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Risk assessment of arsenic from contaminated soils to shallow groundwater in Ong Phra Sub-District, Suphan Buri Province, Thailand

Weerawut Tiankao[a], Srilert Chotpantarat[b,c,d,e,*]

[a] Department of Chemistry, Mahidol Wittayanusorn School, Nakhon Pathom 73170, Thailand
[b] Center of Excellence for Environmental and Substance Management (HSM), Chulalongkorn University, Bangkok, Thailand
[c] Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
[d] Research Program of Toxic Substance Management in the Mining Industry, Center of Excellence on Hazardous Substance Management (HSM), Chulalongkorn University, Bangkok, Thailand
[e] Research Unit of Green Mining Management (GMM), Chulalongkorn University, Bangkok, Thailand

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ABSTRACT

Study region: The Arsenic (As) concentrations found in Ong Phra sub-district, Dan Chang district, and Suphan Buri province are approx. 20 times higher than the average concentration of As in agricultural soils of Thailand.

Study focus: The objectives of this current study were to investigate the As contamination in soil and groundwater and further develop the risk assessment map of As from contaminated soils releasing to shallow groundwater by combining DRASTIC method with contamination factor (CF) and mobility factor (MF).

New hydrological insights for the region: According to the sequential extraction result, the concentrations of total As in 39 soil samples ranges from 4.8 to 1070.4 mg/kg. The highest As concentration in shallow groundwater was found at well number 3, located within < 0.5 km. downstream from the old tin mine. The Index of DRASTIC groundwater vulnerability, is in the range of 59–147, which is categorized into three vulnerability zones as follows: low (< 100), moderate (100–130) and high (> 130). The high vulnerability area, found along the waterway, is approximately 35 km^2 (18.65% of the study area). Interestingly, the DRASTIC index of the old tin mine is indicated as the zone of moderate and high vulnerability. The findings in this study reveal that the integration of the DRASTIC risk map with CF can well elucidate As contaminated in shallow groundwater.

1. Introduction

Arsenic (As) is one of the most toxic substances foundin the environment. Exposure to sufficiently high concentrations of As in the natural environment, such as in surface water, groundwater, sediment, and soil, has proven to be harmful to human health and the ecosystem. A significant route for As exposure is the consumption of groundwater, which has been reported from different parts of the world (Bhattacharya et al., 1997, 2002; Chotpantarat et al., 2014; Muhammad and Muhammad, 2011; Quazi et al., 2011; Smedley and Kinniburgh, 2002; Wongsasuluk et al., 2018a,b; Zhiyuan et al., 2014). In the case of abandoned mines, the mining waste consists

* Corresponding author at: Department of Geology, Faculty of Science, Chualongkorn University, Bangkok, Thailand.
E-mail address: Srilert.C@chula.ac.th (S. Chotpantarat).

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of roaster piles, tailings ponds, waste rock piles and acidic mine water (Alshaebi et al., 2009). Percolation from the tailing ponds can leak and, eventually, contaminate the groundwater system and move down-gradient from the ponds. The main toxic metal concentrations of concern are: As, iron (Fe), cadmium (Cd), copper (Cu), lead (Pb), manganese (Mn), nickel (Ni), and zinc (Zn), with levels exceeding the water quality criteria in the stream around mining areas (Wikiniyadhanee et al., 2015; Alshaebi et al., 2009; Chotpantarat et al., 2015; Boonsrang et al., 2017). Arsenic is usually an unusable by-product that can be introduced into the environment through the natural process of erosion of mineral deposits or through the mining and milling of these deposits.

Most tin ores are found in alluvial deposits and mining operations by dredging and gravel pumping, which use water for the mechanical separation of tin ore from the tin-bearing earth. The tailings, therefore, are grouped into two main types consisting of slime and sand, including gravel as a minor proportion (Tanpibal and Sahunalu, 1989). The coarser materials are found close to the discharge point with a continuous gradation to fine particles at the lower end of the slope. These form the fan-shaped tailings. Thailand is one of several countries in Southeast Asia, having problems with tin residue. The waste piles, resulting from tin mining, contain high As (as arsenopyrite). The original case study from a few decades ago discovered at Ron Phibun sub-district, Nakhon Si Thammarat, a province in the southern part of Thailand (Smedley and Kinniburgh, 2002; Williams et al., 1996) that health problems were first recognized in the area in 1987. Approximately 1000 people have been diagnosed with As-related skin disorders, particularly in and close to Ron Phibun town (Choprapawon and Rodcline, 1997; Fordyce et al., 1995; Williams et al., 1996). The affected area lies within the South-East Asian Tin Belt (Schwartz et al., 1995). Arsenic concentrations are found at up to 5000 μg/L in shallow groundwater from the Quaternary alluvial sediment that has been extensively dredged during tin-mining operations. Moreover, the result of the measurement of As content in water and soils in another old tin mine at Dan Chang, Suphan Buri, finds As contamination in the soils and tap water (Pansamut and Wattayakorn, 2010). Specifically, the result from a health risk assessment of As contamination in a project in 2010 at Ong Phra sub-district revealed that people have a carcinogenic risk from As exposure The DRASTIC method, commonly used for assessing aquifer vulnerability, was developed by Aller et al. (1987). Recently, many studies have developed the risk assessment by combining the aquifer vulnerability from DRASTIC (Konkul et al., 2014) and the potential release of contamination sources, mainly focusing on nitrate and pesticides in agricultural areas (Gonzalez et al., 1997; Goodarzi and Javadi, 2016; Hamutoko et al., 2016; Kisaka and Lema, 2016; Mondal et al., 2017; Zghibi et al., 2016). However, few studies (Hamutoko et al., 2016; Mondal et al., 2017) have not been supported by field measurement, especially heavy metal concentrations in soil and groundwater, to check their reliability of risk assessment map. Therefore, the objectives of this current study were to investigate the As concentrations in soil and groundwater in Ong Phra sub-District, Suphan Buri Province and further develop the risk assessment map of As from contaminated soils releasing to shallow groundwater by combining DRASTIC method with the different approaches of potential leaching assessment of As (both contamination factor (CF) and mobility factor (MF)). Finally, the reliability of the integration of the vulnerability of the area and potential leaching of As in the study area was investigated to proof the reliable result of this technique and can be applied to delineate the risk assessment map of groundwater contamination in this area.

2. The study area

Dan Chang is the northwestern district of Suphan Buri Province (Fig. 1) and is located between latitudes 14°49′22″–14°50′32″ N and longitudes 99°21′12″– 99°22′22″ E. The terrain of Dan Chang is high mountainous ranges in the west and undulating to rolling terrain and slope down to the east. Annual rainfall in Dan Chang district is 915.34 mm. Ong Phra sub-district is one of seven sub-districts in Dan Chang with a population of about 7000 people who are mainly in the agricultural sector. The old tin mine in Ong Phra sub-district is approximately 80 km west of Dan Chang district, and south-west of the old mine is Sombut-Jarern sub-district, Nong Prue district, Kanchanaburi province. The old mine areas are clustered in 13 pits, as shown in Fig. 1.

Geology and hydrogeology of the study area are classified by secondary data (such as rock types, well log of groundwater exploration), obtained from the Department of Mineral Resources (DMR) and the Department of Groundwater Resources (DGR). Geology of the study area mostly comprises terrain and colluvium deposits of Quaternary age and Ordovician limestone, as shown in Fig. 2(a).

Hydrogeologic units in the study area consist of two main types of aquifer, which are unconsolidated and consolidated media. The hydrogeological map (Fig. 2(b)) shows the unconsolidated aquifers in colluvium (Qcl) and terrain deposit (Qt) units and the consolidated aquifers in granite, Ordovician limestone (Ols), and Silurian-Devonian Metamorphic (SDmm) and Permo-Carboniferus metasedimentary (PCms) units. Groundwater samples are collected in shallow wells, mainly located in the terrain deposit aquifer (Qt).

3. Materials and methods

3.1. Groundwater and soil sampling locations

Approximately 39 selected soil samples were collected at the old mining site in Ong Phra sub-district, Dan Chang district, Suphan Buri province which covering upstream and downstream parts of the mining site as shown in Fig. 1. Top soil samples were taken at the 15 cm depth. Soils were dried overnight and sieved through a 2 mm sieve to eliminate stones and other materials, like litter, extraneous to soil, and then stored in polyethylene bags at room temperature prior to each analysis.

The sampling of groundwater was focused on wells currently in use, which consisted of 7 private ring wells and 14 public tube wells. The depth to groundwater table was measured by electrical groundwater-level and a groundwater sample was then pumped through a flow-through cell, containing multi-measuring probes to measure groundwater parameters such as pH, electrical