Mine Closure 2009 — A.B. Fourie, M. Tibbett (eds)
© 2009 Australian Centre for Geomechanics, Perth, ISBN 978-0-9804185-9-0
https://papers.acg.uwa.edu.au/p/908_19_Ahn/

Water quality within mine waste impoundments at an incompletely remediated Cu-Pb-Zn mine site in Korea

J.S. Ahn *Korea Institute of Geoscience and Mineral Resources, Korea*

Y-W. Cheong *Korea Institute of Geoscience and Mineral Resources, Korea*

G-J. Yim *Korea Institute of Geoscience and Mineral Resources, Korea*

Abstract

Many of the closed mines in Korea have been abandoned without proper environmental protection measures. Some failures in preventing contamination from mine wastes have been reported even where remediation works were conducted. In this study, water quality variation in borehole groundwater and surface runoff was investigated on a seasonal basis within the waste impoundments at a mine site where previous rehabilitation measures were unsuccessful. The groundwater was typical acid mine drainage with pH 3.5–4.6 and high total dissolved solids (TDS) (390–3330 mg/L) during the dry season, and decreases of pH to 2.7–3.6 and increases in metal contents during the rainy season. Surface runoff showed a similar pattern of water quality variation. Good correlations were found between the concentrations of major and trace elements measured. It is suggested that dissolution of soluble secondary salts caused by flushing of weathered waste rocks and tailings directly influenced the water quality within the waste impoundments. Increases in acid and metal concentrations and their loadings from mine wastes are anticipated in the rainy season. It is necessary to apply more appropriate cover systems on waste rocks and tailings with the consideration of more extreme conditions in the study mine.

1 Introduction

Most of the metalliferous mines in Korea were abruptly closed ten to forty years ago for economic reasons. They were abandoned without implementation of proper mine closure procedures and environmental protection plans. During the last ten years environmental reclamation has been carried out at many of the sites by national and local authorities. However, some failures have been reported in mine waste stabilisation, revegetation and acidic drainage treatment. For example, at Geopung Mine retaining walls and soil covers of waste rock piles and tailings deposits were implemented in 2003. While mechanical erosion and dispersion of waste materials were prevented, vegetation on top of the waste impoundments later died, and acidic leachate was continuously released into receiving streams. In this study, variations in water quality in boreholes and surface runoff within the waste impoundments of the mine were investigated by monitoring water level, electrical conductivity (EC) and temperature, and chemical analysis on a seasonal basis.

2 Study mine and methods

Geopung Mine located at the centre of the Korean peninsula (Figure 1) was sporadically mined for Cu, Zn, Pb, Au and Ag during the 1960s and 1970s. Finally, it was closed in 1998. The mine exploited a fissure filling deposit along the boundary between Jurassic granite and metasedimentary rocks of unknown age. After closure, mine wastes were abandoned without proper treatment. The waste rock contained chalcopyrite, pyrrhotite and pyrite, and continuously produced acidic drainage. Tailings had high concentrations of Cd, Cu and Zn, and served as the major contamination source at nearby agricultural fields. During 2003, reclamation works (erosion control measures) were conducted at tailings (8,184 m^3) and waste rock (2,500 m^3) impoundments. The waste material was covered with 20–100 cm of soil and was seeded. Unfortunately, the waste rock cover soils were later subsequently eroded, and revegetation efforts failed (KIGAM, 2007).

Boreholes with 7–13 m depths were drilled in waste impoundments GW#1 to 3 (Figure 1) for the collection of groundwater samples. Average thickness of tailings and waste rocks in boreholes was 3 m. Groundwater was periodically sampled from March to October 2008. Surface leachate waters (SW#1 and SW#2 in Figure 1) were collected at available sampling points along drainage ditches. During rainfall events, runoff waters (RW) on the waste rock impoundment were sampled from collection pipes. Temperature, pH, and electrical conductivity (EC) were measured in the field. Water samples were filtered through 0.45 µm membrane filters and two aliquots, one acidified with nitric acid and one unacidified, were stored at 4°C before analysis in the laboratory. Acidified aliquots were analysed for most cations with ICP-AES. Ion chromatography (IC) was applied to analyse sulphate in unacidified aliquots.

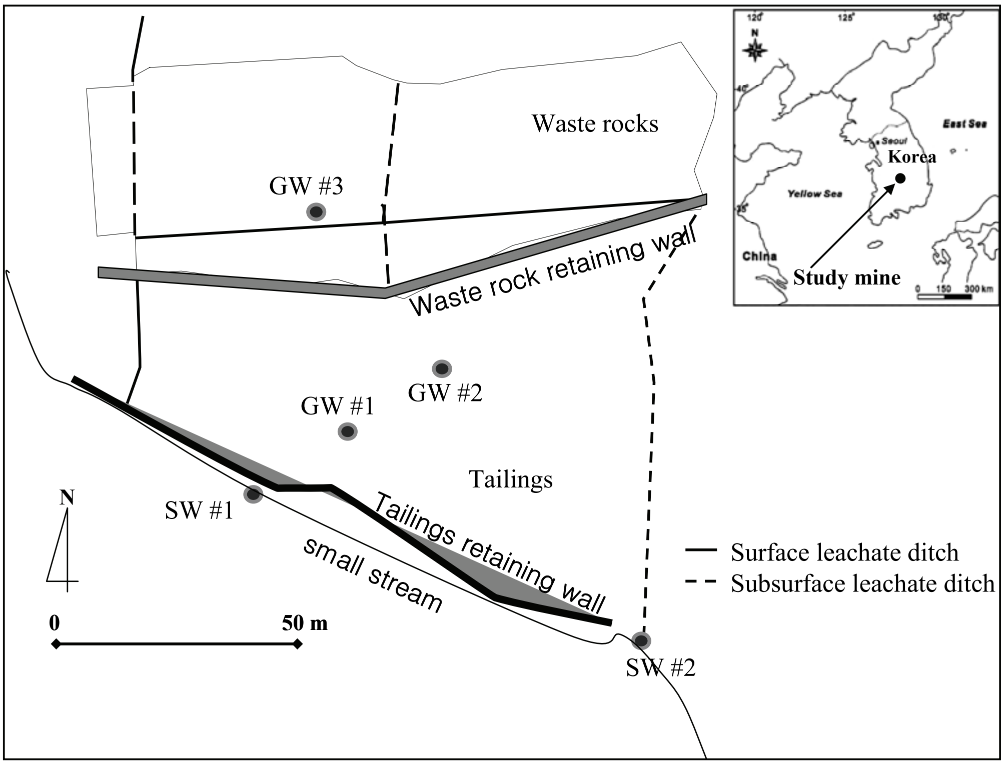


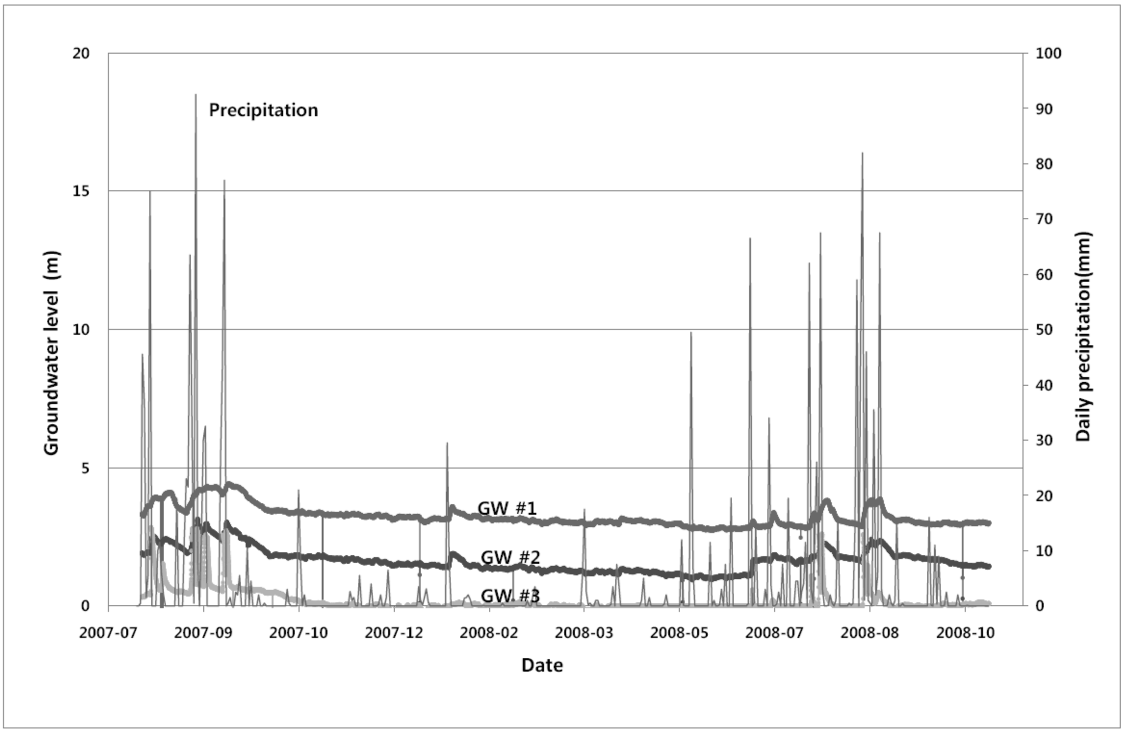
Figure 1 Plan of waste impoundments and sampling locations at Geopung Mine

3 Results and discussion

3.1 Groundwater level and water quality at waste impoundments

The highest daily precipitation during the monitoring period at Geopung Mine was about 90 mm and most rain events were concentrated during June to early September, corresponding to the rainy season in Korea (Figure 2). Groundwater with high EC was detected in the waste rock impoundment (GW#3 in Figure 2) only in the rainy season indicating a transient perched watertable. Groundwater had comparable pH and EC values in a full-screened borehole (GW#2) in the tailings impoundment, whilst in a bottom-screened well (GW#1), groundwater showed lower EC, although this gradually increased after rainfall events. Groundwater flow regime analysed through numerical modelling (Visual Modflow Pro; Waterloo Hydrologic) showed general downward flow from high altitude to a stream in low altitude following a geographical gradient (Figure 3a). Tracer modelling also showed groundwater in the waste rock impoundment flows downward via tailings impoundment into a stream (Figure 3b). Based on the groundwater flow pattern, groundwater beneath both the tailings and waste rock impoundments seemed to have similar reactions in the waste materials.

Summary statistical data of chemical analyses for the water samples are presented in Table 1. Generally, groundwater had acidic pH (3.5–4.6) and high dissolved heavy metal content (TDS 390–3330 mg/L). Groundwater from GW#2 showed the lowest pH and the highest contents of SO_4, Fe, Al, Mn, and other heavy metals. Similar results in GW#3 were recorded, indicating water interactions with waste rocks and tailings. In a bottom-screened well (GW#1), it can be inferred that upper acidic water affected the composition of deeper groundwater. In the case of surface leachate waters, SW#2 had more acidic conditions and higher metal contents than SW#1 collected at the point where waste rock leachate joined with a natural small stream (Figure 1). Runoff waters in the waste rock impoundment during rain events showed lower concentrations of metals, but higher acidity, reflecting direct interaction of rainwater with the waste rock.



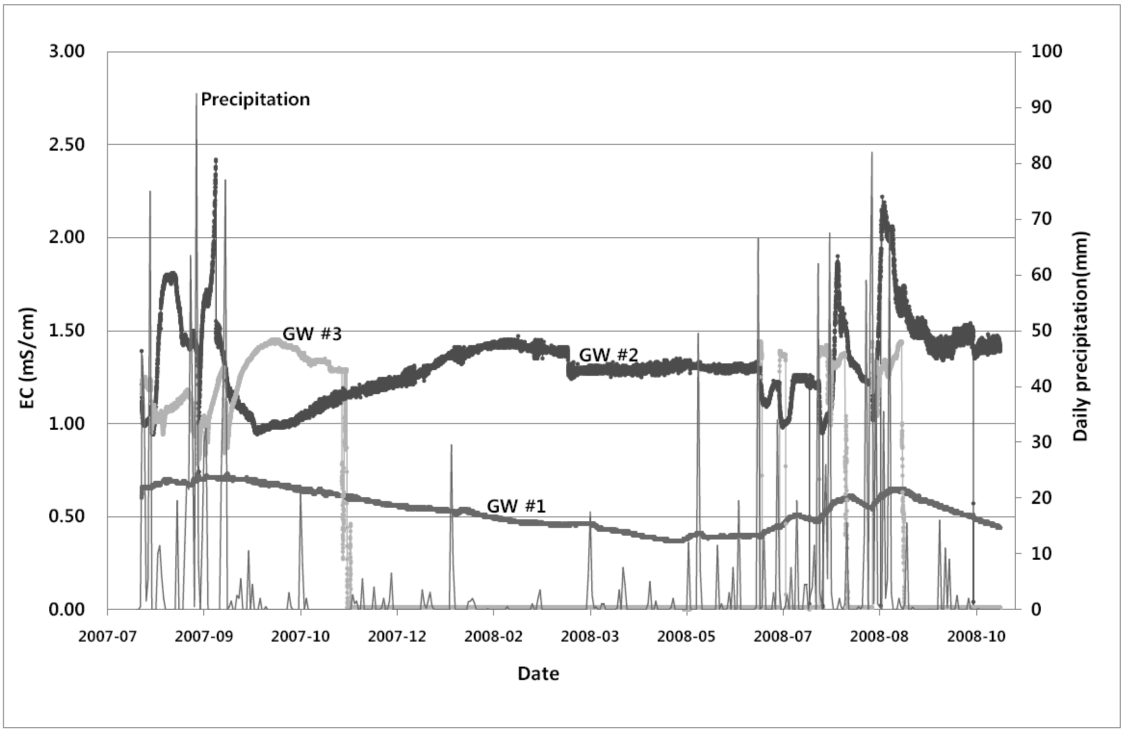


Figure 2 Effects of daily precipitation to groundwater level and electrical conductivity (EC) of groundwater in the waste impoundments

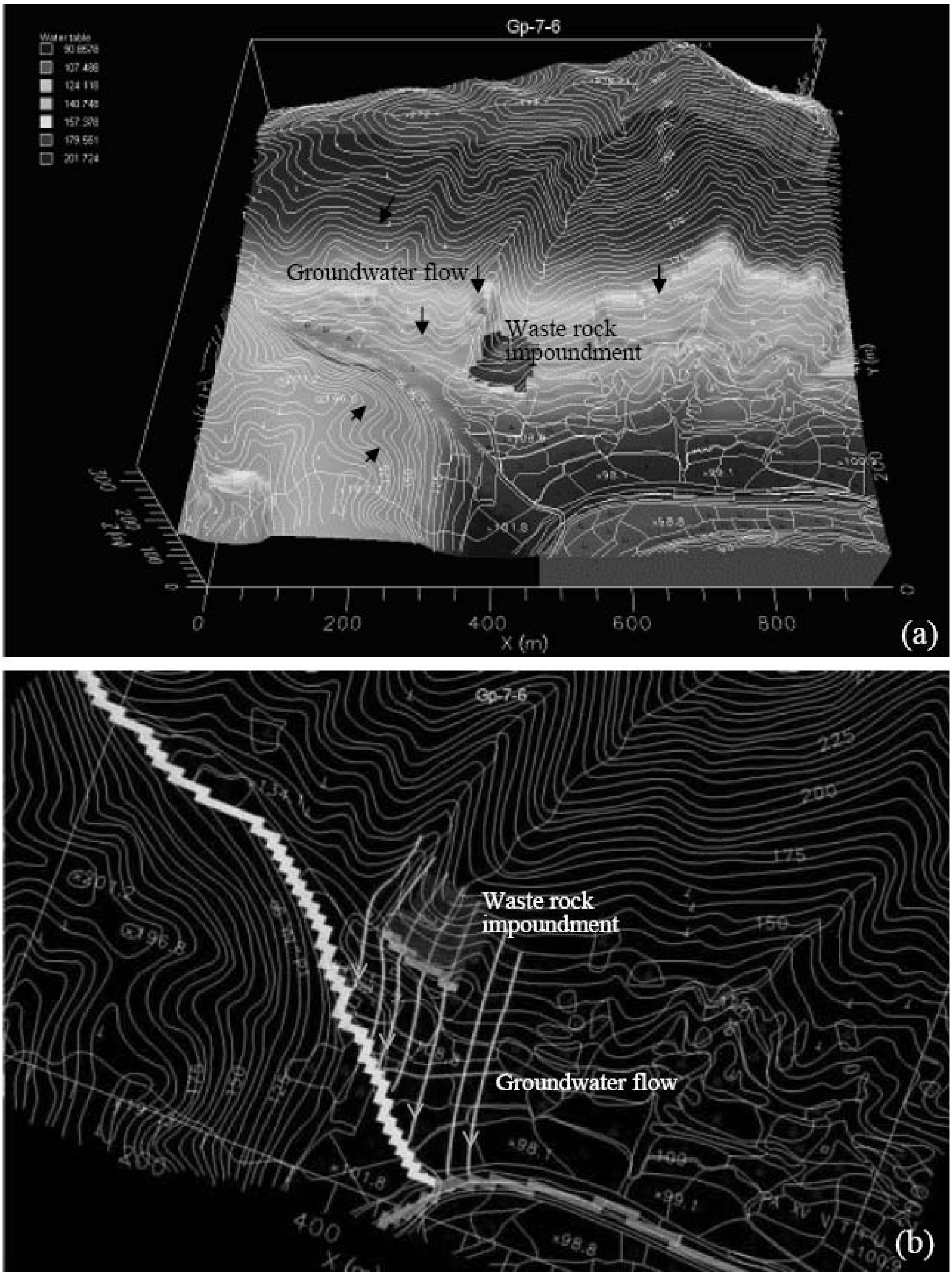


Figure 3 **(a) Groundwater table at the Geopung Mine, and (b) groundwater flow through the waste impoundment**

Table 1 Summary of the chemical components (mean and range, unit in mg/L except pH) of the water samples

Sample	GW#1 (n = 6)	GW#2 (n = 6)	GW#3 (n = 6)	SW#1 (n = 5)	SW#2 (n = 5)	RW (n = 6)
pH	3.84	3.30	3.68	5.56	4.11	3.17
	(3.52–4.42)	(2.71–3.91)	(3.03–4.62)	(4.37–6.91)	(3.25–5.13)	(3.02–3.43)
Si	13.9	55.0	33.6	9.14	15.2	4.37
	(20.3–17.5)	(41.3–63.6)	(26.5–43.6)	(7.17–11.0)	(10.6–22.9)	(2.10–6.59)
Na	6.11	12.3	11.6	4.50	5.28	1.02
	(7.95–6.91)	(9.99–13.5)	(6.76–14.7)	(4.17–4.98)	(4.30–6.90)	(0.19–1.98)
K	1.65	3.83	5.79	0.62	1.45	0.62
	(2.86–2.21)	(3.38–4.61)	(2.99–14.7)	(0.50–0.95)	(0.86–2.50)	(0.21–1.39)
Mg	11.2	69.5	55.4	3.80	8.84	3.17
	(15.8–14.4)	(45.1–88.4)	(24.9–79.7)	(2.90–5.23)	(4.10–18.3)	(0.65–8.69)
Ca	44.7	210	192	10.2	38.2	16.0
	(65.8–53.4)	(166–263)	(133–254)	(4.80–19.9)	(13.1–83.1)	(3.51–38.0)
Fe	0.30	148	0.60	0.03	5.56	0.30
	(0.08–0.58)	(4.75–718)	(0.09–1.83)	(0.02–0.04)	(3.31–7.50)	(0.08–0.54)
Al	6.49	66.1	27.2	0.48	6.47	5.30
	(4.51–0.04)	(38.4–100)	(3.97–53.9)	(0.03–2.24)	(1.11–17.6)	(0.91–16.6)
Mn	3.92	44.4	7.93	0.29	3.82	1.78
	(3.12–5.05)	(21.4–63.2)	(4.85–11.6)	(0.03–0.92)	(1.64–8.26)	(0.35–3.89)
Cu	5.76	59.3	18.2	0.43	2.86	4.73
	(3.93–8.40)	(26.4–94.8)	(3.55–34.8)	(0.04–1.65)	(0.47–8.29)	(1.35–12.6)
Zn	15.1	282	55.9	1.01	19.1	8.77
	(11.2–19.8)	(97.5–548)	(46.7–65.1)	(0.13–3.47)	(6.85–41.0)	(1.56–25.6)
Pb	0.05	0.51	0.12	<0.01	0.01	0.07
	(0.03–0.10)	(0.23–1.16)	(0.06–0.20)		(<0.01–0.05)	(<0.01–0.10)
Cd	0.25	10.1	0.82	0.01	0.18	0.14
	(0.18–0.38)	(1.32–29.7)	(0.70–0.93)	(<0.01–0.05)	(0.06–0.37)	(0.03–0.41)
SO_4	277	2088	967	44	221	125
	(226–336)	(1180–3120)	(838–1130)	(23–96)	(84–503)	(31–334)

3.2 Seasonal variations and geochemistry of mine waters

Seasonal variation in pH and concentrations of selected metals in the water samples is shown in Figure 4. At GW#1, lower pH and higher metal concentrations were found during the rainy season (July and August) than the dry season. Dilution effects by rain were frequently observed in mine water quality in other studies (Gomes and Favas, 2006). However, water quality continued to deteriorate in the Geopung Mine after rainfall. In general, secondary sulphate minerals are produced in abundance in sulphide-rich mine waste dumps, and result in the storage of acidity and heavy metals during dry periods (Smuda et al., 2007). The stored minerals include efflorescent salts and Fe- and Al-hydroxysulphates, which release acid and heavy metals upon dissolution during wet seasons (Jerz and Rimstidt, 2003; Hammarstrom et al., 2005; Valente and Gomes, 2009). The salts were found to vary in colour commonly at Geopung Mine and were analysed using SEM-EDS (Figure 5). They were mostly Fe-sulphate minerals containing heavy metals. It is assumed that during the rainy season these secondary salts are dissolved and affect the groundwater quality in the mine waste impoundments. The deterioration of water quality was also observed at GW#2, with high increases of Zn and Fe contents in August. A slight small decrease in metal concentration in July may indicate a dilution effect during the early rainy season. Surface leachate waters (SW#1 and #2) showed a similar pattern of seasonal variation. In summary, peak metal loads at the Geopung Mine can occur during the rainy season. Chemical composition had no specific seasonal variation except that concentrations increase in the rainy season. Good correlations were found between the major and trace elements measured (Table 2 and Figure 6). This suggests that dissolution of soluble secondary salts, caused by flushing of weathered waste rocks and tailings, directly influenced the water quality within the waste impoundments.

Nordstrom (2007) summarised the trends in the mobilisation of acid mine waters and natural acid rock drainage in the western US indicating that large rainstorm events after extended dry periods result in sudden and dramatic increases in the concentration of acid and metal. He also suggested that these changes in concentrations and loadings are related to the dissolution of soluble salts and the flushing of waters that were concentrated by evaporation, and these observations can be generalised to predict future conditions caused by droughts related to El Nino and climate change. Seasonal variations in water quality observed at the Geopung Mine may also demonstrate this pattern of water-quality change by the effect of climate conditions.

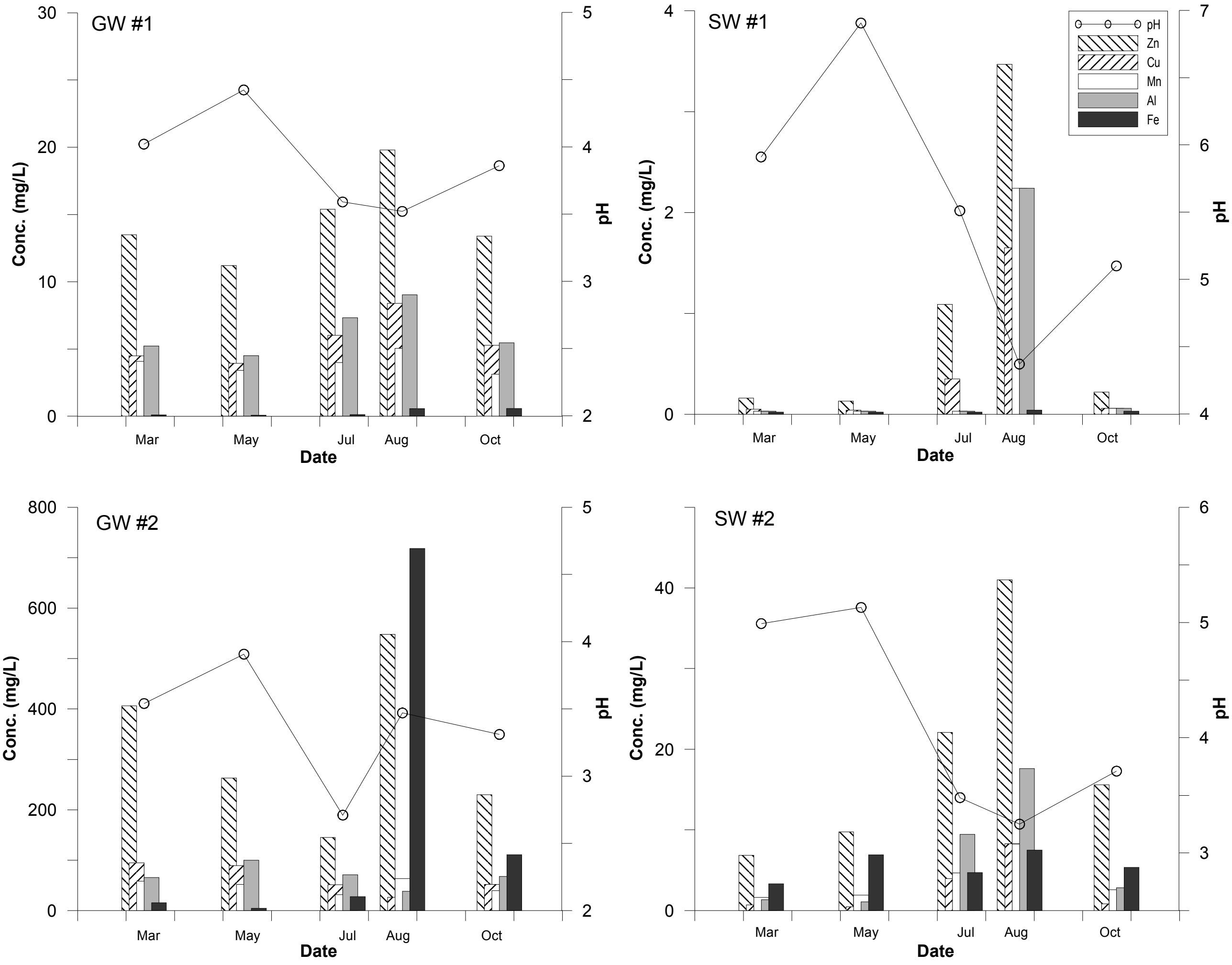


Figure 4 **Seasonal variations in pH and metal concentrations in groundwater and surface water recorded at Geopung Mine**

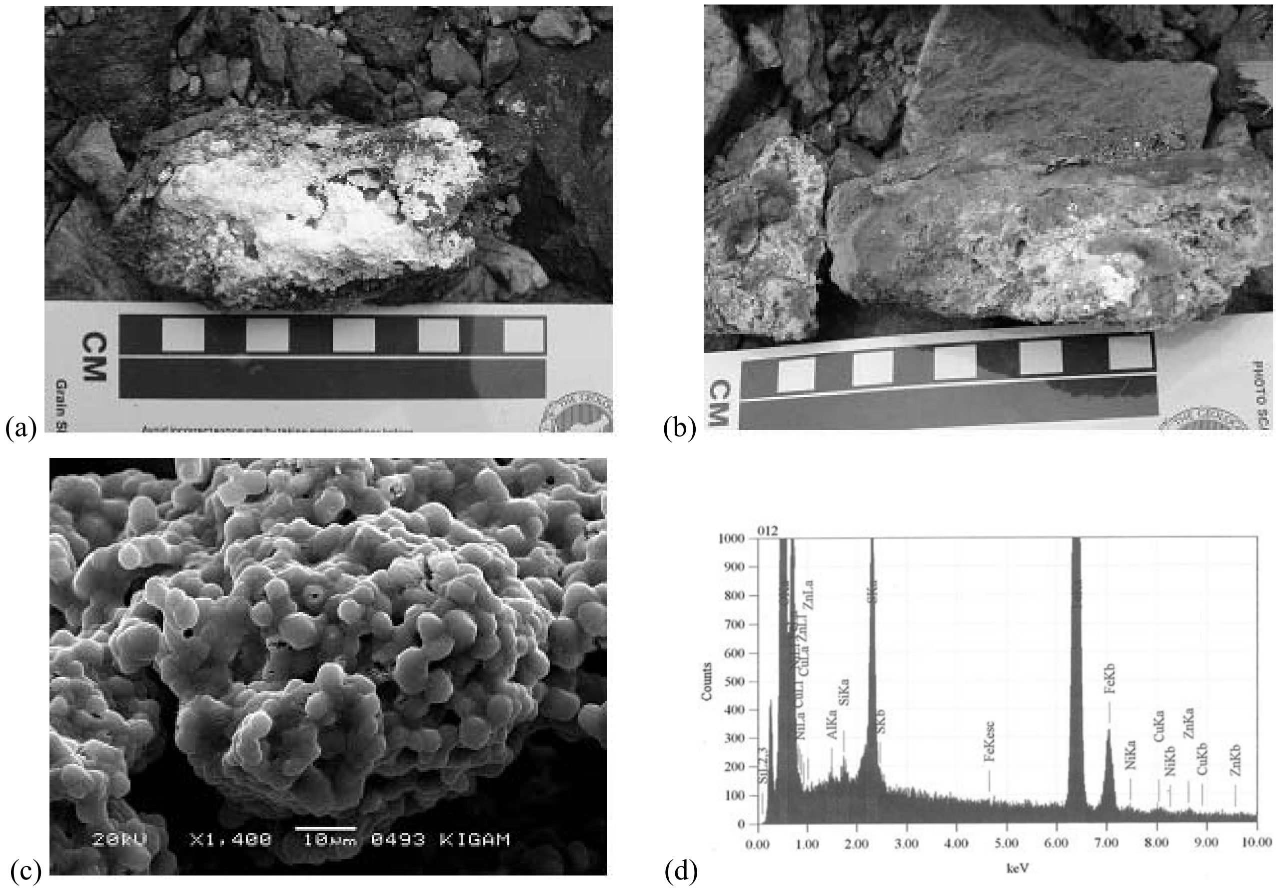


Figure 5 **Field and SEM images of secondary salts on waste rocks: (a) white salts (rozenite dominant); (b) bluish salts (melanterite dominant); (c) SEM image of white salt materials; (d) EDS spectra of white salts shown in (c), showing the presence of Ni, Cu, and Zn**

Table 2 **Pierson correlation coefficients between chemical components in groundwater, surface leachate and runoff water**

	Cd	Zn	Pb	Cu	Mn	Fe	Al	Si	Na	K	Mg	Ca	SO_4
Zn	0.844**												
Pb	0.749**	0.966**											
Cu	0.744**	0.720**	0.627**										
Mn	0.829**	0.966**	0.907**	0.855**									
Fe	0.390*	0.746**	0.834**	0.133**	0.600**								
Al	0.535**	0.654**	0.605**	0.944**	0.802**	0.183							
Si	0.425**	0.626**	0.589**	0.829**	0.747**	0.237	0.920**						
Na	0.395*	0.560**	0.480**	0.566**	0.596**	0.241	0.586**	0.786**					
K	0.209	0.336*	0.319	0.331*	0.325	0.151	0.354*	0.526**	0.739**				
Mg	0.560**	0.720**	0.643**	0.708**	0.751**	0.337*	0.697**	0.800**	0.927**	0.701**			
Ca	0.435**	0.649**	0.615**	0.719**	0.701**	0.310	0.786**	0.878**	0.892**	0.725**	0.941**		
SO_4	0.711**	0.927**	0.894**	0.822**	0.950**	0.603**	0.833**	0.841**	0.749**	0.511**	0.877**	0.872**	
TDS	0.712**	0.940**	0.914**	0.794**	0.951**	0.647**	0.805**	0.820**	0.737**	0.506**	0.865**	0.856**	0.998**

*Significant at the 0.05 level, **significant at the 0.01 level.

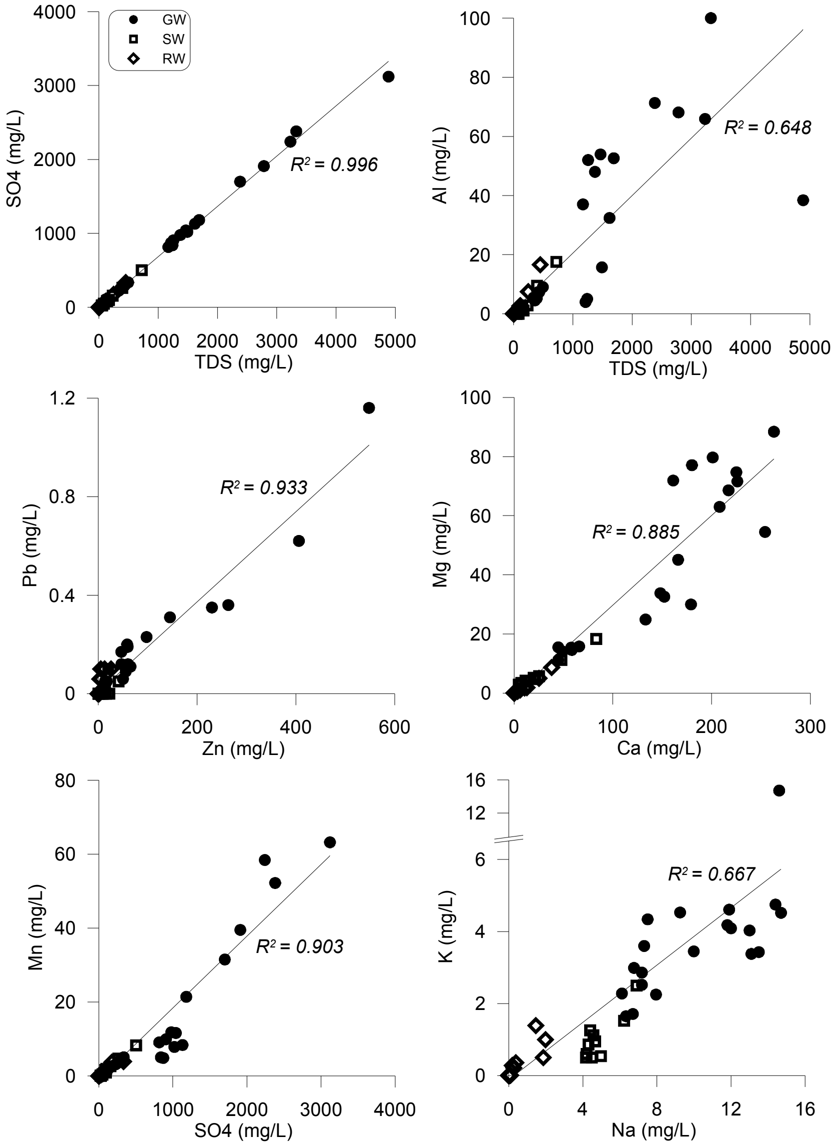


Figure 6 Relationships between chemical components in groundwater, surface leachate and runoff waters

4 Conclusions

Seasonal variations of water quality at Geopung Mine in central Korea could be related to the dissolution of secondary salts on waste rocks and tailings material. Increases in acid and metal concentrations and their loadings from mine wastes are anticipated in the rainy season. Secondary sulphate salts subsequently formed on the weathered waste rocks and tailings continuously have influenced the water quality through dissolution in rain water. The salts can be accumulated, and residual evaporated vadose and groundwater will have increased concentrations of soluble constituents due to extended dry periods as one of the effects by climate change associated with global warming. More consideration needs to be given to appropriate cover systems on waste rocks and tailings in light of the possibility of more extreme future climatic conditions.

Acknowledgement

This research was supported by the Basic Research Project (09-3411) of the Korea Institute of Geoscience and Mineral Resources (KIGAM) funded by the Ministry of Knowledge Economy.

References

Gomes, M.E.P. and Favas, P.J.C. (2006) Mineralogical controls on mine drainage of the abandoned Ervedosa tin mine in north-eastern Portugal, Applied Geochemistry 21, pp. 1322–1334.

Hammarstrom, J.M., Seal II, R.R., Meier, A.L. and Kornfeld, J.M. (2005) Secondary sulfate minerals associated with acid drainage in the eastern US: recycling of metals and acidity in surficial environments, Chemical Geology 215, pp. 407–431.

Jerz, J.K. and Rimstidt, J.D. (2003) Efflorescent iron sulfate minerals: Paragenesis, relative stability, and environmental impact, American Mineralogist 88, pp. 1919–1932.

KIGAM (2007) A study on prevention of contamination of soil and water at the abandoned metal mines, Korea Institute of Geoscience and Mineral Resources NP2007-005-2007(1), 163 p.

Nordstrom, D.K. (2007) Effects of seasonal and climatic change on water quality from acid rock drainage in the western United States, IMWA Symposium 2007: Water in Mining Environments, R. Cidu & F. Frau (eds), Cagliari, Italy, pp. 11–16.

Smuda, J., Dold, B., Frise, K., Morgenstern, P. and Glaesser, W. (2007) Mineralogical and geochemical study of element mobility at the sulfide-rich Excelsior waste rock dump from the polymetallic Zn-Pb-(Ag-Bi-Cu) deposit, Cerro de Pasco, Peru, Journal of Geochemical Exploration 92, pp. 97–110.

Valente, T.M. and Gomes, C.L (2009) Occurrence, properties and pollution potential of environmental minerals in acid mine drainage, Science of the Total Environment 407, pp. 1135–1152.