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Environmental regulatory failure and metal contamination at the Giap Lai pyrite mine, Northern Vietnam

N. Håkan Tarras-Wahlberg[a], Lan T. Nguyen[b,*]

[a]Swedish Geological, P.O. Box 19090, 104 32 Stockholm, Sweden
[b]Department of Water and Environmental Studies, Linköping University, 581 83 Linköping, Sweden

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Abstract

The causes for the failure in enforcement of environmental regulations at the Giap Lai pyrite mine in northern Vietnam are considered and the environmental impacts that are associated with this mine are evaluated. It is shown that sulphide-rich tailings and waste rock in the mining area represent significant sources of acid rock drainage (ARD). The ARD is causing elevated metal levels in downstream water bodies, which in turn, represent a threat to both human health and to aquatic ecosystems. Metal concentrations in impacted surface waters have increased after mine closure, suggesting that impacts are becoming progressively more serious. No post-closure, remediation measures have been applied at the mine, in spite of the existence of environmental legislation and both central and regional institutions charged with environmental supervision and control. The research presented here provides further emphasis for the recommendation that, while government institutions may need to be strengthened, and environmental regulations need to be in place, true on the ground improvement in environmental quality in Vietnam and in many other developing countries require an increased focus on promoting public awareness of industrial environmental issues.

Keywords: Metal contamination; Environmental policy; Acid rock drainage; Vietnam

1. Introduction

This paper examines the causes for the failure in enforcement of environmental regulations at the Giap Lai pyrite mine in northern Vietnam (Fig. 1), and evaluates the environmental impacts that are associated with this mine. The research was conducted as part of a development cooperation project, supported by the Swedish International Development Agency (Sida), and the Vietnamese Ministry of Industry.

Baker (1990) suggested that the two main reasons for environmental policy failure are: (i) regulatory, when no legal mandate exists for environmental protection and (ii) related to enforcement, when the agency charged with environmental supervision and control lacks the infrastructure and/or power to enforce regulations. Efforts to encourage improved environmental management in developing countries have generally focused on the development of environmental regulations, and the setting up of state environmental agencies charged with the implementation of these regulations. Important efforts have also been made in introducing and promoting environmental awareness and the related concepts of cleaner production (CP) and environmental management systems (EMS) within mining companies (Hilson, 2000; Hilson and Nayee, 2001). Internationally, this has led to significant environmental improvements at many mine sites. In developing countries, there have even been cases where international mining companies have assisted developing country regulators in developing new environmental regulations to help ensure responsible mining (e.g. see Hilson and Murck, 2000).

In Vietnam, the legislative framework for environmental management is laid out in the National Law on Environmental Protection (NLEP) from 1993. The NLEP calls for the parties responsible for environmental pollution to pay compensation (the polluter pays principle), and provides a basis for the elaboration of environmental standards, and

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*Corresponding author. Tel.: +46 13 282 959; fax: +46 13 133 630.
E-mail address: LanNg@tema.liu.se (L.T. Nguyen).

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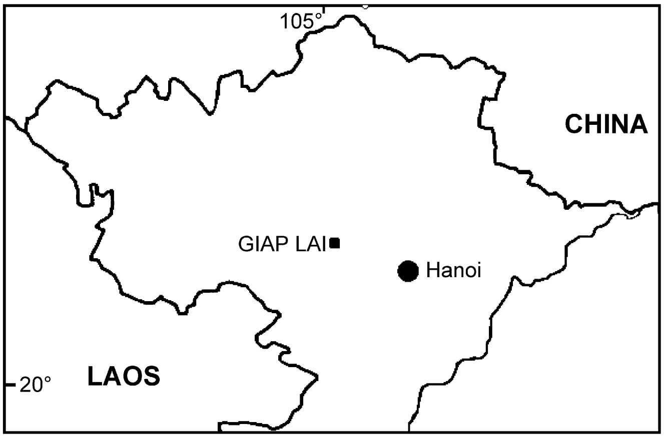

Fig. 1. Map showing location of the Giap Lai mine in Northern Vietnam.

the requirements for Environmental Assessments on both new and existing facilities. The main agency responsible for environmental supervision and control is the National Environment Agency (NEA), within the recently created Ministry of Natural Resources and Environment (MONRE). At the local level, the government has established Departments of Science, Technology and Environment (DOSTEs) in each province, charged with implementing environmental laws for all but the largest firms. So-called Peoples Committees also play an important role in implementing government policies at the local level. People's Committees exist at a range of levels, from village to commune (a group of villages). In this paper, the Giap Lai mining operations serve as an example of to what degree the regulatory regime outlined above is being implemented.

Metal mine sites are often significant sources of metal pollution in water bodies and soils, with associated effects on local ecosystems (Lottermoser et al., 1999). World-wide, there have been many instances of environmental degradation caused by metal contamination from abandoned mining operations (e.g. see Environment Australia, 1997; Bervoets et al., 1998; Azcue, 1999; Apodaca et al., 2000; Martin et al., 2001). The release of metals from such sites is often caused through so-called acid rock drainage (ARD). ARD is generated when sulphide minerals oxidise, releasing sulphuric acid and hence metal ions into solution (Loxham, 1988; Salomons, 1995). Typically, ARD is formed in abandoned mine adits or in tailings impoundments and waste rock deposits. It has been shown that once the formation of ARD has been initiated, it is extremely difficult to mitigate and/or manage. As ARD formation typically takes place over very long time spans, this process may lead to the creation of significant and long-term environmental liabilities (Harries and Ritchie, 1988; Loxham, 1988). The Giap Lai pyrite mine may be such an environmental liability.

2. Study area

The Giap Lai mining area is located in the province of Phu Tho, about 80 km west of Hanoi (Fig. 1). The area is situated in the Doidong valley, at an altitude of 70 m and nestled in among low hills, which reach 200–400 m in height. Currently, about 500 people live in the immediate vicinity of the mine site, and some 5000 live in small villages situated within a 10 km radius.

Mining of pyrite by the Giap Lai pyrite company occurred during the period 1975–1999, after which these operations ceased. The company was then renamed to the Phu Tho Mining and Mineral servicing company and it is now operating a number of smaller kaolin, feldspar and other industrial mineral mines in the area.

Until recently, all mine ventures in Vietnam belonged to the state. Thus, the Giap Lai pyrite company belonged to the Vietnam Mineral Corporation (VMC), which in turn, is positioned within the Ministry of Industry. At the height of operations, activities employed some 1100 people, and 3–4000 people, largely dependent on the mine, were living in areas adjacent to the operations. Most of the employees and beneficiaries were people from the nearby districts, with only some 20% of the work force being drawn from other provinces. At present, the company employs some 150 people.

The mining area is located on a regional water divide, and is drained by two small streams (Fig. 2). These are the Thanh Son, which empties into the Bua River (6.5 km to the NW), and the Thanh Thuy, which empties into the Da River (7 km to the SE). The Thanh Son's discharge varies between 10 and $100\,\mathrm{l\,s^{-1}}$, whereas the Thanh Thuy's discharge varies between 5 and $350\,\mathrm{l\,s^{-1}}$. The Bua River carries $7–50\,\mathrm{m^3\,s^{-1}}$, whereas the Da River is a very large river with flows of several hundred cubic metres per second (SGAB-CIE, 2002).

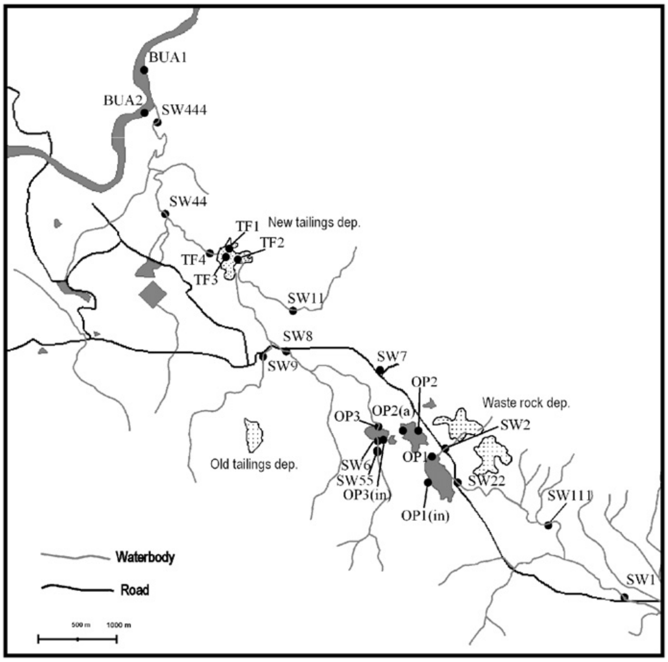

Fig. 2. Map showing the location of all surface water and sediment sampling sites in the Giap Lai mining area.

The climate is monsoonal, with an annual rainfall average of 1600 mm, and with high humidity (80–90%) throughout the year. There is one rainy season, from April to September, during which the monthly rainfall exceeds 200 mm whereas in the remainder of the year, it ranges from 30 to 80 mm. Yearly mean temperature is 23 °C.

During pyrite mining, the exploited ore consisted of three massive ore bodies, with a total length of about 2 km and a grade of pyrite in the range 26–34% (SGAB-CIE, 2002). Mine records suggest that initially, the annual production figures were in the range 10–50 thousand tonnes of pyrite ore. The mine was expanded substantially in the mid-1980s when production initially peaked at over 200 thousand tonnes of ore, then gradually decreasing to below 30 thousand tonnes in the late 1990s (SGAB-CIE, 2002). Mining was performed in three pits. Open Pit 1 (13 ha) was mined from 1975 to 1995, Open Pit 2 (15 ha) from 1992 to 1996 and Open Pit 3 (2 ha) was mined from 1996 to 1999 (Fig. 2). The mining operation terminated in 1999, and all three pits are now abandoned and filled with water. Open pits 1 and 3 have surface water outflows, whereas the second pit is hydrologically closed (SGAB-CIE, 2002).

Mine records suggest that a total of more than 5 million m^3 of waste rock was removed from the three pits during mining. About one million m^3 of this waste rock is stored in two deposits situated to the north of the open pits, and it is also believed that a substantial part of waste rock has been used to backfill the three open pits (SGAB-CIE, 2002). The ore was treated in a central concentration plant, and mine records suggest that a total of 1.2 million tonnes of pyrite ore was produced. Tailings from the process where deposited in two tailings facilities (Fig. 2). A first tailings dam was used up until the late 1980, and it contains about 200,000 tonnes of material. The newer facility, used from the late 1980s until mining ended contains some 880,000 tonnes of tailings (SGAB-CIE, 2002).

3. Methods

The work performed was multidisciplinary in nature and both quantitative and qualitative information has been collected. Most data were collected either on site in Giap Lai or at the Ministry of Industry in Hanoi. Fieldwork was conducted on four occasions from 1997 to 2002: in September 1997 when operations were still ongoing; April 2001; February 2002; and March 2002 when operations had ceased.

3.1. Literature review and interviews

The research included a review of the Vietnamese policy framework, the relevant legislation and the institutions involved in environmental management issues. Interviews with mine management and staff at the Ministry of Industry as well as relevant local institutions (DOSTE and People's committees) were undertaken to obtain detailed information relevant to this case study.

3.2. Waste characterisation

The waste products produced from the mining operations were analysed to assess their long-term potential to produce contamination. This was achieved by analysing metal content and by conducting leaching experiments. The solid waste samples were collected during February and March 2002.

Composite samples of solid waste were sampled from waste rock deposits north of the open pits (10 samples), and from new and old tailings facilities (3 samples each). At each site, composite samples comprising five different 0.5 kg subsamples collected from areas of about 10 m^2 were collected. The samples were taken both at the surface and at depths of as much as 0.5 m. The composite samples were thoroughly mixed and then crushed in a mortar, whereafter they were dissolved in aqua regia before the contents of Al, Fe, Cu, Ni, Pb and Zn were determined by Atomic Absorption at the NIMM laboratories in Hanoi.

Four source materials for metal contamination were selected for leaching experiments using humidity cells: (i) waste rock; (ii) fresh material from the new tailings facility; (iii) older and partly oxidised material from the new tailings facility and (iv) material from the old tailings facility. The procedures and designs of the leaching tests followed Sobek et al. (1978), and the tests were run for a period of 28 weeks. The objective of such tests is to accelerate the processes of leaching and buffering, and in this way ascertain if the material will, in the longer term, generate ARD. Water from the new tailings impoundment was used to moisturise these tested samples before the oxidation process to ensure the presence of bacteria during oxidation. The leachates collected each week were analysed for pH, electrical conductivity, and sulphate concentration. The leachate analysis was carried out by using handheld instruments, through titration and by using a spectrophotometer, respectively, at the NIMM laboratories in Hanoi.

3.3. Assessment of environmental impacts

The severity of environmental impacts was investigated by collecting samples of surface waters, and stream sediments at selected sites in and around the mining area (Fig. 2). Surface water was taken during all sampling campaigns. Stream sediment sampling was collected twice (in September 1997 and February 2002).

3.3.1. Surface water

Physico-chemical parameters were determined in the field by standard handheld instruments and complimentary wet chemistry analysis at National Institute of Mining and Metallurgy's (NIMM) laboratories in Hanoi. The water samples for analysis of metals were passed through a

0.45 μm filter and thereafter acidified to pH 2 in acid-washed polyethylene bottles. Metal concentrations were analysed by ICP-AES/MS at the Analytica laboratories in Luleå Sweden.

3.3.2. Stream sediment

Stream sediment composite samples, comprising three water-saturated subsamples, were collected with a spatula at each site, with each subsample weighing about 250 g. The subsamples were thoroughly mixed together to make up the composite samples, and these were collected in plastic bags and then kept in a cooler. The samples were submitted to the Analytica laboratories in Luleå, Sweden for analysis. At the laboratory, the samples were wet sieved through $<63\,\mu$m mesh and dried before they were bomb digested in a mix of concentrated nitric acid and hydrogen peroxide (30%). The samples were then analysed by ICP-AES/MS for all metals, except mercury, which was analysed by Cold Vapour Atomic Fluorescence.

3.3.3. Method of interpretation

The evaluation of impacts is based upon comparisons with: (i) estimations of world wide average concentrations of metals in water and sediment (Wedepohl, 1991; Förstner and Wittman, 1983); (ii) WHO guidelines for drinking water quality (WHO, 2004); (iii) US EPA water quality standards for the protection of aquatic life (US EPA, 2005a); (iv) US EPA sediment quality guidelines for the protection of aquatic ecosystems (US EPA, 2005b) and (v) conditions at sites that have not been affected by mining and processing, or other industrial activities—so-called background values.

4. Results

4.1. Waste characterisation

The sources of metal contamination in the mining area mainly consist of: (i) waste rock, and (ii) process tailings. Table 1 summarises the metal content of samples taken from the two tailings impoundments and the waste rock deposits. It can be seen that most of the samples contain appreciable amounts of metals. Further, the levels of toxic trace metals are similar in all three types of material.

The results of the leaching tests are illustrated in time series in Fig. 3. The progressive leaching of a fresh sample from the new tailings impoundment (new tails) shows that this material is initially well buffered, as the pH remains high until week 6. However, after week 6 the pH falls dramatically to stabilise at between 2 and 3. Simultaneously, there is an increase in the conductivity of the leachate coupled with a concomitant increase in sulphate levels. This provides good evidence that, in spite of initially being well buffered, this material will eventually generate ARD.

The other three samples, representing waste rock, material from the old tailings impoundment, and already oxidised parts of the new tailings impoundment have similar leaching characteristics. Unlike the new tails, pH values are low already from the onset, equilibrated at around 3. The pH remained stable through the duration of the experiment. Conductivity readings and sulphate concentrations gradually decrease with time, showing how the easily leachable sulphide minerals become progressively scarcer. Thus, it is suggested that waste rock and tailings material will generate considerable amounts of ARD, and that this may occur over a long periods of time. These conclusions are corroborated by the results of the field sampling and analysis (see below).

4.2. Environmental impacts

Three main areas of surface water contamination were examined: (i) areas downstream of the new tailing impoundment; (ii) water in the open pits and (iii) water downstream of the waste rock deposits. Further, six water samples were collected to represent local background conditions. The median background values were thus calculated. The results are summarised in Table 2.

The background conditions encountered are overall in line with existing estimation of worldwide background levels. Thus, there appears to be no significant natural elevation of metal levels in water upstream of the mining area. Conversely, the contrast between the background conditions and impacted areas is marked.

Table 1
Median metal content in waste rock, and material from the old and new tailings facilities

		Al (%)	Fe (%)	Cu (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})
Waste rock	Median	8.1	16.7	76	*92*	26	88
($n = 11$)	Std. dev	2.7	24	106	63	24	57
Old tailings dam	Median	3.4	23.9	97	*55*	19	223
($n = 3$)	Std. dev	0.69	9.2	23	5	0.58	68
New tailings dam	Median	5.9	4.9	125	*58*	22	69
($n = 6$)	Std. dev	1.7	4.1	111	56	9.2	39
US EPA (ERM)		—	—	270	52	218	410

US EPA sediment quality guidelines are used for comparison.

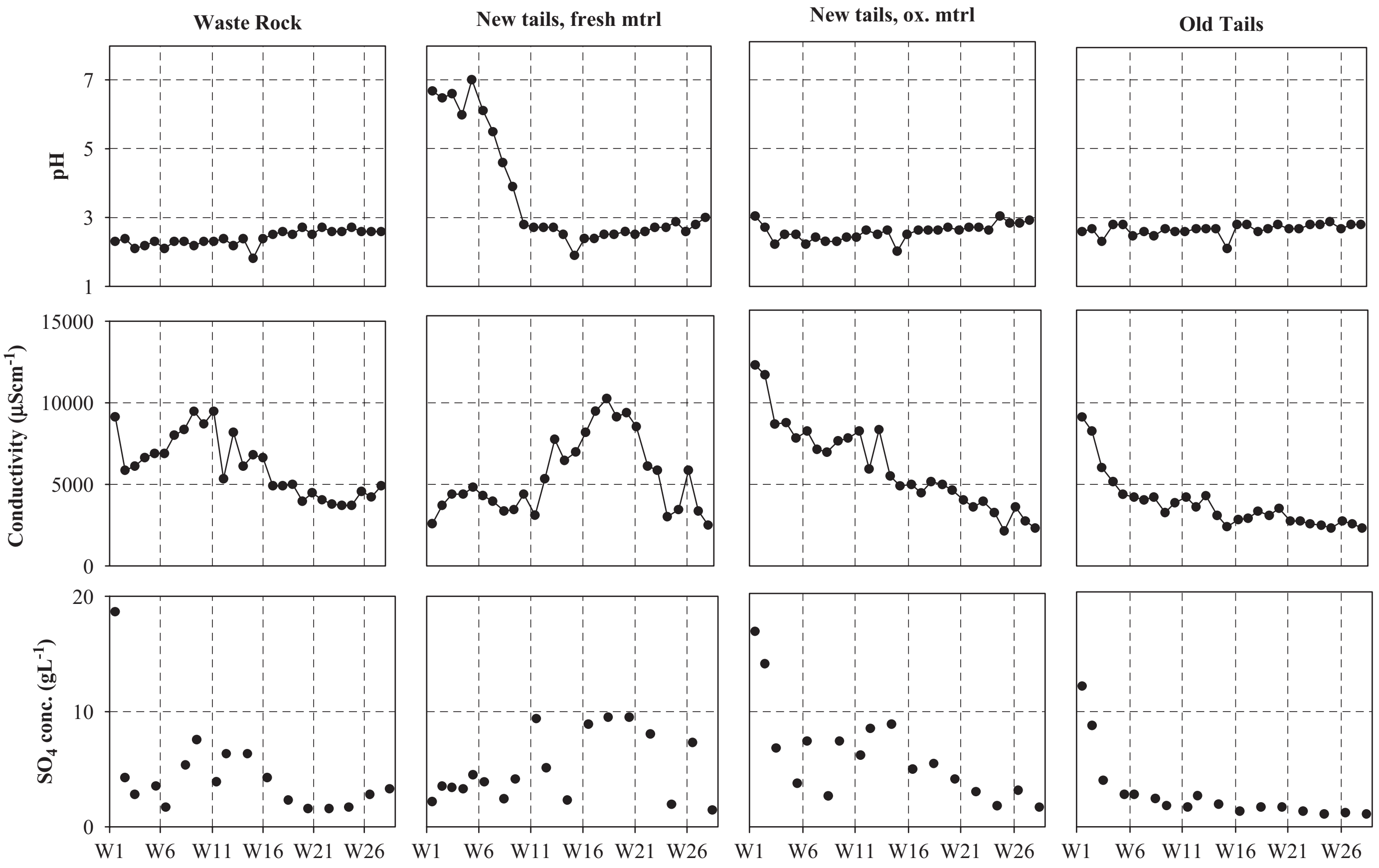

Fig. 3. Graphs showing results of the leaching experiments.

Samples collected downstream of the new tailings impoundment have low pH and highly elevated concentrations of Al and of the trace metals Cd, Cu, Ni, Pb and Zn. Further, concentrations of the less toxic Zn and Mn are very highly elevated downstream of this facility. Seepage appearing at the foot of the tailings impoundment (TF4) contains especially high concentrations of metals, and sampling at this site in 1997, 2001 and 2002 suggests that metal leaching is becoming progressively more severe with time (Fig. 4). The pH of this seepage has decreased dramatically during this period, from just below neutral in 1997 when operations were still ongoing (6.3), to strongly acidic in 2001 and 2002 (5.4 and 3.0, respectively). In the 2002 investigation, the seepage water contained high concentrations of metals that are toxic to both humans and to aquatic life. The concentrations are, however, relatively rapidly diluted downstream (Fig. 5). Thus, the metal concentrations at SW444, a bit more than 1 km downstream of the new tailings impoundment, although still noticeably elevated, no longer exceed US EPA water quality standards. Further, the effect on the Bua River (cf. samples Bua 1 and Bua 2) appears to be negligible (Fig. 5). Similarly, water samples collected downstream of the waste rock deposits have low pH and elevated concentrations of Cd, Cu, Ni, Pb and Zn (Table 2). However, low metal concentrations in samples taken some distance downstream (e.g. SW111 and SW1) suggest that significant impacts are restricted to an area less than a few kilometres downstream of the waste rock deposits.

Water samples collected from the three open pits show that water quality varies significantly between the pits (Table 2). Water in open pits 1 and 3 is of good quality, with near neutral pH, and only modestly elevated levels of metals (although with a fairly high level of Cd being recorded in Pit 1 in 1997). In contrast, the water in open pit 2 has levels of Cd, Cu and Ni that exceed water quality criteria for protection of aquatic life. Further, it is clear that water quality of Pit 2 deteriorated from 1997 to 2002. The pH was 6.7 in 1997, whereas it was 3.1 in 2002. The concentration of Al, Cr, Cu, Mn and Pb increased dramatically during the same period (Table 2). The reason for the poor water quality found in Pit 2 is likely to be a result of the hydrological regime of the pit in combination with the presence of large deposits of sulphidic waste rock on the pit's northern and eastern shores. As Pit 2 has no surface water outflow, the ARD drainage that is formed in these deposits cannot be drained out of the pit. Thus, once the buffering capacity of the water and the sediment in the pit were exhausted, the pH dropped and metals entered into solution. As a result, Pit 2 is devoid of life, whereas the other two pits support aquatic fauna (SGAB-CIE, 2002).

Stream sediment quality data are shown in Table 3. Site SW55 was selected as a background site. However, it can be seen that the levels of As, Cd, Cu, Hg and Zn

Table 2
Analysis results for surface water samples collected in the Giap Lai mining area

Sample	Date	pH	Al (μg l^{-1})	As (μg l^{-1})	Cd (μg l^{-1})	Cr (μg l^{-1})	Cu (μg l^{-1})	Mn (μg l^{-1})	Ni (μg l^{-1})	Pb (μg l^{-1})	Zn (μg l^{-1})
Samples affected by drainage from the new tailings deposits											
TF1	Feb-02	7.0	4.8	0.18	0.023	0.05	1.1	230	1.5	0.078	0.88
TF2	Feb-02	3.1	***1700***	0.093	**0.98**	2.4	**81**	*1700*	***72***	**3.9**	69
TF3	Sep-97	6.8	15	1.1	**10**	0.89	**54**	*3400*	***180***	<0.20	**220**
TF4	Sep-97	6.3	***390***	<4.3	***3.7***	1.6	**35**	*3300*	***73***	1.5	74
	Apr-01	5.4	***1960***	2.4	***3.9***	0.7	**290**	*6700*	***240***	0.97	**130**
	Feb-02	3.0	***26,000***	*19*	***3.4***	*66*	**720**	*3000*	***280***	**8.1**	**300**
SW44	Apr-01	6.6	***190***	0.91	***2.1***	0.027	**61**	*4000*	***130***	<0.030	55
	Feb-02	3.8	***4700***	0.13	**0.73**	5	**160**	*980*	***53***	0.28	60
SW444	Apr-01	7.2	17	0.66	0.18	0.072	2.7	*730*	11	0.21	3.2
Samples affected by drainage from the waste rock deposits											
SW1	Sep-97	7.2	***170***	0.65	0.077	0.84	0.86	*1400*	7.1	0.34	7
SW111	Apr-01	6.7	6.3	0.5	0.11	0.026	0.51	*5300*	10.7	<0.030	4.9
SW2	Sep-97	6.8	***880***	0.47	0.24	1.5	**16**	*1600*	14	0.94	18
	Apr-01	6.5	28	0.32	**0.6**	0.019	2.2	*6300*	*24*	<0.030	65
SW22	Mar-02	6.4	39	0.72	0.18	<0.05	<0.5	*7000*	18	<0.050	26
SW3	Sep-97	7.2	***16,000***	<4.8	**1.2**	12	**73**	*9600*	***170***	**9.1**	**220**
SW4	Sep-97	4.6	***6700***	<4.3	**1.9**	5.4	**160**	*8300*	***99***	0.57	**140**
SW8	Sep-97	7.3	***1000***	1.4	0.12	5.6	**14**	390	5.3	**8.4**	19
Samples form the open pits											
OP1	Sep-97	6.7	69	<1.0	1.3	0.69	1.7	*1100*	*31*	<0.20	220
	Apr-01	8.0	66	0.38	0.21	0.039	1.4	*500*	9.1	0.18	12
	Mar-02	7.6	20	0.45	0.15	0.034	0.75	*550*	6.6	0.074	9.6
OP2	Sep-97	6.7	***116***	1.2	***7.6***	0.89	**36**	*6100*	***250***	<0.20	**1400**
OP2 (a)	Mar-02	3.1	***9400***	<0.10	***3.1***	5.2	**79**	*8200*	***220***	**4.4**	**350**
OP3	Apr-01	7.7	28	0.56	0.0089	0.12	2.1	100	3.1	0.058	0.7
OP3 (out)	Nov-01	6.9	5.2	1.9	0.0025	0.076	1.2	*530*	2.6	0.033	1.4
Samples from the Bua River											
BUA1	Apr-01	7.4	6.4	0.23	0.0083	0.19	0.64	15	0.36	0.093	0.7
BUA2	Apr-01	7.4	7.6	0.24	0.014	0.2	0.76	20	0.42	0.14	1.3
Background sites											
OP1 (in)	Nov-01	6.7	***190***	0.7	0.1	0.36	2	110	1.5	0.94	9.4
OP3 (in)	Nov-01	6.9	***112***	1.4	<0.002	0.15	3.6	100	0.56	0.26	2.2
SW11	Sep-97	7.0	***160***	<0.30	<0.020	1.4	0.94	68	1.3	0.68	1.5
SW55	Apr-01	7.0	7.5	0.49	<0.005	0.26	0.43	*650*	1.2	0.05	11
SW6	Sep-97	7.4	***97***	<0.30	<0.020	1.2	0.4	82	1.3	0.24	2.1
SW9	Sep-97	7.4	***200***	0.73	<0.020	1.2	0.84	150	1.7	1.7	2.3
Median background		7.7	***112***	0.7	0.02	0.36	0.84	110	1.3	0.26	2.3
Background (Förstner & Wittman, 1983)					0.07	—	1.8	—	—	0.2	0.5
US EPA CCC[a]			87	150	0.25	74/11[b]	9	—	52	2.5	120
WHO			100	10	3	50	2000	400	20	10	3000

Data in bold exceed the chronic level of US EPA quality standards for the protection of aquatic life, whereas data in italics exceed WHO guidelines for drinking water quality. Data in italic bolds exceed both standards.

[a] Dissolved concentration in water hardness of 100 mg l^{-1} $CaCO_3$.

[b] Cr (III)/(VI).

encountered at this site are high in comparison to the world average for metal concentrations in sediments (Förstner and Wittman, 1983). Downstream of the contamination sources, the metal levels are elevated compared to background. The elevations are; however, modest, and there are only a small number of cases where metal levels exceed US EPA standards. Those highest concentrations are found at the sites TF4 and SW44 which are both situated downstream of the new tailings facility. The impacts on sediment quality rapidly become less serious further downstream. This is illustrated by two samples taken from the Bua river were the sample taken upstream of the influence of the Giap Lai mining area is near identical to the one taken further downstream (Fig. 6).

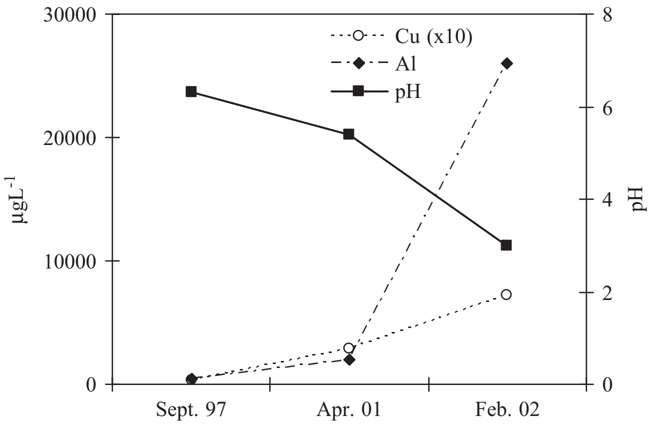

Fig. 4. Graph showing pH and the concentrations of Cu and Al at a site (TF4) downstream of the new tailings deposit.

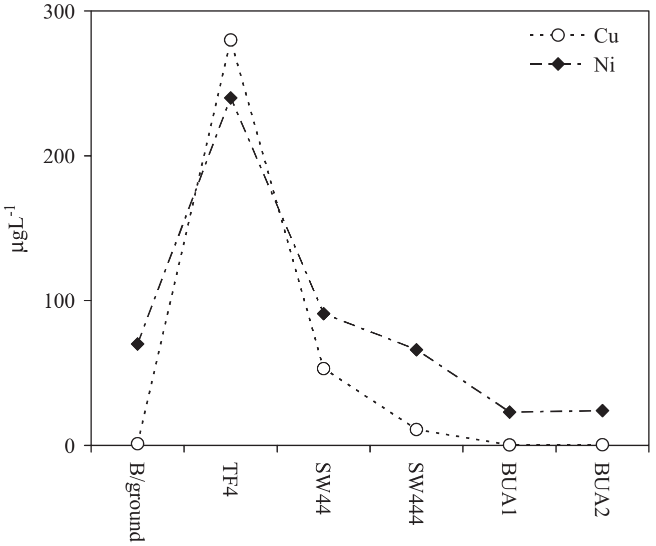

Fig. 5. Cu and Ni concentrations in surface water affected by drainage from the new tailings facility. The sampling locations are plotted in downstream direction, left to right. Samples taken in April 2001.

4.3. Policy discussion

It is shown that sulphide-rich tailings and waste rock in the Giap Lai mining area represent significant sources of ARD, causing elevated metal levels in downstream water bodies, which in turn, represent a threat to both human health and to aquatic ecosystems. The mine site now represents a considerable environmental liability.

Furthermore, as a result of the failure to undertake any efforts to remediate this liability, the impacts are becoming progressively more severe.

In addition to the NLEP, the Mineral Law of 1996 contains environmental regulations that specifically target the mining sector. In this law, it is stated that activities in the sector must use technologies that are environmentally friendly, and that after the completion of mining the affected land and surroundings must be rehabilitated and/or reclaimed. The Mineral Law also states that any organisation or individual involved in a mining venture must deposit funds in an authorised bank account in order to assure that funds for rehabilitation will exist at the end of the mine's life. Additionally, the Vietnamese

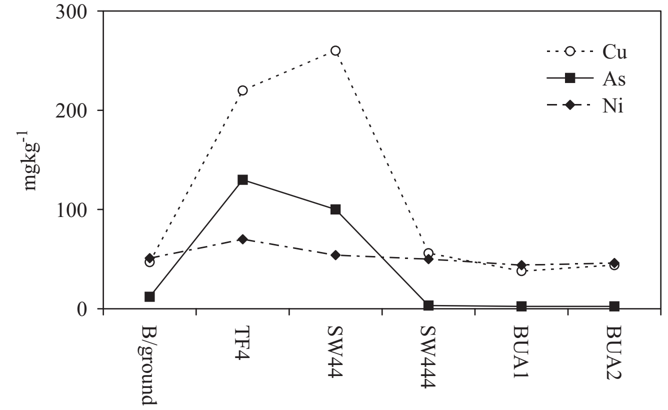

Fig. 6. Cu, Ni and As concentrations in sediments downstream the new tailings facility. Sampling locations are plotted in downstream direction, left to right.

Table 3
The content of metals and arsenic in sediment samples

Sample	As (mg kg^{-1})	Cd (mg kg^{-1})	Co (mg kg^{-1})	Cr (mg kg^{-1})	Cu (mg kg^{-1})	Hg (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})
TF4	**130**	0.72	12	99	220	0.042	**70**	12	120
SW44	**100**	0.45	11	100	260	0.057	**54**	21	87
SW444	3.2	0.33	27	100	56	0.044	50	24	98
BUA1	2.4	0.21	23	103	38	0.081	44	23	85
BUA2	2.4	0.32	22	100	44	0.075	46	24	93
OP1	36	0.53	8.9	34	21	0.043	40	12	**420**
SW2	**110**	0.67	18	110	110	0.090	**54**	27	300
SW55	12	0.99	42	69	47	0.12	51	24	220
World average	6	0.35	—	—	30	0.06	—	35	90
US EPA ERM	70	9.6	—	370	270	0.71	52	218	410

World average and US EPA sediment quality guidelines are included for comparison. Sample SW55 represent background conditions. Data in bold exceed US EPA sediment quality guidelines.

Government Circular from 1999 provides further guidelines for how such funds should be set up, and stipulates requirements for mine closure. Further, according to Ministry of Industry staff, these laws and regulations were communicated to all Vietnamese mining operations. It is clear, thus, that a legal mandate exists for environmental protection in the Vietnamese mining industry.

In many countries, informal community pressures have been shown to increase the frequency and effectiveness of environmental supervision and control (Dasgupta et al., 2000; O'Rourke, 2004). Also in the Giap Lai area, during active mining, there were cases were the local community lodged environmentally related complaints to the company; including in these complaints were issues such as contamination of water resources, and agricultural land. In line with Vietnamese policy, these complaints were lodged at the People's Committee, as well as with the Phu Tho DOSTE. According to mine management, the complaints led compensation being paid out for damage caused in cases where drainage from the mining operations found their way into farming areas and domestic wells.

Before closure there were activities undertaken by the Ministry of Industry, which suggest that the need for environmental measures were acknowledged by the mine owners. Investigations were undertaken and needs for mitigation measures identified (SGAB-CIE, 2002). The waste materials were identified as significant environmental liabilities, which needed to be addressed. Importantly, the significance of not allowing the new tailings facility to oxidise and thereby cause ARD was identified at a relatively early stage (SGAB-CIE, 2002). However, no effective measures were subsequently taken. Instead, the new tailings facility which was water covered during operations, was subsequently allowed to drain and partially dry out and, as predicted by leaching experiments, thereby exposing the tailings to extensive oxidation and associated mobilisation of metals. This, in turn, is leading to a progressive worsening of downstream impacts (cf. above). Mine management argued that the lack of appropriate environmental measures was a consequence of "the financial support for addressing these impacts not being forthcoming, neither from the VMC nor the Ministry of Industry…". This statement, in turn, implies that the Giap Lai pyrite company was not prepared to, on its own accord, take on the environmental responsibility that is stipulated in Vietnamese law. The end effect was that no effective post-closure, remediation measures were applied. Possible reasons for this regulatory failure are discussed below.

Tarras-Wahlberg (2002) suggests a number of reasons behind the failure to apply existing environmental regulations in a mining district, some of which may be relevant in Giap Lai area. These include a lack of financial resources on part of the mining companies; lack of awareness of the legislation on part of the mining companies and/or the supervising authorities; inadequate capacity of the governmental and provincial authorities charged with environmental supervision and control and lack of public participation and pressure in issues related to environmental management. O'Rourke (2004) reports from Vietnam and identifies public involvement in industrial environmental management issues, not including mining, as the key driver in cases where environmental regulations have been successfully applied in this country. The type of public participation identified by the author is, however, not official participation in the regulatory process (which is, in any case restricted by law) but rather a more spontaneous and unofficial form. O'Rourke (2004) identifies a number of further characteristics that are important in these cases where public participation has succeeded in influencing the regulatory process, including community cohesion and mobilisation, and external political linkages (mainly to local government authorities through personal connections).

Even in the Giap Lai case, it is clear that the community has been active and lodged complaints against the company, and as a result some limited compensation was paid out. However, with regards to issues of major environmental importance, that is the adequate and long-term management of the mine's waste products, this public pressure was not sufficient to prompt the company to take appropriate action. Neither was funds deposited for post-closure rehabilitation, in spite of the existence of such a regulatory requirement. O'Rourke (2004) suggests that when a Vietnamese firm has a direct linkage to the state through ownership, this may increase its ability to resist community pressure and the firm thereby not be forced into compliance. Further, the lack of international investments in the Vietnamese mining sector, has meant that the local industry has not become exposed to, and learned from, the significant improvements of environmental performance in mining operations that have been achieved in recent years (c.f. Warhurst and Bridge, 1996; Hilson and Murck, 2000). It is suggested that these facts, coupled with the general finding that mining companies that are not forced to plan for closure, usually do not have sufficient funds available for remediation once a mine is due for closure, are the important reasons for the lack of enforcement of environmental regulations at the Giap Lai mine.

5. Conclusion

Sulphide-rich tailings and waste rock in the Giap Lai mining area represent significant sources of ARD. The ARD thus formed is causing elevated metal levels in downstream water bodies, which, in turn, constitute a threat to both human health and aquatic ecosystems. It is shown that metal concentrations in impacted surface waters have increased after mine closure, suggesting that impacts are becoming progressively more serious.

No post-closure, remediation measures have been applied at the Giap Lai mine, in spite of the existence of environmental legislation and both central and regional institutions charged with supervision and control. The research presented here provides further emphasis for the recommendation that, while government institutions may need to be strengthened, and environmental regulations need to be in place, true on the ground improvement in environmental quality in Vietnam and in many other developing countries require an increased focus on promoting public awareness and participation in industrial environmental issues.

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