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Life cycle impact assessment of artisanal sandstone mining on the environment and health of mine workers

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ABSTRACT

Artisanal and small scale mining (ASM) is considered as a means to support and improve the quality of rural life, and is often the only activity that local communities have to sustain themselves. It is important to understand the nature of ASM and associated environmental effects in order to make informed decisions on the management, licensing and policy formulation of the ASM sector. Compared to other mined commodities such as, gold or diamond, the studies focusing on environmental and health impacts of sandstone mining are limited. This study used life cycle assessment (LCA) tool to evaluate the overall impact of artisanal sandstone mining (ASAM) on the environment and human health. The impact categories assessed in the study included: resource depletion, global warming, ozone layer depletion and acidification. It was observed that the impact of ASAM on the environment was minimal, however the high physical demand of the work negatively affected the health of the miners. The most common health related issues with the miners was observed to be silicosis and musculoskeletal problems. Fossil fuel used during transportation was observed to be the highest contributor for most of the impact categories.

1. Introduction

Mining plays a vital role in the growth and development of any nation in the world. Mining and its industries are critical for the socio-economic development of South Africa. South Africa contributed to about 1.82% of the global mineral production in 2015 with a corresponding value of around 113 billion USD (Reichl et al., 2017). In 2016, the mining sector in South Africa contributed to about 7.9% of the total GDP (Stats SA, 2017). Compared to large scale mining, artisanal and small scale mining (ASM) remains largely informal and contributes less to the total income from the mining industry. ASM is a subsistence mining activities carried out by individuals, families or groups (Debrah et al., 2014), which is very labor intensive and mostly performed manually using basic or simple tools and techniques (Chakravorty, 2001; Dorner et al., 2012). ASM is being practiced over 80 countries involving about 100 million people compared to 7 million in the industrial mining (World Bank, 2013), however it is most common in developing countries and is generally seen as a poverty driven activity to sustain local communities (Dreschler, 2001; Buxton, 2013). Since ASM miners often move around searching for the areas where work and resources are available, there is no way of controlling and monitoring how their activity may affect the environment and, therefore, many view ASM as an environmental disaster in the making (Dreschler, 2001). However, ASM has a potential to contribute to the sustainable development of the nation through the creation of job and poverty reduction in the local communities. Hence, its contribution cannot be ignored.

In South Africa, ASM was officially recognized after 1994 as a source of social and economic development of rural communities (Ledwaba, 2017) and since then the sector has been growing substantially (Mutemeri et al., 2010). An estimated number of 10,000 people are reported to be involved in ASM activities (Dreschler, 2001; Buxton, 2013), especially in mining precious metals and stones such as gold and diamond, industrial minerals such as kaolin and limestone, as well as construction materials such as granite and sandstone (Mutemeri et al., 2010). Over 90% of ASM in South Africa exploits industrial minerals and construction materials (Ledwaba, 2017).

The mining of dimension stone is annually growing at a rate of 7% with a global turnover of around 60 billion USD per annum (Ashmole and Motloung, 2008a). Sandstone, which belongs to the family of dimension stone, is a natural stone and has a great market for domestic constructions (e.g. pavement, landscaping, tiling and walls) and for making housewares, ornaments and artistic monuments (e.g. tombstones, sculptures, etc.). Artisanal sandstone mining (ASAM) is

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generally characterised by the use of basic and simple tools (e.g. hammer and chisel) to extract stone from quarries. The stone is used in its natural state and does not require concentration and extraction from an ore (Ashmole and Motloung, 2008b). Therefore, the mining process mainly involves the careful extraction of large blocks or slabs of stones from the quarries, followed by the transportation to processing plants where the slabs are cut, polished and prepared for commercialization (Borlini et al., 2012). South Africa holds some of the most spectacular sandstone landscapes and landforms in the world (Grab, 2015), and the local economy in QwaQwa, Free State Province, relies heavily on sandstone mining with countless artisanal sandstone mine quarries and dealership scattered all over the area.

In the recent years, mining activities has been perceived negatively due to issues concerning its impact on the environment, such as deforestation, destruction of natural landscape, release of dusts, pollutants and greenhouse gases (GHGs). For instance, high metal and acid deposits from sulphur mining can lead to pollution of water sources (Luís et al., 2011), high mercury intoxication and contamination from artisanal gold mining can result in serious health hazards (Limbong et al., 2003; Taylor et al., 2005; Rajaee et al., 2015) which might even require medical treatment (Bose-O'Reilly et al., 2010a; Bose-O'Reilly et al., 2010b). Other health and safety issues associated with mining sector may include ergonomic stresses, injuries, noise, child labor, landslides resulting from mining, infectious diseases, etc. (Smith et al., 2016). The negative impacts of ASM involve increased dryness and dust, changes in land use and landscapes, exposure of miner to occupational hazards, and increased rate of diseases (Miserendino et al., 2013). Compared to other minerals, the impacts of dimension stone mining on the environment is relatively small, however ASAM miners are exposed to dust, toxic chemicals, noise and vibration, and overexertion (Rupprecht, 2015). The impacts of dimension stone mining involve air, soil and water contamination (Ashmole and Motloung, 2008b); disturbance of land (Ashmole and Motloung, 2008b); destruction of habitat (GDACE, 2008); dust pollution (Kitula, 2006); noise pollution (Langer, 2002); climate change (Ditsele, 2010; Ruttinger and Vigya, 2016); solid waste or overburden (Ashmole and Motloung, 2008b); and health issues (Debrah et al., 2014). These concerns have raised an awareness among mining companies to assess environmental performance and health implications of their activities and identify areas for improvement in order to reduce burdens that this sector puts on the environment and human health.

Much of the attention on environmental sustainability has been given to large scale mining and very little to no attention to ASM, mainly due to informal nature of ASM and difficulty in tracking ASM activities. The availability of data to quantify the inputs and outputs resulting from ASM activities are limited, however few literatures suggested that its production process comes with its fair share of environmental costs (Ashmole and Motloung, 2008b; Borlini et al., 2012). The lack of environmental evaluation can be disastrous in regions where ASM is the sole means of subsistence.As such, it becomes imperative to evaluate the environmental impacts of ASM using a comprehensive assessment tool. Life cycle assessment (LCA) is one of the most effective tool to evaluate all environmental aspects and provides a comprehensive evaluation of the environmental performance of an operation or a system or a product throughout its life cycle.

LCA results have shown that the environmental performance of mining processes can be improved by decreasing the amount of fossil fuel inputs (Burchart-Korol et al., 2016). However, in most mining LCAs, the mining system is simplified or represented as a black box and several aspects of the mining industry, such as treatment and waste handling, are often overlooked (Valdivia and Ugaya, 2011). The shortage of LCA studies on mining is alarming because it does not only undermine the LCI databases that have been developed so far (Awuah-Offei and Adekpedjou, 2011), but also affects the quality of LCA results (Lesage et al., 2008). The only LCI report available on large scale sandstone mining is also limited to quarrying data (Table 1). Furthermore, the application of LCA to ASM is very limited due to the lack of formal way of monitoring the effects of ASM's activities. Limited literatures have used LCA to identify stages in the mining, treating and marketing of red clay which have shown the highest impacts on the environment (Bovea et al., 2007) or to identify appropriate surface area metrics in land use impacts (Spitzley and Tolle, 2004). LCA can provide valuable insights on a number of issues and options that are of interest to the mining sector (Awuah-Offei and Adekpedjou, 2011) and further can be used as a decision making tool to support environmental sustainability (Stewart, 2001).

Table 1
LCI data on sandstone quarrying (Natural Stone Council, 2008).

Items	Amount
Sandstone blocks (t)	62,000
Electricity consumption (kWh/t sandstone)	0.60
Water consumption (L/t sandstone)	12.11
Diesel fuel (L/t sandstone)	5.84
Petrol (L/t sandstone)	0.03

The main purpose of this study is to apply LCA principles in ASAM sector in South Africa to assess the environmental impacts of artisanal sandstone mining activities using the general guidelines of the ISO 14000 series. The study is conducted with an effort to compile life cycle inventory (LCI) and reducing the deficiency in the availability of data. The study also identifies the health risks associated with ASAM activities. The study targets policy makers and environmentalists where decisions on environmental and health improvements prove to be necessary.

2. Methodology

The general principles of the LCA method as defined by the ISO 14040 series was used to assess the impacts of ASAM on the environment. LCA model used includes four stages: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation.

The goal of the study was to determine the environmental and health impacts of ASAM. The scope of the study covers processes of the mining activities and associated environmental impacts. The functional unit (FU) was defined as '1 tonne of sandstone processed at the warehouse'. Life cycle inventory (LCI) for the study was developed using both primary and secondary sources. Primary data were collected using structured questionnaires, personal interviews and observation from the sandstone mining sites in QwaQwa, Free State Province, South Africa. Secondary data sources include industry or government publications, journal and conference articles, books and other published literature.

SimaPro software was used to develop LCA model and analyse LCI data. In the impact assessment stage, the impact categories were selected and assigned to inventory results. Finally, the results of the life cycle impact assessment were interpreted and possible areas from material and energy inputs were identified.

2.1. System boundary

System boundary defines what is to be included or excluded in LCA model (Pradhan et al., 2008; Shrestha and Pradhan, 2010). The system boundary considered for this LCA is presented in Fig. 1 (processes within the dotted box). While selecting system boundary, care was taken to ensure that critical stages which have significant contribution to the environmental performance were not overlooked. The exploration and development phases were not considered in this study because small and artisanal mining requires a very little or no preparation at all before extraction and do not use equipment or machinery, to build special facilities on site.