Material flow analysis for spatiotemporal mine water management in Hon Gai, Vietnam

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Abstract

Hon Gai peninsula is a coal mining area in Quang Ninh, Vietnam. The peninsula has limited water resources while the water demand of mines and other users is increasing. As deficits in dry sea-sons occur, recycling and reuse of mine water are solution approaches for the area. Material flow analysis (MFA) was applied to understand the complex linkages of water related elements and processes with regards to mine water flows, treatment and reuse, and to develop a mine water management tool to ensure efficient water treatment and reuse. The tool uses MFA to model different spatiotemporal situations to support management and investment decisions.

Keywords: mine water, recycling and reuse, material flow analysis, Hon Gai mining area

Introduction

The R&D project WaterMiner funded by the Federal German Ministry of Education and Research (BMBF) focuses on a need-based and efficient reuse and recycling of mine water for mining pur-poses as well as for other purposes, i.e. urban, industrial or agricultural.

The R&D project WaterMiner consists of the following work packages: project coordination (eE+E, RUB); baseline and system analysis (eE+E, RUB); GIS water infrastructure (Disy Informationssysteme Ltd., Karlsruhe); monitoring information system (ribeka Ltd., Bornheim); material flow analysis (MFA) (eE+E, RUB); technical concepts (DGFZ); economic concepts (Environ-mental Economics, Koblenz-Landau); exemplary implementation of technical solutions (DGFZ; LUG Engineering Ltd., Cottbus; VINACOMIN Vietnam National Coal and Mineral Industries Hold-ing Corporation Ltd.).

Hard coal mining by VINACOMIN in Hon Gai is taking place since many decades and has nega-tively affected the water resources. The open pits in Hon Gai are scheduled to be closed over the next 10 years or shift to underground mining (GoV 2016). As a result, mining impacted waters will change according to location, quality and quantity.

The R&D project WaterMiner investigates under different considerations how and to what ex-tent the existing water demand in the mining area and parts of the water demand in the sur-rounding area can be covered by treated mine water. The project develops a management tool for mine water reuse with the following components: material flow analysis (MFA), surface wa-ter and sediment management (Ulbricht et al. 2018) as well as economic investigations (Do et al. 2018) accompanied by data management (ribeka, Disy) and exemplary implementation of moni-toring and waste water treatment (DGFZ, ribeka, LUG Engineering and VINACOMIN)

Study area

The project is located on the Hon Gai peninsula (Fig. 1A). Coal is exploited in the central and north-western part. Both open pit and underground mining technologies are applied with a gradual reduction of open pits. Basic investigations and the development of environmental con-cepts for the mining area including mine water treatment have been performed by the R&D pro-ject RAME (Broemme and Stolpe 2011; Broemme et al. 2014) in the period from 2005-2015.

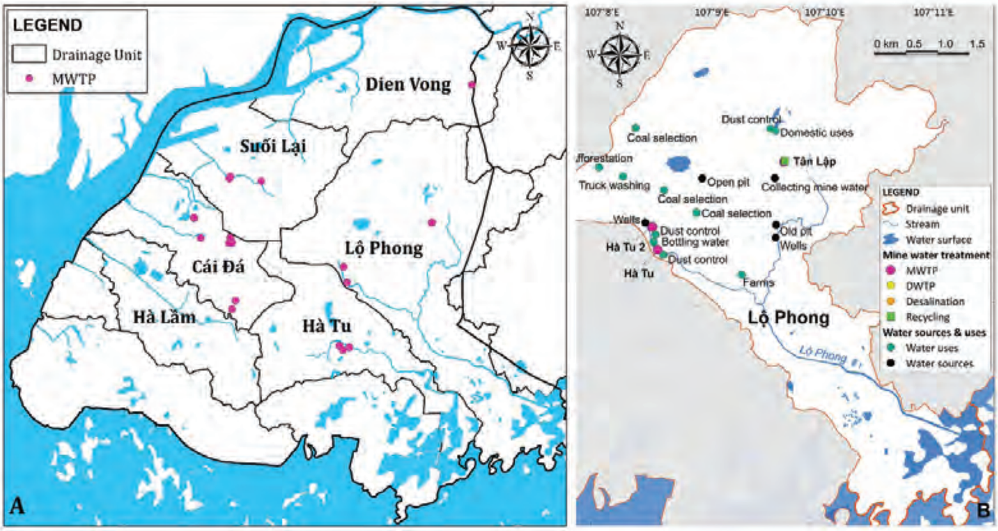

Figure 1 *(A) WaterMiner study area and (B) Example area Lo Phong Drainage Unit*

Five small streams with lengths from 2.2 to 7.1 km drain water into the Halong Bay. The hydro-logical regime is characterised by 80% of annual rainfall during rainy season (May – October) and 20% during dry season (November – April). The lower rainfall in summer leads to water shortages (DONRE, 2016). In recent years water shortages intensified and additional water sources are needed to cover the increasing water demand in the region.

To facilitate an improved mine water management, five drainage units (Fig. 1) were defined based on topology, hydrology features, mine operation and ownership.

The Lo Phong Drainage Unit (Fig. 1) consists of two open pits: Tan Lap and Ha Tu. In its final extension, Ha Tu open pit will be the largest on the peninsula. The open pits are intended to be converted to pit lakes after mining. This provides a possibility to create additional water storage as source for external using purposes in the dry season. Therefore, the focus of the MFA was primarily on this area.

The conceptual model (Fig. 2) shows the main system elements of mine water management: mine water sources, Lo Phong river, mine water treatment, internal uses of mine water and po-tential external uses.

The mine water sources include clean water from the water supply system, discharge from up-stream catchment parts, surface runoff and water withdrawal from wells and ponds. In addition to mine water from open pits or underground mines (mine drainage water, process water e.g. from coal screening) also domestic wastewater (e.g. from pitheads baths) accumulates.

The mine water flows via regulating basins to the mine water treatment plants (MWTP). In the rainy seasons and especially during heavy rainfall events mine water is only partially treated or discharged into the surface waters without treatment. There is also a large amount of surface runoff discharging directly into the rivers.

The treated mine water is partially re-used inside the mines (internal uses). Additionally, there is a large water demand in the surrounding urban area of Ha Long City, especially during dry sea-son (external uses).

Spatiotemporal changes in mine water sources, mine water treatment plants, internal uses and external uses are the significant factors determining changes in mine water management in the region.

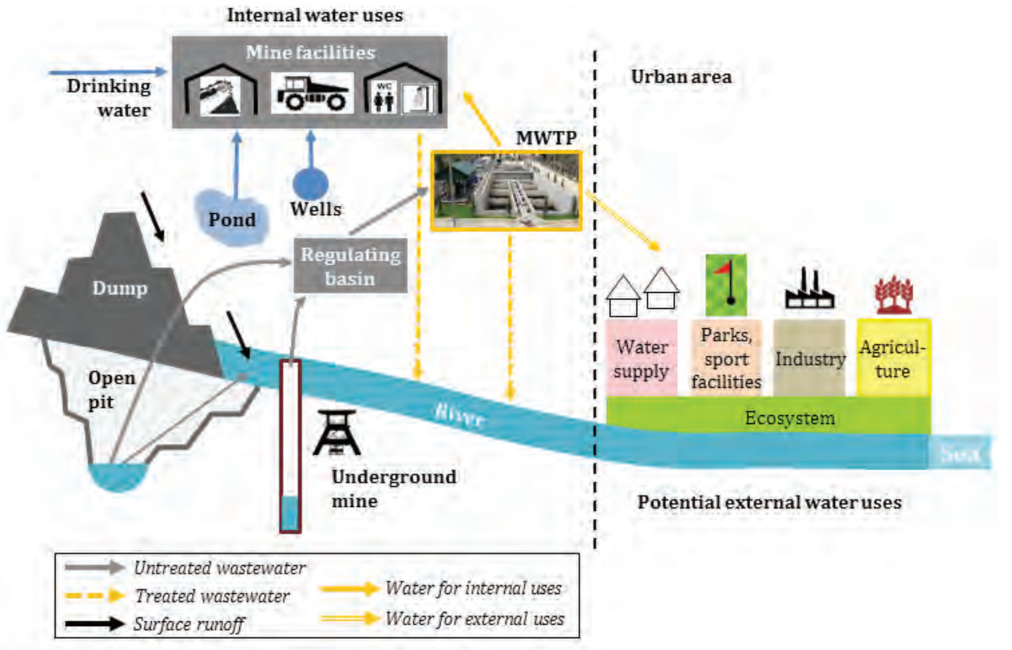

***Figure 2** Conceptual model of the mine water management*

As mining sites are closed, mine drainage water will decrease, mine water treatment plants will reduce or stop their operation and the water consumption for mining purposes will reduce. At the same time, along with the expansion of industry, urban areas and tourism, water extraction will increase to provide adequate water and satisfy higher demands.

Methodology

Data acquisition

As basis for the WaterMiner project as well as for the MFA comprehensive data on coal mining, meteorology and hydrology, geology, river morphology, water uses and land use have been ob-tained from VINACOMIN, provincial authorities, companies and by own field measurements.

Material flow analysis (MFA)

The Umberto NXT Efficiency software is applied to identify, quantify and assess the potential for the reuse of mine water and to improve the mine water management regarding the different situations of the spatial and temporal development of the mining area.

The development and application of the MFA is conducted through three consecutive steps: (1) Definition of relevant spatiotemporal situations; (2) Assembling the material flow model; (3) Modelling and improving the defined spatiotemporal situations.

Development and application of the MFA

The mentioned three steps have been performed with the following specifications.

The relevant spatiotemporal situations for the example drainage unit Lo Phong are defined as following:

- Situation 1: existing situation of mine water sources, mine water treatment and mine water reuse with Ha Tu and Tan Lap mines in operation (2016)
- Situation 2: future situation of mine water sources, mine water treatment and expected mine water reuse after the planned closure of Ha Tu mine (approx. 2025)
- Situation 3: final situation of mine water sources, mine water treatment and mine water re-use after the planned closure of Tan Lap mine (approx. 2035)

The Lo Phong drainage unit covers mining activities in both Ha Tu and Tan Lap mine. The water balance of each mine is prepared and analysed separately. The outflows drain to the Lo Phong River.

According to the conceptual model (Fig 2.) water flow pathways are divided into four phases: sources, treatment, internal uses, and external uses.

Table 1 gives an overview of the 3 defined spatiotemporal situations and defines which components have to be considered in each phase. For each situation, a material flow model is devel-oped which is used to develop and compare different options for each situation and to create improved situations.

The components of each phase are used in Tab. 1 for the definition of temporal situations:

- Sources: 1) mine drainage water from open pits, 2) mine drainage water from underground mines, 3) groundwater extracted from wells, surface water extracted from ponds, lakes, 4) discharge from upstream catchment parts outside the mining area, 5) surface runoff due to rainfall inside the mining area, 6) clean water from the water supply company QUAWACO
- Treatment: 1) upstream regulating basin for pre-sedimentation and homogenization of the MWTP inflow; 2) mine water treatment plant; 3) additional treatment step for domestic wa-ter quality; 4) reverse osmosis filtration step for drinking water quality; 5) former open pit with reservoir function, storage and sedimentation of rain water and surface runoff
- Internal use: 1) water for drinking (bottling station), water for canteen kitchens; 2) water for laundries, pithead baths, sanitary facilities; 3) water for wet coal screening; 4) water for irri-gation of recultivated areas; 5) water for dust control, industrial cleaning, truck washing
- External use: 1) water for irrigation of agricultural areas; 2) water for industrial users; 3) water for irrigation of public parks, urban greens, golf courses; 4) water for the clean water production; 5) minimum water volume in the river to maintain aquatic life and river ecosystems equal to 10% of the average flow (Tuan, 2015)

The material flow model was developed for an average month of the dry season. In the following, the basic modelling results of 2 defined spatiotemporal situations (Situation 1: existing situation, Situation 3: final situation) are shown (Fig. 3).

The defined spatiotemporal situations are the starting point for further improvement and opti-misation by changing and adaption of treatment components, water allocation, water distribu-tion, other technical issues etc. The direction of optimisation is identified based on water de-mands, cost and benefit, mine planning and acceptance.

Figure 3 (left) shows the results of simulated water flows for the existing situation in the form of a Sankey diagram.

Table 1. *Three situations of mine water management exemplary for Ha Tu mine, Lo Phong drainage unit: (1) existing situation, (2) situation 2025, (3) final situation*

Sources	Situation (1)	Situation (2)	Situation (3)	Treatment	Situation (1)	Situation (2)	Situation (3)	Internal use	Situation (1)	Situation (2)	Situation (3)	External use	Situation (1)	Situation (2)	Situation (3)
1) Open pit	☒	☒	☐	1) Regulating basin	☒	☒	☐	1) Drinking, cooking	☒	☐	☐	1) Agriculture	☐	☐	☒
2) Underground mining	☐	☐	☐	2) MWTP	☒	☒	☐	2) Domestic uses	☒	☐	☐	2) Industry	☐	☐	☒
3) Wells, others	☒	☐	☐	3) Secondary treatment	☒	☐	☐	3) Coal screening	☒	☐	☐	3) Park, sport facility	☐	☐	☒
4) Upstream flow	☒	☒	☒	4) RO filtration	☒	☐	☐	4) Recultivation	☒	☒	☒	4) Raw water	☐	☐	☒
5) Surface runoff	☒	☒	☒	5) Pit lake	☐	☐	☒	5) Other mining purposes	☒	☒	☐	5) Ecological flow	☒	☒	☒
6) Clean water	☒	☐	☐												

☒ relevant for the situation ☐ not relevant for the situation

- Sources: The main mine water sources originate in the open pits of Ha Tu and Tan Lap mine and are pumped to the regulating basin. The surface runoff flows directly into Lo Phong river. In addition, clean water is supplied via the urban water supply system. Another mine water source is groundwater which is pumped from wells.
- Treatment: The water is flowing from the regulating basin to the MWTP. In Ha Tu area the treated water is partly used for internal water users. The other part flows into Lo Phong river. The clean water is treated by reverse osmosis filtration to reach the quality standards for drinking and cooking purposes. Groundwater is treated in a secondary treatment. Although a MWTP is available and ready to use in Tan Lap mine, the mine water is just pumped to the regulating basin and then drained to the river.
- Internal uses: A large proportion of treated water is used for internal uses like coal screening or truck washing, the rest is discharged to the river. Water for domestic uses is abstracted from wells located within the mine. The water needed for mining processes is abstracted from streams and wells.
- External uses: Under the existing situation, the water volume for external uses is zero due to the lack of related water infrastructure to ensure adequate water quality and quantity.

Figure 3 (right) shows the results of simulated water flows for the final situation:

- Sources: The only mine water sources in Ha Tu are the water from the open pits and the surface runoff. Rainwater and surface runoff are collected in the pit lake. In Tan Lap still groundwater is pumped via wells.
- Treatment: The only remaining treatment function is the pit lake for sedimentation and reduction of turbidity. There is no treatment by a MWTP anymore.
- Internal uses: A small amount of water is still required for recultivation.
- External uses: In this scenario, the water stored in the pit lake is provided as raw water for the urban water supply system. The final distribution of the additional water source depends on the demand of other users, costs and prioritization of decision makers.

Discussion

The reported results have to be further processed by a quasidynamic analysis of the water flows, by worst case assessment and a modellike implementation of measures for an improved water management.

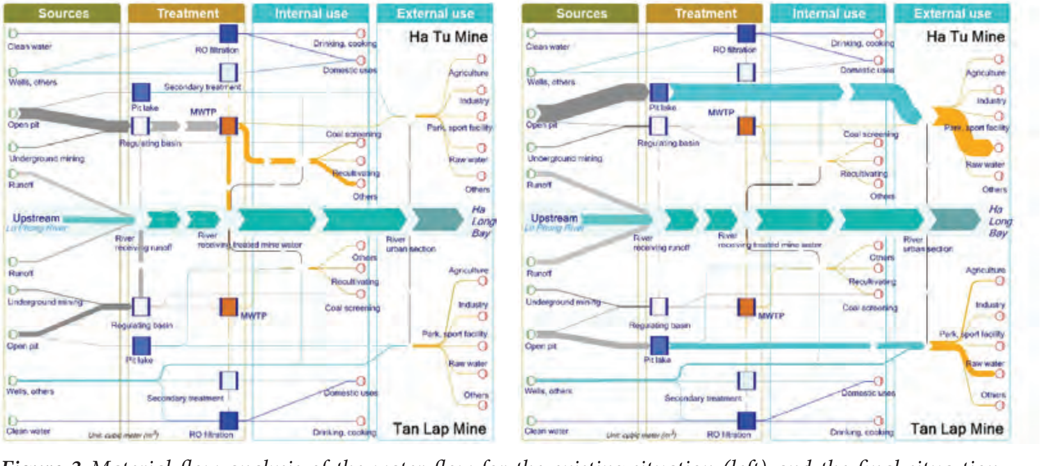

Figure 3 Material flow analysis of the water flow for the existing situation (left) and the final situa-tion (right) (widths of arrows proportionally to flow quantity)

The already applied model is a static model. Dynamic processes over time can be realized through the use of several models in succession where each model describes a short period of time, for instance one month.

Worst case assessments regarding the annual rainfall distribution and extreme variations of the internal and external water demands will be established using the model. Their results help the local decision makers to distinguish between so-called regret and no-regret measures.

The main task of the material flow models is the testing of potential measures for an improved water management. They include improved mine water treatment, additional treatment modules, distribution systems and the use of basins or reservoirs for water storage.

Conclusions

Mining operations and their water management often underlie fast spatial and temporal changes. Therefore, a material flow analysis is a very suitable instrument for the analysis and the management of mine impacted waters.

The developed material flow models describe all relevant components from the various water sources via the treatment steps to the internal and external users. The model is focusing on the water flows but also includes other relevant material flows like energy, supplies, sludges. Furthermore, it supports an economic analysis which is usually the most important factor for decision makers.

The selected Umberto NXT Efficiency software is suitable for the modelling tasks as it is flexible in setting up the model, the resulting Sankey diagrams are a good basis for further analysis and assessments. The lack in dynamic modelling can be solved through the use of several models for small time periods in succession.

Through variations of the water allocation, worst case analyses etc. improved spatiotemporal situations are generated which are the basis for management and investment decisions.

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