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Estimating the escalation of mine tailings disaster risks by using a life cycle assessment approach

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Abstract. Mine tailings should be managed properly to avoid the tailings accident that recorded more than 230 tailings accident worldwide. These accidents caused human and environmental losses. This paper estimates the escalation of mine tailings dam failure using a life cycle assessment (LCA) approach. The LCA functional unit (FU) is defined as 1 tonne of fine coal concentrate slurry generated by flotation cells. SimaPro software was chosen to analyze the material flow data of a mine coal tailings disposal system and focused on impact categories associated with disaster issues including human toxicity, terrestrial eco-toxicity, freshwater eco-toxicity, and marine eco-toxicity. The results showed that the impact escalation of coal mine tailings during 20 years of operation for human toxicity, terrestrial eco-toxicity, freshwater eco-toxicity, and marine eco-toxicity were 13,740 DALY, 27.40 species year, 0.04 species year, and 0.001 species year respectively. These results indicated that a good mine tailings management should be applied by mine site to prevent a human and environmental disaster from mine tailings accident.

Keywords: life cycle assessment, mining, tailings, environmental, impacts,

1. Introduction

Mining operation consists of various complex stages including construction, exploitation, and closure [1]. The construction stage prepares all facilities for supporting the exploitation stage. These facilities can be divided into two categories, namely main facility, and secondary facility. All facilities that have a direct connection with mine operation including crushing plant, processing plant, and filtration plant are classified as the main facility. While the secondary facilities include camp and water treatment plant are aimed to support the mineral production. The production phase is a period for exploiting the mineral reserve to generate final product such as gold, copper or copper concentrate.

Some operational risks are available during the production phase. These risks could harm not only human but also the environment. The risk is usually dealing with two components: probability and negative consequences [2]. One of the mine operational risks is associated with the mine tailings management. The waste generated by processing plant is classified as tailings and around 14 billion tonnes of tailings are produced by mine site worldwide [3]. Currently, there are two common types of tailings disposal management, namely tailings dam and submarine tailings disposal (STP). Both of the disposal strategies have risks and failure opportunities in their operations. A record of tailings dam failure as shown in Table 1 indicates that tailings dam disasters had created a massive destruction to human life and environment [4] [5] [6] [7].

Table 1. Example of Tailings dam failure worldwide

Location	Year	Mineral Types	Release	Impact
Cieneguita mine, Urique, Chihuahua, Mexico	2018	Gold & Silver	249,000 cubic metres of tailings slurries	Three employees died and two injured.
Tonglvshan Mine, Hubei province, China	2017	Copper, gold, silver, iron	200,000 cubic metres of tailings slurries	Contaminated 27 Ha of the fish pond and two persons died.
Dahegou Village, Luoyang, Henan province, China	2016	Bauxite	red mud materials	300 villagers must be evacuated
Baia Mare, Romania	2000	Gold	100,000 m3 of cyanide-contaminated liquid	River contamination, and contaminated drinking water resources of more than 2 million people in Hungary
Los Frailes, Aznalcóllar, Spain	1998	zinc, lead, copper, silver	4-5 million m^3 of toxic water and slurry	Farmland covered by tailings slurry

A good management in tailings management is required to reduce the tailings dam failure possibility. Proposal for reducing the failure with increasing the tailings solid was discussing in [8] [9] [10] where rheology approach was chosen as a method. These current studies haven't discussed yet the escalation of tailings management environmental impact. In addition, an estimation of the possible disaster escalation could be used as an early warning for the stakeholders involved.

Therefore, the aim of this study is estimating the escalation of mine tailings dam failure using a life cycle assessment approach. By estimating the impact of mine tailing dam failure, the stakeholders could prepare a proper disaster management procedure to reduce or avoid the human and environmental damage.

2. Method

This study is using a Life Cycle Assessment (LCA) method for estimating the escalation impact of mine tailings disaster. A case study of coal mine tailings was selected to quantify the environmental impact that might be caused by tailings dam failure disaster. This study focused on some possible impacts include human toxicity, terrestrial eco-toxicity, freshwater eco-toxicity, and marine eco-toxicity.

The LCA is a tool for assessing the environmental potential impacts of a product, process, or service throughout their cycle process, for example, the cradle-to-grave process cycle [11]. Furthermore, LCA would help the stakeholders to identify the possible opportunities in improving environmental performance, selecting the relevant environmental performance indicators, and promoting environmental awareness of a company [11]. Four interconnected steps should be completed to do an LCA analysis as follows (see Figure 1):

1) Determining the goal and scope of the project;
2) Compiling an inventory of relevant material inputs and environmental releases;
3) Evaluating the potential environmental impacts associated with identified inputs and releases;
4) Interpreting the environmental impact results.

The case selected is a coal mine that is projected to extract about 20 million tonnes per annum (Mtpa) of ROM coal and using tailings dam for managing the tailings (fine rejected coal). The column flotation technology is applied for segregating the coal with gauge materials.

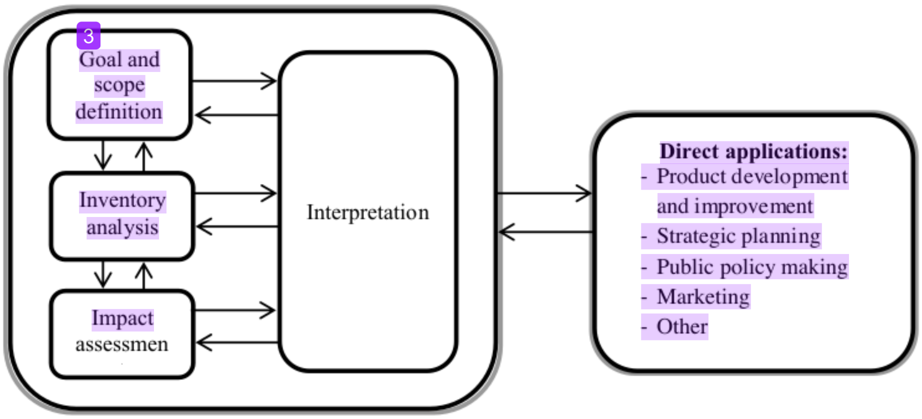

Figure 1. LCA flow diagram

3. Result and Discussion
This section is divided into three sections that consist of goal and scope, inventory analysis, and impact assessment section.

3.1. Goal and scope
The goal and scope of this case study were to assess the environmental impacts of a coal tailings management that used to describe the disaster impact of coal mine tailings. The functional unit (FU) is defined as 1 tonne of fine coal concentrate slurry generated by flotation cells.

3.2. Inventory analysis
In this stage, the material flows were recorded to quantify the material flow in and out from the system boundary. Table 2 indicated that column flotation consumed the highest energy compared to thickener and underflow pumping. The materials involved in the system boundary were chemical, water, and energy (electricity).

Table 2. Material inventory

Material	Unit	Quantity
Column flotation	kWh	864.5
Thickener	kWh	20.75
Underflow pump	kWh	1.9
Chemical	kg	5.8

There are four processes involved, namely segregation, dewatering, transporting, and disposal as shown in Figure 2. Each process requires a certain amount of material for example in the dewatering stage consumed 20.75 kWh of energy and 1.215 Kg of anionic flocculants and discharged 10.12 tonne of water.

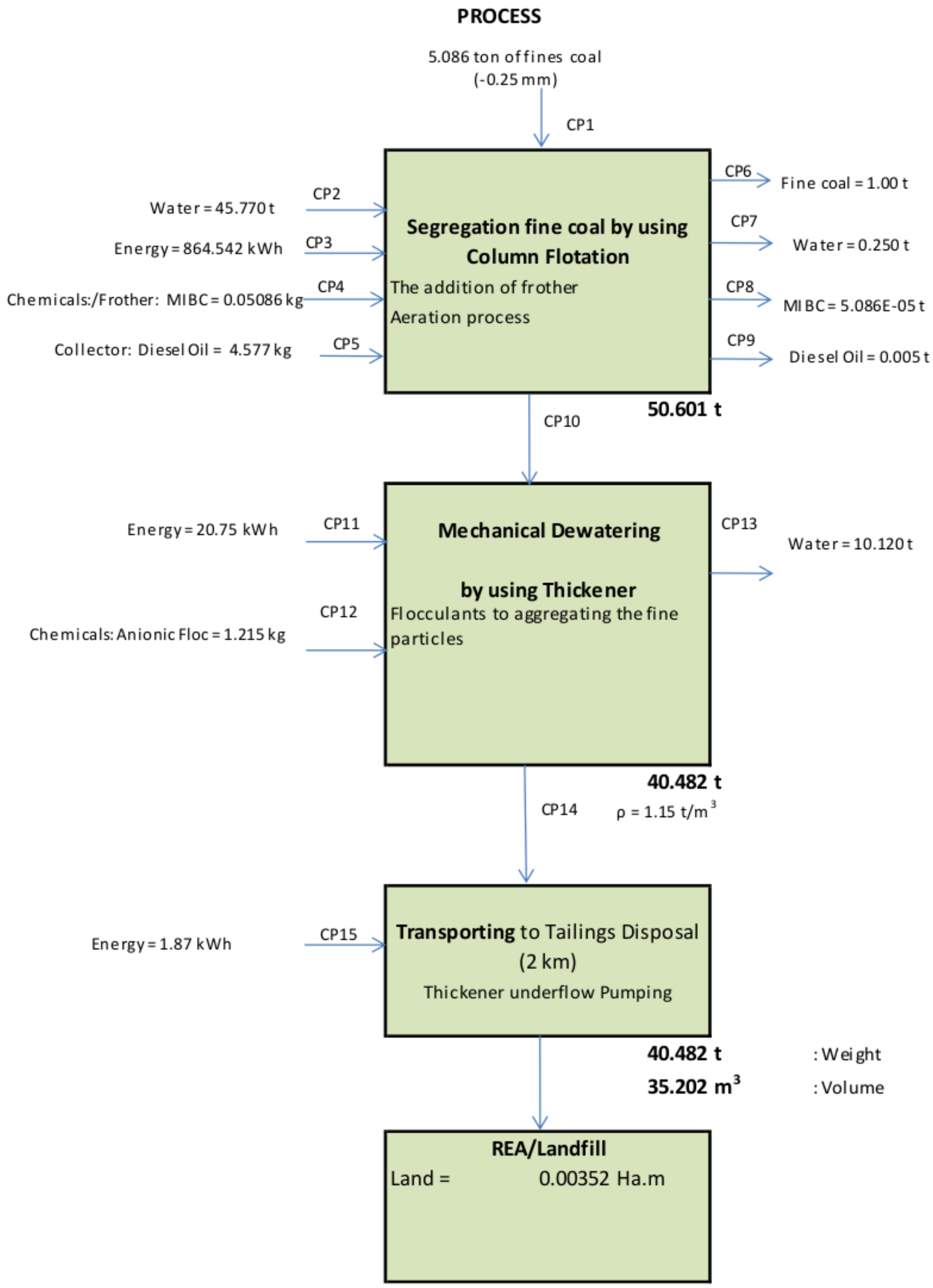

Figure 2. Materials flow

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3.3 Impact assessment

A life cycle assessment software (SimaPro) was applied to generate the impact value and the authors were using ReCiPe as an analysis method. The utilization of ReCiPe method due to its current to be the best available method by integrates normalization and weighting factors into all impact categories [8]. Table 3 showed the impact of one-tonne fine coal slurry that generated by column flotation. Four impact categories were identified as the most critical impacts associated with the mine tailings disaster issue. These four categories are human toxicity, terrestrial eco-toxicity, freshwater eco-toxicity, and marine eco-toxicity. Human toxicity represented potential time loss for a person due to a disease or accident and Eco-toxicity described the loss of local species in a year [12].

Table 3. Impact Assessment

Impact category	Unit	Analysis Result	Simulation of Impact Escalation*
Human toxicity	DALY**	1.5685E-05	13,740
Terrestrial eco-toxicity	species year	1.3883E-09	22.40
Freshwater eco-toxicity	species year	3.1170E-11	0.04
Marine eco-toxicity	species year	1.1453E-13	0.0001

*Production=120,000 tonnes/day **DALY = Disability Adjusted Life Years

Table 3 showed that the terrestrial eco-toxicity impact was the highest impact for eco-toxicity category and contributed approximately 1.3E-09 for local species losses per year. On the other word, every one tonne of fine coal concentrate slurry generated by flotation cells resulted 1.3E-09 of species losses in a year. The impact escalation should be estimated by multiplying each impact category with the total production. The result in Table 3 showed that potential time loss due to human disability was approximately 13,740 for 20 years mine operation.

4. Conclusion

In the best knowledge of the authors, none of the current studies discussed on escalation disaster impact using LCA approach. Utilization of LCA would assist the stakeholders to aware on the impact of a mine project operation. This study indicated that a coal mine tailings disposal has a potential impacts associated with human toxicity, terrestrial eco-toxicity, freshwater eco-toxicity, and marine eco-toxicity. The escalation of those impacts increases linear with the mine-life time. Utilization of LCA for predicting the impact escalation would prevent the massive losses caused by mine tailings accident. In addition, the relevant stakeholders have an opportunity to prepare the disaster contingency plan as a prevention strategy.

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