

# Impact of climate change on acid mine drainage generation and contaminant transport in water ecosystems of semi-arid and arid mining areas



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## ABSTRACT

Disposal of untreated and treated mining wastes and tailings exerts a significant threat and hazard for environmental contamination including groundwater, surface water, wetlands, land, food chain and animals. In order to facilitate remediation techniques, it is important to understand the oxidation of sulfidic minerals, and the hydrolysis of the oxidation products that result in production of acid mine drainage (AMD), toxic metals, low pH,  $\text{SO}_4^{2-}$  and Fe. This review has summarized the impacts of climate change on geochemical reactions, AMD generation, and water quality in semi-arid/arid mining environments. Besides this, the study included the effects of hydrological, seasonal and climate change on composition of AMD, contaminant transport in watersheds and restoration of mining sites. Different models have different types of limitations and benefits that control their adaptability and suitability of application in various mining environments. This review has made a comparative discussion of a few most potential and widely used reactive transport models that can be applied to simulate the effect of climate change on sulfide oxidation and AMD production from mining waste, and contaminant transport in surface and groundwater systems.

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## 1. Introduction

Geochemical weathering and oxidation of sulfide minerals in mining waste and tailings creates a long-term threat to the surrounding environment and, depending on their location and environmental setting, present contrasting physical, hydrological and chemical characteristics controlling the fate and transport of contaminants. Acid mine drainages (AMDs) generated from mining wastes contain high acidity and typically high concentrations of sulfate and toxic metals, create a potential threat to environmental contamination, surface water, groundwater, soil quality and food chain contamination, and may kill fish, flora and most organisms in water and soils (Forstner and Wittmann, 1983; Malmstrom et al., 2008; Chen and Jiang, 2012). The generation of AMD from overburden spoil piles at open-pit lignite mines rendered the quality of groundwater to pH as low as 1, and impacted the mine pits and surface water bodies (Gerke et al., 1998).

Considering that water is a valuable natural resource, conservation of water from the multiple threats of contamination is very important for the economic growth, sustainable existence of nat-

ure and well being of populations. Global climatic and environmental changes will cause erratic rainfall, water scarcity, increased incidence of flood and droughts, which will consequently affect mining activities, agriculture, and livelihood in the semi-arid and arid regions. The groundwater and surface water ecosystems will be threatened due to both disposal of mining wastes and climate change. Therefore, the sustainable and long-lasting remediation and mitigation strategies are needed to confront the impacts of climate change, and protect this valuable water resource in the mining operated semi-arid and arid regions. Before adopting the remediation strategies, it is essential to understand the tailings dissolution, geochemical reactions, AMD production and contaminant transport in the groundwater and surface water ecosystems in response to climate change.

Geochemical modeling is widely applicable and useful technique to investigate the geochemical reactions occurring in the AMD, and contaminant transport in the groundwater and surface water systems (Bertelli et al., 2009). The geochemical model incorporates chemical speciation, precipitation–dissolution reactions, ion exchange, acid–base reactions, and redox reactions. Any geochemical modeling exercise must be approached from an initial conceptual model which is based on well constrained field observations, data collection and a number of geological and geochemical assumptions. The validity of the model is strictly dependent on the quality and quantity of the data, and on the consistency of

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assumptions on which the model is based. In chemical models of geological systems, one of the key areas of uncertainty is the chemical composition of the fluids that interacted with the rocks. The data from fluid inclusion analysis can now be employed to help constrain the chemical system for input into geochemical models. Accurate modeling of geochemical changes in dissolution of mine tailings and waste evolving in AMD can be an important tool in predicting post-mining environmental impacts and site management (Bronswijk et al., 1993; Burke and Banwart, 2002; Brown and Glynn, 2003; Kruse, 2007; Kruse and Younger, 2009).

Very few research studies are reported in the literatures that focused on the impacts of climate change on AMD in mining regions. A recent review by Nordstorm (2009) described the natural processes, that might change the concentrations of acidity and metals in surface waters receiving AMD under the expected conditions of climate change associated with global warming (e.g. rainfall events) based on data from three mines sites in the United States. However, the impacts of climate change on AMD generation, geochemical reactions in mining wastes, water quality of AMD affected streams and transport mechanisms are poorly studied and reviewed. Therefore, the main objective of this review is to explore the implications of climate change on AMD generation from mining waste and tailings, water inflows to surface and groundwater system, water quality and contaminant transport in mining areas of semi-arid and arid zones. In addition, this review also assessed the sulfide oxidation in relation to changing hydrological conditions, fundamental AMD formation and evolution processes, and contaminant transport in surface and subsurface water ecosystems. There are a number of mathematically based codes/models, that are constantly developing, and widely used to describe the different aspects of groundwater and surface water geochemistry affected by AMD. One objective of this review is to make a comparative discussion of the most potential and widely used geochemical models that can be useful in elucidation of metal speciation, mineral saturation calculations, physical or geochemical and coupled physical–geochemical simulators of processes, hydraulic and geochemical changes in tailings and AMD systems.

## 2. Mechanism of sulfide mineral oxidation and acid mine drainage

Oxidation of sulfidic minerals, particularly pyrite ( $\text{FeS}_2$ ), arsenopyrite and pyrrhotite and the hydrolysis of the oxidation products (iron sulfates) in mining waste, mine dumps, and tailings impoundments generate acid drainage,  $\text{SO}_4^{2-}$  and Fe, where  $\text{O}_2$  and water are the oxidizing agents (Balistrieri et al., 1999; Dold and Fontbote, 2001; Abbassi et al., 2009). The second pathway for sulfide oxidation is by reaction with Fe(III). Both pathways are fast. They yield a low pH and Fe(II), which may become oxidized by  $\text{O}_2(\text{aq})$  to Fe(III).

The detailed processes involved in pyrite oxidation from mining waste, generation of acidity, sulfate, metals and metalloids is shown by the conceptual model in Fig. 1. The model also exhibits the contaminant transport and mechanisms of redox reactions controlling the contaminants in shallow and deeper groundwater systems. This oxidation is known to be very slow and unstable at low pH (Singer and Stumm, 1970) except in the presence of microorganisms, which can increase the rate of Fe(III) production by up to six orders of magnitude and more stable at a pH of approximately 8. Acid generation is also demonstrated by chalcopyrite and sphalerite with an indefinite composition ( $(\text{Zn}, \text{Fe})\text{S}$ ) (Schroeter et al., 2001). Minerals such as chalcocite and galena, which sometimes occur in different types of mines, oxidize, but do not produce acidity (Matthews et al., 2008). Arsenic sulfide ( $\text{AsS}$  (am),  $\text{As}_2\text{S}_3$  (am), orpiment, and realgar) oxidation rates increase with increasing pH values (Lengke and Tempel, 2005).

The rate of pyrite oxidation in the mining waste and tailings is mainly controlled by the availability of oxygen and water at the mineral grain surface (Gerke et al., 1998). Most of the previous models considered the one-dimensional vertical oxygen diffusion within the spoil using Fick's first law (e.g. Bronswijk et al., 1993), and first-order kinetics (Elberling et al., 1994). Wunderly et al. (1996) further developed the model by coupling a one-dimensional oxygen diffusion to a two-dimensional transport model where the physical transport of oxygen to the reaction site is the most important rate-limiting step for the oxidation of pyrite. However, they ignored geochemical reaction kinetics (Williamson and Rimstidt, 1994) and the role of bacteria. The kinetics of pyrite oxidation combined with the spatial variability of solute transport and geochemical properties may have a significant effect on the duration of the acidification process, the spatio-temporal movement of the oxidation front, and the long-term evolution of contaminant leaching through the relatively large vadose zone of overburden spoil piles. Gerke et al. (1998) justified the decoupling of kinetic oxygen diffusion from aqueous phase reactive transport in their model because: first, oxygen diffusion was restricted to the air phase; and second, the oxidation products appeared in the aqueous transport equation as source terms only.

## 3. Geochemical reactions and dynamics of AMD in the environment

Many factors affect the chemistry of mine drainage that depends on a variety of geological and geochemical controls including the type and abundance of metal-bearing sulfides in ore and wall rock, kinetic rates of ore and wall rock dissolution, permeability of the ore deposit or mine tailings, and the ability of the host rock to buffer acidity (Plumlee et al., 1993). In and around the mining sites, metal content attenuates to background concentrations

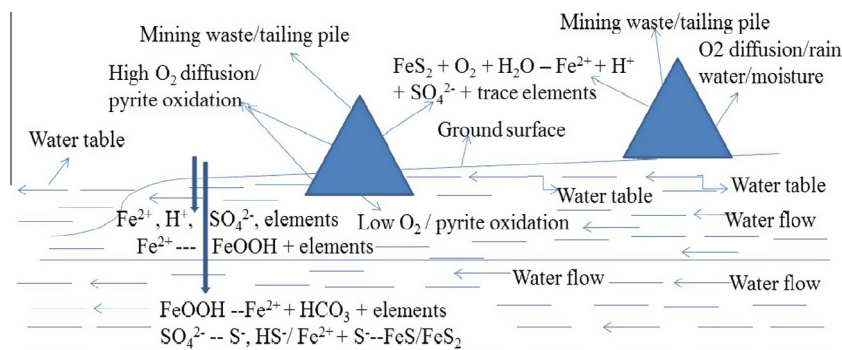


Fig. 1. Conceptual model to present the pyrite oxidation from mining waste, and dynamics of contaminants in shallow and deeper groundwater.

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