# Hydrogeochemical Investigations of the Shour River and Groundwater Affected by Acid Mine Drainage in Sarcheshmeh Porphyry Copper Mine

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## Abstract
Acid mine drainage (AMD) is regarded as the worst environmental problem related to mining that affects surface and groundwater quality. It may be caused when sulphide minerals, especially pyrite, are exposed to air. AMD is generally characterised by high concentrations of iron and sulphate, and low pH. Managing such problems is a major task for mining engineers and environmental groups worldwide. This paper discusses the water pollution problems in the vicinity of the Sarcheshmeh copper mine resulting from AMD originating from waste dumps in the study area. The impacts of AMD on the quality of the surface and groundwater were investigated by sampling the Shour River and wells and springs around the waste dumps, and analysing the samples for hydrogeochemical parameters, particularly toxic metals. The results show the pyrite oxidation process and AMD generation in the waste dumps and their serious impacts on the quality of water bodies. The pH of the water samples in the Shour River varies from 2 to 3.9 and the concentrations of the most of the toxic metals are above their standard limits as presented by World Health Organisation (WHO). Results obtained from such investigations can be used to design an appropriate water quality control program and to propose an effective water treatment system.

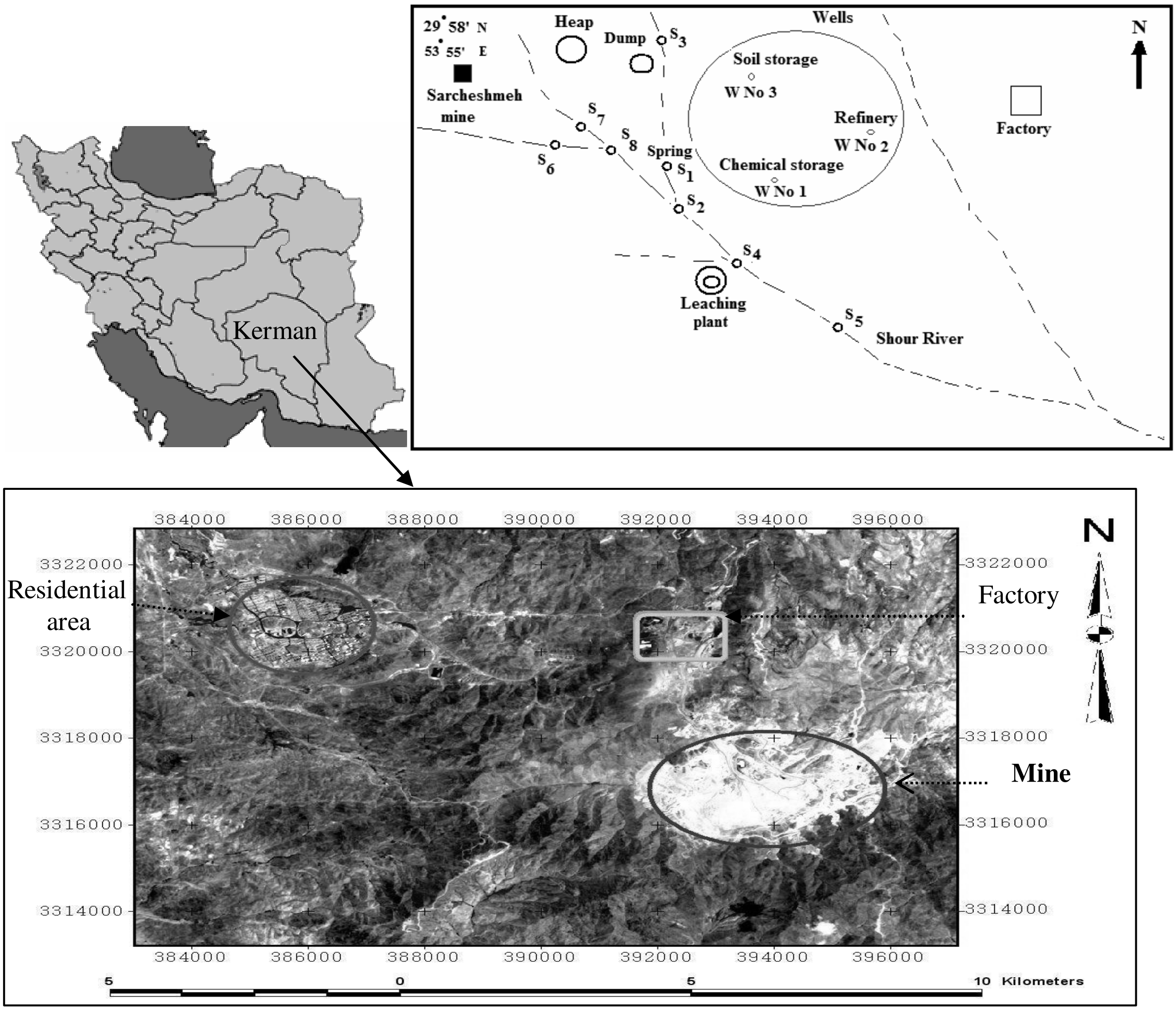
**Key words:** AMD, toxic metals, surface and groundwater quality, Sarcheshmeh, waste dump

## Introduction
The Sarcheshmeh copper deposit, the fourth largest mine in the world, consists of 1 billion tonnes averaging 0.9 % copper and 0.03 % molybdenum (Banisi and Finch 2001). This ore body is located in Kerman province, southeastern Iran. Mining operations have produced many low grade waste dumps and posed many environmental problems. AMD is the most important problem associated with metal sulphide mining and is considered to be a major cause of water pollution contributing high concentrations of iron, sulphate, variable concentrations of toxic metals, and acidity to receiving waters (Williams, 1975; Erickson et al., 1982; and Chen et al., 1999). AMD is generally formed due to the oxidation of sulphides. The rapid oxidation of pyritic minerals exposed to air produces acidic drainage (Ricca and Schultz, 1979; Atkins and Pooley, 1982), which poses a number of problems and has a detrimental effect on surface water, groundwater aquifers and soils (Atkins and Pooley, 1982; Rubio and Del Olmo, 1995).
If the effects and magnitude of a water-related problem can be identified in advance of mining, appropriate water management strategies to minimise the socio-economic and environmental impact of mining activities often can be efficiently incorporated into the mine plan. A major task in developing an effective treatment scheme and environmental management plan is the investigation of the environmental problems due to the long term generation of AMD and toxic metal pollution during the design stage of a large open pit mining operation.
In this paper, the impacts of AMD on the quality of the surface and groundwater were investigated by sampling in the Shour River, wells and springs around the waste dumps and analysing the samples for hydrogeochemical parameters, particularly toxic metals.

### Geology and geographical situation of Sarcheshmeh copper mine
Sarcheshmeh copper mine is located about 160 km southwest of Kerman and about 50 km southwest of Rafsanjan in Kerman province, Iran, in the Band Mamazar-Pariz Mountains. The average elevation of the mine is 1600 m and has a latitude of 29° 58′ N and a longitude of 53° 55′ E. The main access road to the study area is Kerman- Rafsanjan-Shahr Babak road. The average annual precipitation at the site varies from 300 to 550 mm. The temperature varies from +35 °C in summer to -20 °C in winter.

The area is covered with snow about 3 to 4 months per year. The wind speed sometimes exceeds 100 km/h. The topography of the mining area is very rough. Figure 1 shows the geographical position of Sarcheshmeh copper mine.

***Figure 1*** *Geographical position of Sarcheshmeh copper mine including sampling locations*



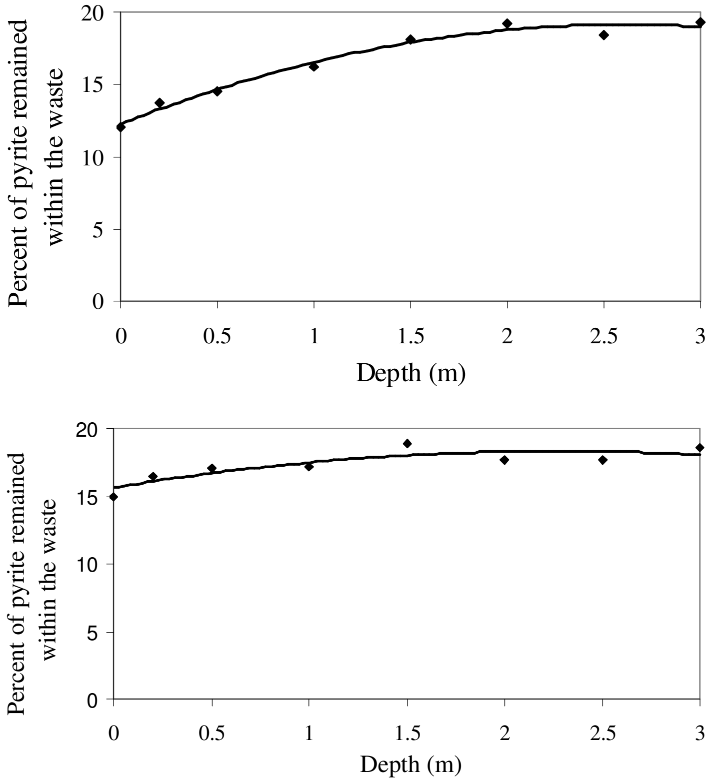

The ore body in Sarcheshmeh is oval shaped with a long dimension of about 2300 m and a width of about 1200 m. This deposit is centred on the late Tertiary Sarcheshmeh granodiorite porphyry stock (Waterman and Hamilton 1975). The porphyry is a member of a complex series of magmatically related intrusives emplaced in the Tertiary volcanics a short distance from the edge of an older near-batholith-sized granodiorite mass. Open pit mining is used to extract the copper deposit, and approximately 40,000 tons of ore at 0.9 % Cu and 0.03 % molybdenum is extracted per day in Sarcheshmeh mine (Banisi and Finch 2001).

## Methodology

### *Pyrite oxidation studies*

Several waste samples each 2 kg in weight were taken from different depths up to 3 m at two points on the dump in order to investigate the pyrite oxidation process. Figure 2 shows the percent of pyrite remaining within the waste particles versus depth. As Figure 2 shows, in zones where oxygen is present in the pore spaces of the waste, the pyrite was oxidised. The oxidation reaction decreased gradually with depths up to 1.5 m. Below this depth, no oxygen is available so the pyrite oxidation reaction completely ceases.

***Figure 2*** *Field data for the pyrite remaining within the waste particles as a function of depth*




***Hydrogeochemical studies***

A hydrogeochemical analysis was carried out to investigate the impacts of AMD on the quality of the surface and groundwater by sampling the Shour River, wells and springs around the waste dumps. About 34 samples were taken around the dump, from both upstream and downstream sampling locations. The pH was measured using a portable pH meter in the field. Analyses for dissolved metals were performed using an atomic adsorption spectrometer (AA220) in the water laboratory of the National Iranian Copper Industries Co. ICP (model 6000) was also used to analyse the concentrations of heavy metals detected in the ppb range. Results from several samples are given in Table 1 and show that AMD emanating from the waste rock dumps combines with leachates from heap structures near the waste dumps seriously affects the quality of groundwater and the Shour River. The pH of the samples from the river varies from 2 to 3.9 and the concentrations of most toxic metals are above their standard limits. Compared to the river, the groundwater in the study area is less affected by acidic drainage. The pH of groundwater samples varies from 6.3 to 7.2, which is in the range that, according to Stiefel and Busch (1983), is acceptable at any surface mine site.

**Conclusions**

AMD is a serious problem in Sarcheshmeh copper mine, having a detrimental impact on groundwater and surface water quality. The major source of water pollution is oxidation of sulphide minerals, particularly pyrite, and subsequent discharge of acid drainage containing toxic metals into the Shour River and groundwater aquifer. Hydrogeochemical analyses of groundwater and surface water downstream of the waste rock dumps show elevated concentrations of toxic metals. Concentrations of $SO_4$ in both surface and groundwater samples are very high. The pH of the water sampled from the river varies from 2 to 3.9, but pH of groundwater samples varies from 6.3 to 7.2, which is acceptable. Although the oxidation of pyrite and other metal sulphides in the presence of air is often unavoidable, studies of the geochemistry of waste materials, hydrological aspects, and the mine plan can help in the design of the mining operations to minimise the various effects on the environment during the activities. The effects of AMD may remain long after mine closure, hence careful environmental management is a necessary task during mining operations and a basic mine closure strategy has to be developed to prevent the subsequent generation of AMD.

***Table 1*** *Geochemical analysis of the water samples affected by AMD associated with waste rock dump*

| Parameter | Sampling location | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | W N 1 | W N 2 | W N 3 | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | S8 |
| Fe (ppm) | 0.3 | 0.04 | 0.01 | <0.01 | 183 | 6.1 | 3890 | 3450 | 9.7 | 1.3 | 5.6 |
| Zn (ppm) | 0.05 | 0.05 | 0.01 | 3.10 | 28 | 7.40 | 470 | 400 | 17.1 | 8.3 | 18.8 |
| Cd (ppm) | <0.01 | <0.01 | <0.01 | 0.04 | 0.21 | 0.06 | 2.0 | 1.70 | 0.08 | 0.13 | 0.1 |
| Pb (ppm) | 0.06 | 0.06 | 0.06 | 0.08 | 0.21 | 0.12 | 1.8 | 1.60 | 0.6 | 0.4 | 0.2 |
| Bi (ppm) | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 1.5 | 1.70 | <1 | <1 | <1 |
| Se (ppm) | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Cu (ppm) | <0.01 | 0.29 | <0.01 | 0.83 | 50.0 | 43 | 2100 | 2050 | 70 | 158 | 109 |
| Cr (ppm) | 0.02 | 0.02 | 0.02 | 0.01 | 0.18 | 0.02 | 2.0 | 1.90 | <0.05 | <0.05 | <0.05 |
| Co (ppm) | <0.01 | <0.01 | <0.01 | 0.05 | 1.70 | 0.40 | 44 | 36 | 0.8 | 0.9 | 0.9 |
| Mo (ppm) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.3 | 0.3 | <0.05 | <0.05 | <0.05 |
| Mn (ppm) | 4.20 | 2.90 | 0.04 | 9.20 | 54.0 | 22 | 850 | 740 | 46 | 26 | 52 |
| Ni (ppm) | 0.02 | 0.02 | 0.01 | 0.49 | 9.3 | 0.6 | 140 | 126 | 0.8 | 0.8 | 1.1 |
| Mg (ppm) | 42.0 | 36.5 | 34.5 | 44.0 | 180 | 93 | 1420 | 1310 | 100 | 123 | 118 |
| Ca (ppm) | 164 | 176 | 132 | 368 | 320 | 208 | 108 | 100 | 130 | 325 | 185 |
| Cl (ppm) | 149 | 96 | 82 | 71 | 78 | 230 | 195 | 436 | - | - | - |
| $SO_4$ (ppm) | 284 | 27 | 249 | 1164 | >3000 | 1413 | >3000 | >3000 | 955 | 1526 | 1324 |
| Ec ($\mu s / cm$) | 1385 | 1151 | 920 | 1732 | 4337 | 2011 | 20550 | 19100 | 1950 | 2260 | 2110 |
| pH | 6.6 | 6.3 | 7.2 | 3.3 | 3.1 | 3.3 | 2.0 | 2.0 | 3.3 | 3.9 | 3.5 |
| TDS (ppm) | 672 | 559 | 446 | 841 | 2105 | 976 | 9976 | 9272 | 947 | 1097 | 1024 |
| $HCO_3$ (ppm) | 433 | 628 | 238 | 116 | Tr | Tr | Tr | Tr | - | - | - |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