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Impact of Tailing Dams on Land and Water Environments Makeng Underground Iron Mine, China

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Abstract: A recent study was carried out around three tailing dams (2 previous and one in operation) in order to determine the impact of tailing from iron ore processing on land and water in the Makeng Underground Iron Mine. The survey focused on the content of sulfate, iron, calcium, bicarbonate, copper, sodium and magnesium in 50 samples of soil, tailing and water (surface and ground water) from 22 different sampling stations distributed around the three dams, together with electrical conductivity and hydrogen potential. The research set out to compare the samples from downstream sampling stations with samples from reference points and samples from upstream sampling stations, relative to each tailing dam, in order to identify the effect of the impoundment on the environment. The research also aimed to compare the tailing sample results between one impoundment to another in order to understand the migration over time of substances from the dams to land and water and to control acid drainage. The research result revealed that the concentration of elements contained in the samples from downstream stations affected by tailing dams is slightly higher than those from reference points and upstream stations that were not affected by tailing. The pH and EC value from downstream areas were also slightly higher compared to those from upstream areas. The result also revealed that EC from the tailing sample from the oldest dam (abandoned 20 years ago) was significantly lower than that obtained in tailing samples from the previous dam abandoned three years ago. The sulfate concentration in the tailing samples from the 2 previous dams were significantly higher than sulfate concentration from tailing samples obtained from the new dam currently in operation. The data made it possible to infer that the tailing in the Makeng Iron Mine had little impact on water and land, which can be explained by an increase in the pH and substances above the background level in the areas affected by the tailing storage.

Key words: Tailing, dams, pH, EC, sulfate, acid drainage, soil, waters, upstream, downstream, reference points

INTRODUCTION

The drop of pH and an increase of sulfate concentration in water samples (surface and ground water) recorded around the Makeng Mine activity area during the previous study (undertaken in 2006) investigation the focus on fine tailing survey. Tailings, waste materials rejected from a mill as slurry after the recoverable valuable minerals have been extracted, in the Makeng Mine are directly spread over the land surface in an upstream constructed dam and contain chemicals from ore processing and unwanted elements which, under the influence of natural conditions, can undergo chemical reactions, thus, resulting in leachate generation. This leachate, containing dissolved metals, can have a significant, adverse impact on land and water if not managed properly.

Makeng underground iron mine is located in longyan city approximately 13 km South-East from Longyan City, China. The geographic coordinates of the mine site are: 117° 04' 16''-117° 06' 04'' Longitude and 24° 57'-25° 01' Latitude.

During 2004 mine exploitation began and in 2006, 900,000 tons of iron ore was exploited. This value is below the estimated value. Among the total ore exploited during the year 2006, there were 410,000 tons of iron (Fe) and 490,000 tons of tailings. The tailing is also divided into coarse particles (130,000 tons) and fine particles (360,000 tons).

The main objectives of the research were to compare the impacts of the different tailing dams on land and water resources and to establish a correlation between these impacts and the environmental change srecorded during the previous study.

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Climates and geology: The climate of the Makeng iron mine is sub-tropical characterized by a relatively short and wet season. The annual rainfall is very irregular. From 1936-1986, the annual precipitation varied from 13349.3-1986.4 mm.

Daily air temperature varied between 18.5 and 26°C in April and the daily water temperature varied between 17 and 24°C during the same month.

The geology of the mine area has been affected by a series of cutting faults forming a natural boundary in some areas (Chen *et al.*, 2006). A very important thick quartz vein has been encountered in the tunnel and a few levels of skarn associated with sulphide mineral (Chalcopyrite: $CuFeS_2$). The chalcopyrite has a metallic brightness varying from brass yellow to gold yellow and can be found in the skarn (Foucault and Raoult, 1980-1995).

Basically, the geology is dominated by limestone, skarn, dolomite, mudstone, sandstone and granite (Fig. 1).

Figure 1 represents the different geological formation types encountered in the Makeng Mine.

The main iron ore bodies (magnetite: Fe_3O_4) of the Makeng Mine are located at the lowest base in the zone of corrosion, 420 m below the land surface. It occurred during the formation of geological layers from the carboniferous (C_2j). A tremendous thickness of karst, rich in water, occurred during the Upper Carboniferous (C_3c).

MATERIALS AND METHODS

Apparatus: Much apparatus and materials were utilized during the field work in order to accurately sample and record to international standard.

Reagent: During the field trip 2 types of reagents (limestone and nitric acid) were used in order to safely conserve the collected water samples. Limestone ($CaCO_3$) was used to ensure the quantity of CO_2 in water samples and nitric acid (HNO_3), for keeping the cations in samples contained in plastic bottles.

Sample collection: When selecting the sampling points different criteria were kept in mind and applied:

- The samples should be taken from the areas affected by tailing (downstream location relative to the dam) and from the areas not affected by tailing (upstream locations relative to the dam).

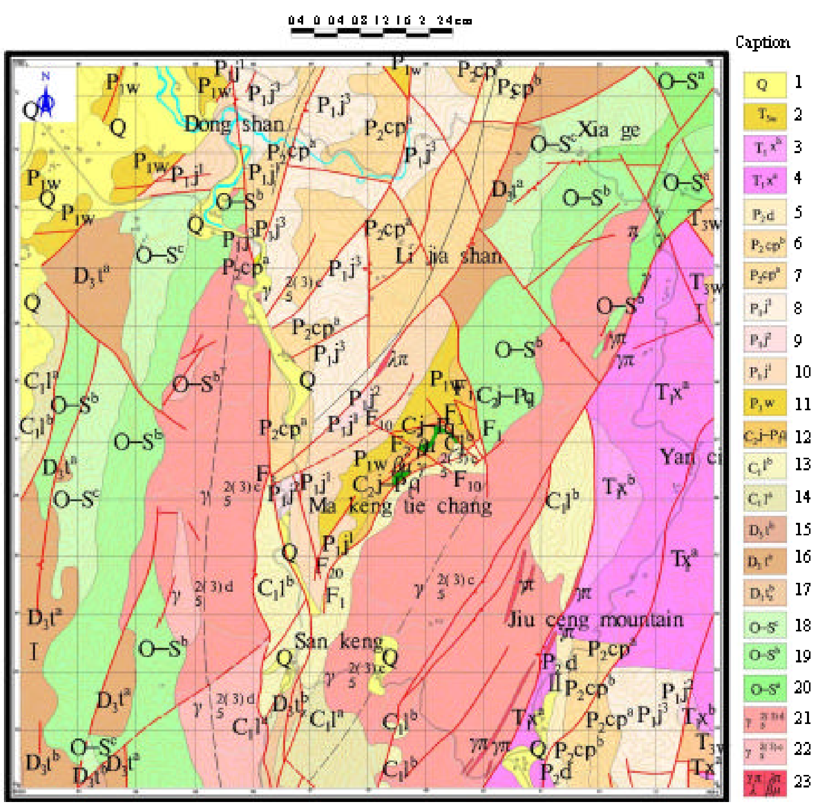

Fig. 1: Geogical map of the makeng mine site

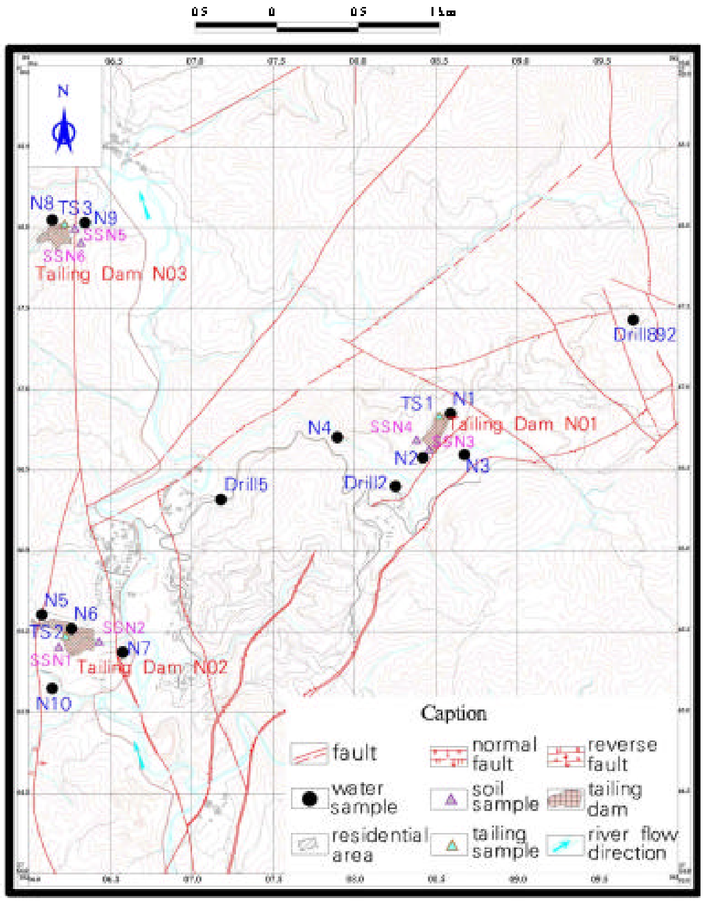

Fig. 2: Makeng unfergroung iron mine's tailing storage facilities map

- The samples should be taken from a reference point outside the mine lease area for comparative purpose; and
- The samples should be taken and kept in a good condition for laboratory analysis.

Different sampling techniques have been applied to soils, surface water and groundwater according to the expected goal. The soil samples were collected with a cup at different depths: below the upper 6 inch (15-20 cm) at upstream locations and above 6 inch (5-10 cm) at downstream locations. The samples, at upstream point, have been taken at a deep zone in order to get accurate information about the background soil conditions. The surface (0-6 in) reflects the deposition of airborne pollutants in particular and also pollutants that do not move downward due to attachment to soil particles (Benjamin, 1992). The dust from tailing can also affect the upper zones. Therefore, the sampling program conducted in these areas will not represent the background soil conditions. Unlike the soil samples, tailing samples were taken at 50-60 cm depth while wearing the protective gloves. Water samples were taken using a grab sampling method. Three samples were collected from each sampling station and each sample taken was represented on a map (Fig. 2) and labeled with date and time, sampling location, as well as sample identification (Spellman and Whiting, 1999).

The Fig. 2 represents the different tailing dams in the Makeng Mine, together with the different sampling stations. The water samples containing nitric acid were analyzed for cations monitoring and those containing limestone for bicarbonate ion (including CO_2) and water samples devoid of reagent were analyzed for anions monitoring. For the tailing and soil samples, only a single sample was analysed (except the sample from the dam N01 where 2 samples were analysed) due to an understanding that these samples reflected the tailing and soil content.

The collected samples were immediately sent to the laboratory of Environmental Monitoring, China University of Geosciences.

Data analysis: Data analysis took place in the laboratory of Environmental Monitoring, China University of Geosciences (Wuhan) for the determination of sulfate, copper, calcium, iron and bicarbonate, sodium ions in water samples and for the determination of sulfate, copper ions, calcium, iron, sodium, pH and EC in soil and tailing samples. For water samples, pH and EC were directly measured in the field.

For the determination of target elements in the soil and tailing, the wet samples were dried in an electric oven at 80°C over night. An addition of 10 mL of HCL was made to 0.5 g of dry samples in a small beaker. The obtained solution was boiled until it was almost dry. In the same way HNO_3 (15 mL), hydrofluoric acid HF (10 mL) and perchloric acid $HCLO_4$ (5 mL) was added in order to break down the liaison between chemical elements and eliminate organic matter contained in the samples. Deionized water was used for obtaining the remaining solution. The solution obtained was stored over night and passed through 0.45 μm diameter pore sized filter before ICP Mass analysis in order to monitor the cation. For the determination of sulfate ion in soil and tailing samples, twenty grams of dry filtered sample was taken and added to 100 mL of deionized water. The resulting solution was mixed in an electrical blender for one hour and stored over night until the soil particles were deposited. Finally, the solution was carefully passed through 0.45 μm diameter pore sized filter for IC (Ion Chromatograph) analysis.

The EC and pH were determined by adding 10 g of dry filtered sample to 50 mL of deionized water, after rinsing the material with water devoid of CO_2, in order to avoid a misleading result. A standard substance, whose pH is known, was used as a control in order to check the accuracy of measurement devices. The solution was mixed and filtered after standing in order to measure EC and pH.

The water samples acidified by adding nitric acid in order to conserve the cations were analyzed by passing the water sample through a filter of 0.45 μm diameter.

The filtered water was analyzed by an Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for cations monitoring. For anions, the water samples devoid of any reagent were filtered and used for anions analysis by means of IC (Ion Chromatograph). The bicarbonate ion was analyzed using the common titration method.

RESULTS AND DISCUSSION

The results of soil and tailing sample analysis are expressed in Table 1.

Table 1 depicts the concentration, in part per million (ppm), of some selected ions (sulfate, iron, copper, calcium and sodium ion) from the sample analysis results, together with EC (in micro Siemens per Centimeter) and pH.

Table 2 depicts the concentration, in part per milligram per Liter, of some selected ions (sulfate, iron, copper, calcium and bicarbonate ion) from water sample analysis results, together with EC and pH.

From the results it can be clearly seen that the data collected (soils and waters) at downstream locations (relative to the different dams) suggest that the impact of tailing on the surrounding environment is slightly an increase in soils, water pH and EC and there is an increase in the quantity of dissolved particles in soils and water. This can be explained by the high value of these parameters at downstream locations (disturbed areas) and by the high value of these parameters in leachate from the different dams. These leachates, if escaped, can contribute to an increase in pH, EC, Ca, HCO_3 and SO_4 at downstream locations (Table 2). The impact is similar around the three dams, that is to say, the value of these parameters at a downstream point relative to each dam is slightly higher (Table 1 and 2) compared to that from upstream locations (undisturbed areas). The values of soil EC, pH and SO_4 from undisturbed areas are generally lower in comparison with those from disturbed areas. This weak value is possibly attributed to the natural soil which tends to become acid as a result of: Rainwater leaching away basic ions (sodium, calcium. Magnesium, potassium), carbon dioxide from decomposing organic matter and root respiration dissolving in soil water to form a weak organic acid and formation of strong inorganic acids (nitric acid and sulfuric acid) from decaying organic matter (Praasterink, 2000).

The low value of SO_4 in undisturbed areas suggests that the sulfate formation is due only to natural process acting on rocks and soils containing gypsum, iron pyrites and other sulfur compounds. Sulfur is widely distributed in nature and can be found in many minerals and ores, for instance, gypsum, iron pyrites and galena (Yunming, 1986).

The increase of SO_4, pH and EC in the tailing storage area and at the downstream locations (affected by tailing) suggests that the dissolution of limestone has played an important role in the process of neutralizing the sulphide mineral (chalcopyrite contained in skarn). The skarn included, or associated with the iron ore body, was broken during the ore processing operations and stored in the tailing impoundment. These broken materials (sulphide mineral and limestone), in contact with oxygen and water, underwent neutralization reaction. This results in pH increase (alkaline) since the amount of limestone is greater compared to the skarn associated with iron ore

Table 1: Tailings and soils chemistry in the Makeng Iron Mine

Samples	Locations/Dams (Locations relative to the Dams)	Date	Time	PH	EC (μS/cm)	SO_4 (ppm)	Fe (ppm)	Cu (ppm)	Ca (ppm)	Na (ppm)
Soil S1	Undisturbed area/damN01	04-04-2007	8:30	5.89	81.9	16.199	323.94	0.26	24.34	17.4
Soil S2	Disturbed area/damN01	04-04-2007	8:37	7.78	94.8	53.256	411.87	0.37	55.20	16.7
SoilS3	Disturbed area/damN02	04-04-2007	10:02	5.65	277.0	95.426	393.46	0.44	14.59	17.88
Soil S4	Undisturbed area/damN02	04-04-2007	10:18	5.21	61.7	2.056	945.15	1.03	10.34	26.01
Soil S5	Disturbed area/damN0 3	04-04-2007	16:17	5.03	68.1	15.835	130.45	0.19	17.14	14.93
Soil S6	Undisturbed area/damN03	04-04-2007	16:21	4.73	108.8	33.569	162.96	0.22	9.11	16.96
Tail S1-1	DamN01	23-03-2007	9:40	7.36	448.0	304.472	1162.81	1.59	1178.22	28.91
Tail S1-2	DamN01	23-03-2007	9:40	7.61	537.0	253.654	1247.26	1.89	1238.82	30.02
Tail S2	DamN02	23-03-2007	17:33	7.01	338.0	183.988	1493.65	2.63	1080.44	17.35
Tail S3	DamN03	30-03-2007	9:35	8.59	122.7	19.897	813.17	0.71	1342.91	30.95

Table 2: Leachate, surface and groundwater chemistry in the Makeng Iron Mine, China

Samples	Locations/Dams	Date	Time	PH	EC (μS/cm)	SO_4 (mg/L)	Ca (mg/L)	HCO3 (mg/L)	Fe (mg/L)	Cu (mg/L)
WS1	Upst/DamN01	23-3-2007	9:29	6.3	164.0	19.031	30.300	73.2240	1.24	0.01
Leachate	DamN01	23-3-2007	9:55	6.2	569.0	220.522	77.860	42.1038	0.22	0.01
WS2	Upst/DamN01	23-3-2007	10:15	6.4	80.0	4.696	11.840	54.3078	3.13	0.01
WS3	Dwnst/DamN01	23-3-2007	10:45	6.5	112.0	12.996	15.160	48.8160	1.20	0.01
WS4	Upst/Dam N02	29-3-2007	17:05	6.2	29.0	3.983	1.750	30.5100	0.43	0.00
WS5	Downst/Dam N02	29-3-2007	17:20	6.4	1568.0	34.698	26.310	67.1220	3.38	0.04
Leachate	Dam N02	29-3-2007	17:55	6.7	1567.0	786.700	344.170	231.8760	0.37	0.01
WS6	Upst/DamN03	30-3-2007	10:12	6.2	40.0	5.474	1.890	30.5100	0.17	0.01
Leachate	DamN03	30-3-2007	10:44	6.3	1144.0	357.350	101.330	85.4280	1.85	0.01
WS7	Reference point	30-3-2007	16:30	6.0	42.0	3.674	3.410	29.8998	1.08	0.01
WS8	Drill 2	N/A	N/A	6.5	430.0	33.980	77.485	232.0700	2.33	0.01
WS9	Drill 5	N/A	N/A	6.5	207.0	9.330	46.115	139.4300	0.21	0.00
WS10	Drill 892	N/A	N/A	6.2	33.3	1.720	1.568	6.0300	0.49	0.01

Table 3: Comparative study of tailing samples from different dams

Samples	Locations	Age	PH	EC (μS/cm)	SO_4 (ppm)	Fe (ppm)	Cu (ppm)	Ca (ppm)	Na (ppm)
TailS1-1	DamN01	Abandoned 3 years ago	7.36	448	304.472	1162.81	1.59	1178.22	28.91
TailS1-2	DamN01	Abandoned 3 years ago	7.61	537	253.654	1247.26	1.89	1238.82	30.02
TailS2	DamN02	Abandoned 20years ago	7.01	338	183.988	1493.65	2.63	1080.44	17.35

body (Fig. 2). This suggests that, in the part of tailing investigated by sampling program, the Net Neutralizing Potential (NNP) is greater than 20 Kg ($CaCO_3$) /ton of the rock materials (Ferguson and Erickson, 1988) in the tailings.The oxidation and neutralization results in an increase of SO_4, pH, EC, together with copper (Table 1).

The low value of SO_4 (19.897 ppm), Fe (813.17 ppm), EC (122.7 μS cm^{-1}) and Cu (0.17 ppm), recorded in the tailing sample collected at dam N01(in operation), suggests that the neutralization reaction that increases the soluble elements has not yet begun (Table 1).

Environmental impact of tailing on land and water: The current and future environmental impact of tailing on land and water in the Makeng Mine, is and will be, the increase of soluble elements above the background level in the areas that are subjected to leachate from the different dams. A comparative study of the different tailings, summarized in Table 3, shows clearly the migration of soluble elements from the tailing dams to the environment.

From analysis, it appears that there is a correlation between the lowest value of the pH from the oldest dam and the lowest value of calcium ion (Ca^{2+}) that can increase the pH. This weak pH is explained by natural process (acidic rainfall) under which the tailing tends to become acidic.

The lowest value of the EC (338 μS cm^{-1}), SO_4 (183.99 ppm), Ca (1080.44 ppm), Na (17.35 ppm) recorded in the tailing sample from the oldest dam (abandoned 20 years ago) is due to the migration over time of substances to land and water, hence the tailing impact on environment. The highest values of Fe (1493.65 ppm) and Cu (2.63 ppm) is due to the possibility that these values were significantly higher several years ago prior to the sampling period. That also explains the increase of iron and copper in soil and water samples. Another environmental impact associated with the tailing is the destruction of soil structure and texture (for instance the amount of clay and sand). The sandy tailing from the different dams can be easily eroded by runoff water and result in an increase of soil sand and ions (Na, Ca). This increase will hamper the rehabilitation tasks due to the characteristic that such type of soil can not effectively store water and nutrients and lowers the number of particle contacts (Farahani, 2002). The storage of abandoned tailing dams will also have an impact on environment by rendering the soil anaerobic. This will smother the soil and deteriorate the soil structures (Sam, 1995).

Measures to minimize environmental impact: The tailing from Makeng Mine is stored over the land (terrestrial impoundment) in an upstream constructed impoundment, localized in the valley, which involves advancing the crest of the embankment progressively upstream as the impoundment is raised (Cooling and Lewis, 1995). Tailing, waste materials rejected from a mill as slurry after the recoverable valuable minerals have been extracted from Makeng is stored in the zone of discharge (valley) that is typically lower (shallow zone of unsaturated material between ground surface and water table) and more subject to runoff water. Spreading the waste materials over the land, in the area where ground water level is near the surface, is an important environmental issue, particularly if the geological strata underlying the wastes are favorable to the percolation of leachate to groundwater. In addition to these risks associated with the tailing storage area, the upstream embankment itself includes some management problems and is not suitable for significant water storage (Vick, 1983).

However, many measures were undertaken in the Makeng Mine in order to minimize the environmental impact. These include: The selection of less sensitive areas where the geology is favorable to the reduction of contamination (for instance, storing the tailing over un-fractured granite), the diversion of runoff water from the tailing storage facility and the carefully controlled discharge of tailing by spigotting off dyke in order to ensure that the coarser tailings are deposited near the starter bund. This is essential to control see page pressures on the embankment and it also provides the strongest materials near the walls for stability and a permeable borrow for the later embankment lifts (Cooling and Lewis, 1995) and the use of grass over the dry sandy tailing as riprap for minimizing wind and water erosion.

CONCLUSION

Further to an environmental analysis of the study carried out on tailing in the Makeng Mine, it can be clearly concluded that the effect of tailing on environment is and slightly increase of soluble substances in land and water. The leachate from the different dams is alkaline due to the dissolution of limestone that has released calcium and bicarbonate ions and the dissolution of other rock materials (dolomite: (Ca, Mg) $(CO_3)^2$) containing electrolytes (such as: calcium, magnesium and sodium ions) which are mainly responsible for increasing EC and pH at downstream locations. The migration of substances from the dams to the environment will significantly increase over time if the dams are abandoned without any follow-up and monitoring plan, particularly, from dam N01(abandoned three years ago) where the permeable limestone is under the tailing at a depth of about 20 m.

The different measures undertaken in order to minimize environmental impact were useful but can be supplemented with an ongoing monitoring system in order to control the amount of metals that will be emitted to the soil and water body. These monitoring procedures need to be continued in and around the different abandoned tailing dams; otherwise, the data provided in Table 3 will by no means adequately describe the effect of tailing on the environment. These data, nevertheless, suggest that mining activity in Makeng has caused minimal degradation to local soil and water resource quality.

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