# The Role of Gypsum Karst in Contaminant Transportation from Agh Darreh Tailing Dam in Iran

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## Introduction

Thousands of tailing dams worldwide contain billions of tones of mineral processing industry wastes. Tailing dams possess specific characteristics and are used for disposal of dangerous or undangerous wastes. Tailing dam is one of the most important mining operations interface with surrounding environment respect to future limitations of environmental regulations. If the dams are constructed on carbonate or gypsiferous terrains, they might be exposed to karstification hazards. Active solutional caves in karst area could provide a hydraulic connection between surface and ground water. These solutional caves consequently can accelerate the groundwater flow and result in contaminant transportation. Groundwater pollution from sources such as waste disposal sites is a worldwide problem. Mining of mineral ores and disposal of resulting wastes pose a significant risk to the groundwater.

Agh Darreh polymetal processing factory is located within 23 Km in the north direction of Takab in West Azarbayjan province, northwest of Iran. Study area is about 4 $Km^2$. The climate is of upland continental type with temperatures reportedly down to -20ºC in winter and up to +30ºC in summer. Most of the precipitations are snow in winter (estimated to be over one meter per year in average); with minor rain in summer and autumn. Precipitation in the whole area is sufficient to sustain permanent creeks and rivers in the lower valleys (overall average is about 325 mm).

After processing works in the factory, remaining wastes which have cyanide as a main contaminant, are disposed in a tailings dam. The tailing dam has been constructed with local fill materials (clay, granular and rock fill) at the end of a naturally occurring valley.

From geological view, the study area is generally covered with alluvium and some members of Qom formation. Qom formation was deposited in central and northern Iran with a thickness of more than 2,700m in the south of Mianeh. The lower layers of this formation include salt, gypsum and anhydrite with alternating layers of silt and clay. The upper layers include siltstone, clay and sandstone. The studying area is tectonically active and quaternary and Pliocene deposits have experienced faulting. The tailing dam is located on an alluvial basin with sediments of clay, silt and marl sandstone.

In this study, the role of gypsum member of Qom formation in hydraulic connection between the tailing dam and downstream karst springs and cyanide contaminant transportation between them are discussed.

## Materials and Methods

Geological map of area (1:2000) was provided using aerial photo interpretations and field works. Water levels in piezometers and some selected spring discharges were measured weekly between September 2005 and February 2006. In order to determine the hydrogeochemical conditions in the dam area, water samples were collected from one well and seven piezometers and two selected springs in August 2006. Major ion concentrations ($HCO_3^-$, $SO_4^{2-}$, $Cl^-$, $Ca^{2+}$, $Mg^{2+}$, $Na^++K^+$) and some parameters such as temperature, electrical conductivity (EC) and pH were measured. For the interpretation of chemical Analysis results and determining the saturation indexes (SI) for calcite, dolomite and gypsum, the Piper diagram and some ionic ratios were used.



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Geophysical investigations with ERI (Electrical Resistivity Imaging) method were carried out at the downstream part of the dam in order to obtain underground geological information and provide a schematic image of gypsum karst and fractured zones development.

Apparent electrical resistivity measured along a 950m line parallel to the dam axis at the downstream region of the dam. The results of the measurements were provided and interpreted as an apparent resistivity traverse section along this line. For environmental monitoring, cyanide concentrations were measured in the water resources of the study area from September 2005 to February 2006. Variations of cyanide concentrations in water resources of area at this period were then discussed. Tracing inspections were also carried out at April 2006 using the NaCl in order to discuss the hydraulic connection between the tailing dam reservoir and the downstream.

**Discussion**

The study area is geologically located in Alborz zone and beside the folded vast Persian plateau. Structural geology of the area includes two orogenic phases of Precambrian and Albian. The study area generally consists of quaternary depositions and Qom formation members such as red to brown sandstone and yellow to green gypsy marls that outcrops in the area. Southern part of the area consists of about 200m thick green to yellow marlstones with intercalations of sandstone. The tailing dam and its reservoir were constructed on these layers. These marlstones containing white to gray gypsiferous layers in the area were expanded from the tailing dam reservoir to karst springs in the vicinity of Agh Darreh River. The dominant layers at northern part of the area include dark brown to red sandstones. Agh Darreh factory and tailing dam were constructed on the anticlinal folded structure that tends to southeast at 5-15 degrees. One fault was reported in the study area in northeast-southwest direction. This fault is responsible for the geological layer displacement at southern part of the area. Also, along this fault some sinkholes exist in marl-Gypsum layers of Qom formation. All sinkholes are solutional and of falling type. This kind of interstratal karstification results from contemporary underground erosion processes and karstic evolution. These sinkholes provide a connection between surface flows and canalized underground flows. This sinkholes exist in the west side of the tailing dam and in the vicinity of the factory main road. These fractures cause the development of gypsum solution and provide conduits for groundwater flow towards the east. Water resources in the study area consist of surface and ground water. Agh Darreh River in the west side of the study area has a permanent flow and numerous small springs appeared at the rim of this river. Gorgha River with seasonal flow lies in the vicinity of the study area in the east side. Some springs with low discharges are present near the Agh Darreh River among which N-3 and N-4 karst springs are the main ones. According to information obtained from the drilling of over 100 piezometers and the results of water level measurements in the area, there is an aquifer characterized as a joint dominated aquifer. With respect to topographic conditions, the aquifer recharge is only dependent on precipitation. According to these measurements, the groundwater flow direction depends on the area's topography. General groundwater flow direction is from north of the area towards the south. In the southern part of the area where karstified gypsum layers exist, these layers pose a controlling role on groundwater flow direction. With respect to Piper diagram, most of the samples are from magnesium bicarbonate type and samples N-3, N-4 and N-8 are from calcium sulfate type. This indicates the solution of sulfate minerals in aquifer. The source of these minerals is gypsum member of Qom formation which expanded in the tailing dam and reservoir area. The ratio of $Ca^{2+}/ Ca^{2+}+ SO_4^{2-}$ equals to 0.5 and the ratio of $HCO_3^-$/all anions is below 0.8, which indicates the solution of gypsum. Most of the groundwater samples are saturated with respect to calcite and dolomite and under saturated with respect to gypsum. Samples N-3, N-4 and N-8 have saturation indices near zero and are nearly saturated. This indicates the accelerated solution in these samples. The ionic ratios in samples collected from the downstream of the dam indicate the solution of gypsum at the karstic conduits of this zone. According to the geophysical investigations with ERI method, the apparent resistivity generally decreases from the left bank to the right bank of the dam. These decreases can be due to lithologic variations of sandstone to marl and gypsum and also can be due to increase of moisture content of rocks and the saturation of fractures with water. In addition to these, some anomalies with low resistivity at the deepest part of the valley as well as some parts of the right bank can be witnessed. With respect to geological setting and drilling data, it is obvious that some gypsum caves exist under the valley. If these caves were filled with air, it was expected that they show high resistance anomalies, but the anomalies with low resistivity in the deepest part of the valley show that the gypsum caves at present act as passways for groundwater.



The low resistance anomalies in the right bank could also result from the development of water saturated small fractures in marlstones. Abnormal high hydraulic gradients can drive the water impounded in the reservoir downstream through fractures reaching below the dam. Under such conditions, the natural process of karstification is accelerated to such an extent that high leakage rates may arise, which endanger the tailing dam. The first leakage of cyanide bearing liquid occurred as a leakage surface at the elevation of 1922m in downstream marlstones. By the time, the tailings level behind the dam was 1934m. Contamination of the N-3 and N-4 springs due to this leakage was reported. These springs lie in the elevation of 1865m with 450m distance from the tailing dam. This leakage occurred in result of the sudden occurrence of a sinkhole in the southwest part of the dam reservoir in the elevation of 1931m. In N-8 piezometer water seepage with cyanide concentrations equal to that of the tailings liquid was also reported in the elevation of 1893m. This indicates the direct relation of them. According to results from environmental monitoring data of the study area, except for N-8 well and the karstic springs of N-3 and N-4, other water resources had no pollution. In order to inspect the variations of cyanide concentration in these three resources, cyanide concentration versus time was prepared as a line diagram. With respect to the high differences in the values of the three resources, the vertical axis of the diagram was considered logarithmic. This contributes to easier comparison and interpretation of the data. In order to specify dry and wet periods of the year, the discharge of the karstic springs of N-3 and N-4 were used. With respect to hydrogeological conditions of the study area, excess of N-3 spring discharge compared to N-4 spring discharge indicates the dry period of the year. According to this diagram, at the dry period of the year until well N-8 was not pumped, cyanide concentration in this well and springs of N-3 and N-4 are the same and low in value. Disposal of mine tailings in southwestern part of the dam reservoir both in dry and wet periods causes the increase of cyanide concentration in well N-8 and springs of N-3 and N-4. This indicates that the southwestern part of the dam reservoir has inherent potential for the seepage of tailing liquids. Pumping of well N-8 at the dry period can cause a decrease in cyanide concentration of spring N-3 and N-4. While the water table depression resulted from pumping, ultimately causes an increase in hydraulic gradient towards the well N-8 and increases the entrance of the polluted liquid to this well. According to the effect of precipitation and increasing the gradient behind the dam, passing water amount from well N-8 area increases so that pumping of this well cannot discharge all of this water. This results in an increase in cyanide concentration in the downstream karst springs.

**Results**

Karst system development in gypsum layers of tailing dam reservoir area poses a controlling role on the trend of groundwater flow. This trend is from northern part of the area to the southwest. According to ERI investigations which were accomplished along a line downwards of the tailing dam axis, the values of apparent resistivity generally decrease from the north bank of the dam to the south one. This can occur due to both lithologic variations from sandstone to marlstone and gypsum and increase in moisture contents and saturation of the fractures with water. Low resistance anomalies in deepest part of the valley indicate that solutional conduits act as a passway for groundwater. With respect to the investigations on the behaviors of N-3 and N-4 springs, these two karstic springs have a unique source and their water is provided from solutional conduit that ends to the well N-8 area. According to cyanide concentration measurements in well N-8 and springs of N-3 and N-4, carried out from September 2005 to February 2006, it can be concluded that there is a hydraulic relation between the southwestern part of the tailing dam reservoir and well N-8 and karstic springs of N-3 and N-4 at downstream.



**Key words**

Gypsum karst, contaminant transportation, tailing dam