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Groundwater assessment and environmental impact in the abandoned mine of Kettara (Morocco)☆

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ABSTRACT

Many questions about the soil pollution due to mining activities have been analyzed by numerous methods which help to evaluate the dispersion of the Metallic Trace Elements (MTE) in the soil and stream sediments of the abandoned mine of Kettara (Morocco). The transport of these MTE could have an important role in the degradation of groundwater and the health of people who are living in the vicinity. The present paper aims to evaluate the groundwater samples from 15 hydrogeological wells. This evaluation concerns the hydrogeological parameters, pH, Electrical conductivity, temperature and the groundwater level, and the geochemical assessment of Mg, Ca, Ti, Cr, Mn, Fe, Co, Ni, Zn, Cu, As, Se, Cd, Sb, Tl and Pb. Furthermore, the Metallic Trace Elements are transported in the saturated zone via the fractures network. The groundwater flow is from the north-east to south-west. The spatial distribution of As, Fe, Zn and Mn is very heterogeneous, with high values observed in the north, upstream, of the mine site. This distribution is maybe related to: i) the existence of hydrogeological structures (dividing and drainage axes); ii) the individualization of the fractures network that affects the shaly lithostratigraphical formation; iii) the transport of the contaminants from the soil towards groundwater; and iv) interaction water/rocks. Some MTE anomalies are linked to the lithology and the fracturation system of the area. Therefore, the groundwater contamination by Arsenic is detected in the hydrogeological wells (E1 and E2). This pollution which is higher than guideline standards of Moroccan drinking water could affect the public health. The hydrogeological and geochemical investigations favor the geological origin (mafic rocks) of this contamination rather than mining activities.

1. Introduction

Pyrrhotite mineral, which is considered as a gangue in the mining industry, served at Kettara mine as source of sulphur for the manufacturing of the sulphuric acid used by Maroc chimie company, Morocco for the treatment of phosphates and the phosphoric acid production and its by-products. Kettara mine activities began in 1933 and were forced to stop in 1982. Many works reveal that the abandoned pyrrhotite mine contains more than 3 million tons of mine wastes deposited in an environment without protection (Hakkou et al., 2008a,b; El Amari et al., 2014). The Acid Mine Drainage (AMD) is the result of the abandoned mine related to the exposition of the sulphide bearing to the oxygen and water. The chemical processes that are based on the oxidation of the sulphide have been mentioned in many works (El Amari et al., 2014; Pyatt and Grattan, 2001). The AMD and geochemical assessment of soil in the mine environment have been described in several works: i) the environmental impact of the AMD and especially on the soil/water (Cidu et al., 2011; Equeenuddin et al., 2010); ii) the geochemical and eco-toxicological characteristics of stream water and groundwater (Buzatu et al., 2016; Han et al., 2017; Blowes et al., 2003); the comprehension of the Acid mine drainage risks by using the modeling approaches, conceptual model and system characterization (Myers, 2016; Lefebvre et al., 2001), and the assessment of metal loads in watersheds affected especially by acid mine drainage by using tracer injection of NaCl and synoptic sampling (Kimball et al., 2002). The damage to the ecosystem, to the local

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communities in the vicinity of the abandoned mines and the effect of mining wastewater on drinking water quality have been demonstrated in several works (Boulanger and Gorman, 2014; Hernandez et al., 2003; Lu et al., 2014, 2015).

Currently, mining has generated a considerable volume of mining waste in the wild. The region of Marrakech in the south of Morocco is concerned by this problem. Abandoned mine of Kettara has led to the regional economic decline, followed by numerous environmental problems due to its sulphide solid wastes. In the previous works realized in the Kettara mine, the analysis and the interpretation of geochemical results showed that the soil is contaminated by the Metallic Trace Elements (MTE). Indeed, El Amari et al. (2014) have confirmed the presence of the metal and metalloid in the soil of Kettara (As, Pb, Zn, Cd, Ni, Mn, etc.). Soil contamination is linked especially to the lithology of the area and only stream sediments in the near downstream of the tailings are polluted by mining activity (El Amari et al., 2014). The principal sources of MTE contained in Kettara tailings are pyrrhotite, pyrite, chalcopyrite, and galena. AMD produced from these tailing wastes has affected the ground water quality, located downstream, especially by sulphate ions (Toughzaoui et al., 2015a,b).

Based on the fact that sulphate production means sulphide minerals dissolution, Metallic Trace Elements contained in the exploited sulphide ore (El Amari et al., 2014) could be also transported by AMD solutions. This paper focuses on the assessment of the impact of these Metallic Trace Elements (Ti, Cr, Mn, Fe, Co, Ni, Zn, Cu, As, Se, Cd, Sb, Tl, and Pb) on the groundwater quality of Kettara watershed. It is necessary to identify the distribution anomalies of the principal contaminants and to indicate the likely impact on the health from the wells exploited by the local population. Even if drink water is officially supplied by the Moroccan National Office of Drinking Water from a well, located a few kilometers SW of the village, the population does not hesitate to drink water from other wells. Drinking water is pumped from the deep aquifer. In order to understand the AMD in the saturated zone of the Kettara area, it is necessary to collect more information about the aquifer fracturation and the groundwater flow in the mine media. Geochemical analysis and interpretation in the study area allow assessing the groundwater quality which supplies rural communities of the Kettara especially for agricultural activities and livestock in the region. This paper is based on a geological, hydrogeological and hydrochemical campaign realized during 2015.

2. Materials and methods

2.1. Study area

The Kettara village is located at 35 km northwest of Marrakech city (Fig. 1a and b), along the national road 7 in the direction of the Safi city. The abandoned Kettara mine is located on the East side of the village. The climate of the region is continental semi-arid, hot and dry during the summer and cold and relatively humid during the winter. One year is divided into two parts: a rainy season, from October to April, and a dry season, from May to September. Rains do not fall homogeneously either during one year or during one season. Precipitation is concentrated during certain days and may be absent for a very long period of time. The average temperature of the region (about 20 °C) is not representative. Variations in temperature are visible on several scales (21 March 2017, the meteorological station record 11 °C at 6:00 against 23 °C at 15:00). Precipitation in the region is weak and irregular. The mean annual rainfall is about 250 mm (Basin Haouz Tensift Agency, Morocco). The peculiarity of this area lies in the absence of perennial streams. Indeed, during the rainfall episodes, surface flow water is conducted by ephemeral watercourses.

2.2. Geological and hydrogeological setting of the study area

The Central Jebilet, where the mine is located, is composed of two main formations (Fig. 1c).

- The shales of Sarhlef are metamorphosed volcano-sedimentary deposits dating from the Upper visean to the Westphalo-Permian (Huvelin, 1977). The NNE-SSW schistosity is developed during the Hercynian tectonic phase in the latest Carboniferous (Essaifi et al., 2001). The deformation is materialized by a sub-vertical schistosity that corresponds to a low-

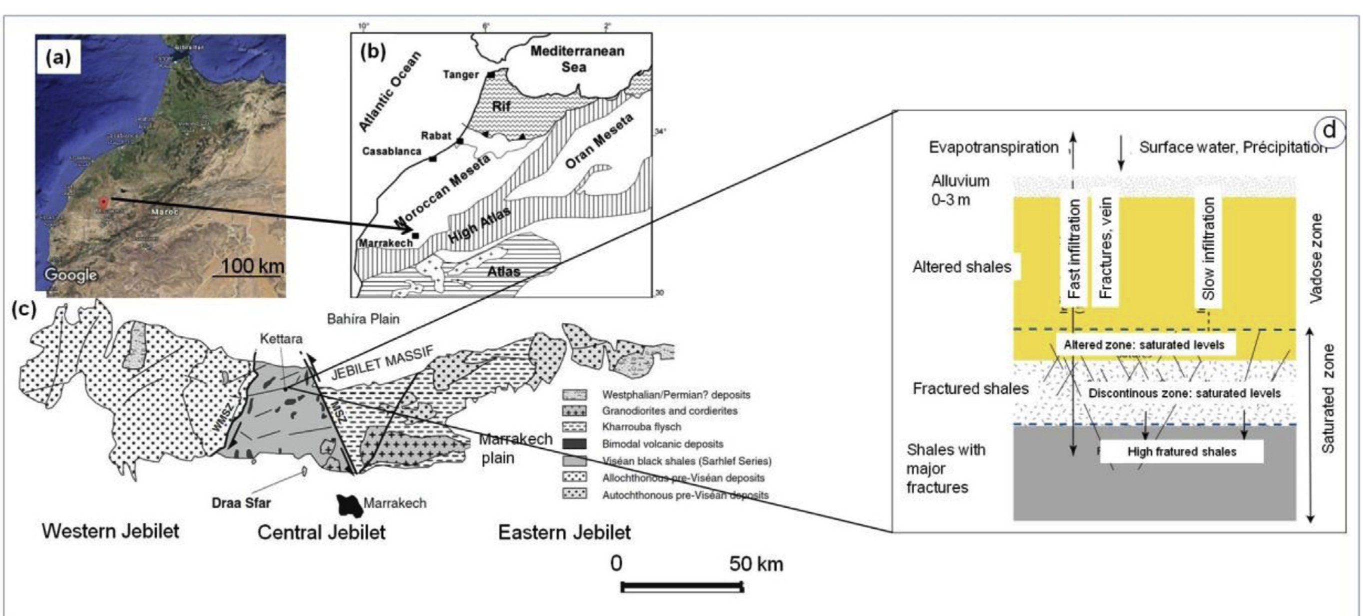

Fig. 1. (a) Geological and hydrogeological characteristics of the Kettara area: location of the Kettara zone and (b) the structural domains of Morocco (Zouhri et al., 2003; modified); (c) Geological sketch map of the Jebilet massif (modified after Huvelin, 1977; N'diaye et al., 2016); (d) description of the aquifer of the study area.