ecosystem and human health. Heavy metals are a group of environmental pollutants that are potentially toxic, persistent, nondegradable, and able to bioaccumulate [1][2]. Heavy metals enter the environment through several processes such as soil erosion of metal ions and leaching of heavy metals, metal corrosion, sediment resuspension, and atmospheric deposition. Their natural sources are dominated by parent rocks and metal-bearing minerals. The weathering of metal-bearing rocks and volcanic eruptions are significant processes contributing to heavy metal pollution. The major anthropogenic sources are industrial and metallurgical activities, agricultural activities, transportation, wastewater discharge, and waste disposal [3]. Like many other heavy metals, cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) can cause a combination of environmental and health problems. Major sources of these metals in agricultural applications are, for example, fertilizers, pesticides, and livestock manures [4]. Cu and Zn are biochemically classified as essential elements. However, they can be toxic to biota at certain threshold concentrations [4]. Cd and Pb are nonessential metals and are naturally toxic even at low concentrations. Cd is a naturally occurring environmental pollutant derived from both industrial and agricultural sources [5]. One of the major causes of Cd released into the environment is from excessive application of pesticides and phosphate fertilizers [6][7]. Chronic exposure to Cd can invariably cause health problems such as stress, hypertension, kidney dysfunction, proliferative lesions of the prostate, bone fractures, and lung cancer [5][8]. Major contributing sources of Pb in the environment are natural and anthropogenic activities. Much of it comes from burning fuel, production of batteries, ammunition, metal products, and pigment-related manufacturing [9]. Moderate exposure to Pb can significantly impair human reproductive function such as a decrease in human semen quality [1][10]. Concerning the vulnerable groups, i.e., pregnant women, infants, and children under the age of four, excessive intake of lead can cause long-term health problems associated with children's behaviors, growth, and development of their hearing and learning abilities. In adults, lead poisoning impairs the stomach, kidneys, brain, and nervous system [11]. Among other heavy metals, Cu and Zn are classified as essential elements. Apart from being used in electrical systems, copper compounds are used in agriculture as fungicides, algaecides, and feed additives while Zn uses vary such as in fertilizers, batteries, medical drugs, and household applications. Major contributions of Zn and Cu contamination in the surface waters are both point and nonpoint sources. For the Chan Thnal reservoir, the possible sources of Cu and Zn contamination in the environment are improper disposal of household waste and wastewater, direct use of pesticides on paddy soils, burning of coal, or waste-burning operations. Their toxic effects on humans are relatively less than those of other nonessential metals [12]. Adults typically need 2 to 3 mg of Cu and 12 to 14 mg of Zn daily. Exposure to Cu above certain levels may lead to liver and kidney dysfunctions. The provisional tolerable weekly intake (PTWI) value of Cu is 3500 µg/kg body weight/week [13][14]. The oral reference dose (RfD) of Zn is 300 µg/kg body weight/day [13][15]. Effects of Zn toxicity can be diverse. Excess intake of Zn over the destroying capacity of the body can interfere with metabolic processes and stress development [16]. Indications of Zn overexposure are a combination of gastrointestinal effects and pancreatitis [17].

The Chan Thnal reservoir located in Cambodia was built in 1976 during the Pol Pot period. Rainwater is the main water source of this reservoir. With a capacity of approximately 3,000,000 m^3, it is the major water source for approximately 2300 farmers in Krang Chek commune, Kampong Speu Province, which is known to be one of the lowest income provinces in Cambodia with a low landholding area of 0.3 ha per *farmer* household [18]. People use water from this reservoir for agriculture and daily consumption. During the wet season, the surplus water from the reservoir is discharged to supply the downstream area through irrigation gates and canals, as shown in **Figure 1**a. Generally, the presence of heavy metals in the aquatic environment comes from both natural and anthropogenic activities [2][19][20][21][22][23][24][25][26]. Chan Thnal reservoir is surrounded by large agricultural areas, scattered farmer households, commercial and residential areas, poultry farms, schools, and community markets. In recent decades, an increase in population and urbanization has led to an increase in quantities of both non-hazardous and hazardous waste production [19][24][27]. It can be expected that the catchment of this reservoir has been affected by improper waste disposal since open dumping and open burning of household and agricultural hazardous wastes (i.e., batteries, empty bottles of pesticides, and herbicides) are common practices in this area. In addition, excessive use of fertilizers and pesticides in a vast agricultural area is responsible for producing heavy metals in the water and soil. These activities can cause an increase in the mobilization of heavy metals in the environment [1][6][28]. It is likely that the Chan Thnal reservoir receives drainage from this catchment via runoff and two road canals connected to the reservoir, as shown in **Figure 1**a. Road canal 1 runs from the northwest and road canal 2 runs from the northeast. The road canals carry residential, commercial, and agricultural discharges to the reservoir. Increasing heavy metal pollution may cause significant adverse effects on invertebrates, fish, and human health [27][28][29][30][31][32][33][34][35][36]. Recently, water pollution and metal contamination in this reservoir have become major environmental and health concerns for the people and local authorities. Thus far, the quantitative analysis of heavy metals pollution in the Chan Thnal reservoir has not been undertaken. Our study is the first to provide insight and information on the heavy metals contamination in both the water and sediment of the Chan Thnal reservoir. Hence, this study aimed to: (1) measure the contamination levels and investigate the distribution of four heavy metals (Cd, Cu, Zn, and Pb) in both the water and sediment; (2) use various sediment indicators such as contamination factor, pollution load index, and enrichment factor to evaluate the pollution degree and ecological risk levels of the sediments based on Cd, Cu, Pb, and Zn; (3) use the health index to assess the potential non-carcinogenic health effects; and (4) perform the cluster and factor analysis to determine the possible sources of heavy metals contamination in the water of the Chan Thnal reservoir.



(a)



(b)

Figure 1. (**a**) The Chan Thnal reservoir and sampling locations (L1–L6) and (**b**) geological map of Cambodia and the Chan Thnal reservoir.

2. Heavy Metals Contamination in the Water

Significant variation ($p < 0.05$) in heavy metal concentrations was found in the water from all six locations. The occurrence of the heavy metals might be attributed to the input from road canal 1 carrying both point and non-point sources from the northwestern area (i.e., large rice paddies, households, schools, and animal farms [22][37]). In addition, fertilizers, pesticides, and sewage sludge are common agricultural sources of heavy metals [4]. A significantly high level of Pb was revealed in the water. This finding brought serious health concerns to villagers who are living in the areas because L6 is the location where local water vendors pump the water and sell it to the villagers who do not have access to the public water supply (piped water). Lifelong intake of metal-contaminated water can cause chronic health effects on those villagers or people who live nearby the water. In general, gasoline, paint, fertilizer, pesticides, and ammunition are common anthropogenic sources of Pb in the environment [6][38]. The principal component analysis (PCA) and factor analysis confirmed our assumption that the primary source of the heavy metals is from anthropogenic activities such as urban runoff, agricultural runoff, industrial discharge, sewage effluent, and atmospheric deposition. The occurrence of Cd, Cu, and Zn in the water likely originates from agricultural runoff (i.e., the use of fertilizers) and urban runoff (i.e., improper wastewater treatment and waste disposal) in the catchment of the Chan Thnal reservoir. Agricultural runoff is one of the major sources that generate significant levels of Cu, Zn, and Pb in the water resulting from the use of fertilizers, pesticides, herbicides, and fungicides in farming activities [4][34]. Moreover, the results of factor analysis confirmed additional sources of Pb occurrence in the water which include both direct (e.g., Pb shot and Pb sinkers) and indirect sources. In general, Pb is transferred continuously between air, water, and soil by natural chemical and physical processes such as weathering, runoff, precipitation, dry deposition of dust, and atmospheric deposition. The latest one is one of the largest sources of Pb found in the environment [4]. By considering the location of the reservoir and activities of reservoir utilization by local people, it is believed that an additional source of Pb contamination in the reservoir is likely from an aerial deposition and Pb sinkers used for fishing and fish catching.

3. Heavy Metals Contamination in the Sediment

In contrast, the concentrations of heavy metals (Cu, Pb, and Zn) in the sediment of all locations in the Chan Thnal reservoir were below the concentrations threshold of metals in the sediment based on the sediment quality guidelines for freshwater systems [39], indicating that they are safe for human use for habitation and agriculture purposes. However, these results cannot justify the assumption of no ecological risk or health risk conditions of the Chan Thnal reservoir, as the sediment acidity (pH) and compositions may affect solubility, mobility, and phytoavailability of heavy metals in the sediment [40]. Acidic sediment can cause an increase in solubility and mobility of heavy metals [3], which subsequently increases the bioavailability of heavy metals for plant uptake. For example, Cd, Cu, and Zn are more mobile and bioavailable for plants than others, while Pb is classified as a low bioavailable heavy metal. However, plants can employ several processes to alter the physicochemical properties of the sediment and facilitate heavy metal chelation which subsequently causes an increase in solubility, mobility, and bioavailability of heavy metals in the sediment [40]. Once the heavy metals become bioavailable, they can be either absorbed by algae at a lower trophic level in the food web or by aquatic plants [3]. In particular, the abundance of aquatic plants in the Chan Thnal reservoir, for example, water lily (*Nymphaea*) and lotus (*Nelumbo*) can enhance phytoremediation and translocation of heavy metals in the sediment, resulting in a low concentration of metals in both the water and sediment [40]. Despite the results of this study revealing low to moderate ecological risks based on heavy metals contamination in the sediment, it has brought serious health risk concerns when considering the potential issue of bioaccumulation in the Chan Thnal reservoir.

4. Ecological Risk Assessment

A few parameters (i.e., *PLI*, *PI MPI*, mC_d) reflected a progressive deterioration and indicated moderate to heavy pollution from Cu, Zn, and Pb. However, the contamination level seems not to affect the overall ecological function of the Chan Thnal reservoir. This is probably because the purification capacity (e.g., phytoremediation process) is sufficient to sustain the consistent input of heavy metals in the reservoir. Considering the *PER* value, this parameter integrates the biological toxicity of individual metals into the concentration factor. The classic number of heavy metals to be studied is at least eight species. As can be expected, an increasing number of heavy metals would result in a higher potential ecological risk. However, in this study, the *PER* value is calculated based on fewer heavy metals (i.e., Cd, Cu, Zn, Pb), resulting in a relatively low potential ecological risk of metal pollution in the Chan Thnal reservoir.

5. Human Health Risk

Among the four heavy metals of interest, the Pb level in the water significantly exceeded the guideline for drinking water for all locations. The health risk assessment revealed no risk of the non-carcinogenic effect caused by ingestion of heavy-metal-contaminated water (i.e., Pb, Zn, Cu, and Cd). However, children at the age below 10 and infants are vulnerable to Pb toxicity. The *HQ* of Pb exceeded 1, revealing a non-carcinogenic risk of Pb intake through oral ingestion. Long-term exposure to Pb through oral ingestion can permanently impair the neurological system [4]. The findings highlight the need for mitigation actions to reduce Pb concentrations in the water, along with the use of intervention measures to prevent Pb uptake through ingestion pathways.

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