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Impacts of Fines at Morupule Coal Mine, Botswana

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ABSTRACT

Morupule Coal Mine (MCM) classifies fines as coal particles that are less than 3.35mm in size. Fines are one of the problems MCM is facing and have occasionally led to penalties from some customers. This paper quantifies the fines generated in MCM from the working face to the run-of-mine stockpile and its economic and environmental impacts. Data about the wash plant's production losses were collected through an examination of missed deadlines, stoppages due to tail-end blockages, and conveyor belt breakdowns using company reports. Data on coal dust concentrations were obtained from the mine. It was found that the overall haulage system generates about 27% of the fines of the coal produced monthly. The total monetary loss per shift from production and the wash plant is BWP 418,285. Coal dust concentration underground is kept within acceptable limits due to strict engineering control measures while it exceeds the required levels on the surface and is difficult to control as it is exposed to the atmosphere. As a result, the vegetation around the mining concession is affected by coal dust.

Keywords: Fine generation, Dust production, Coal degeneration, Economic impact, environmental impact.

1. INTRODUCTION

Coal degeneration is the reduction in the size of coal by comminution leading to smaller particle sizes (Ramos and Goodwin, 1987). Several factors affect coal degeneration which includes the cutting techniques of the continuous miner, belt conveyor speeds and drop heights of the transfer points and comminution of coal at the processing plant. Coal degradation results in coal dust that has environmental impacts such as water and air pollution, impacts on the health and safety of workers, and adverse effects on mining equipment and machinery (Halt, 2014). Handling operations from the working face to the stockpile increases the amount of fines generated since factors such as abrasion during conveying come into play. This makes coal degeneration one of the most significant problems in coal handling.

Dropping coal from high elevations generates more fines compared with dropping it from lower heights. According to Tavares and de-Carvalho (2012), the transfer points also play a significant role in coal degeneration. Ramos and Goodwin (1987) concluded that the degradation of coal materials at transfer chutes results from the change in energy imparted to the materials. At

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the same speed, more massive coal particles tend to disintegrate more than lighter ones due to their higher momentum. Speeding up the conveyor belt results in discharge angles becoming relatively large leading to an increase in the spread of projected materials (Ramos and Goodwin, 1987). A feeder breaker is an underground primary crusher for crushing coal before it is loaded unto the conveyor belt. The time taken by the feeder breaker to crush is essential because the longer it stays in the feeder breaker, the more fines are produced. Cutting coal with a continuous miner requires a high level of efficiency to minimise fines generation. The cutting efficiency of continuous miners is dependent on the type of drum, conditions of the cutting picks and the operator's skill as interactions between the cutter head and the coal face are imperative. The parameters that influence cutting efficiency include rake angle, back clearance angle, angle of attack and line spacing (Raghavan et al., 2014). Fines generation has some serious economic impacts in a mine such as blocking of the tail end of the conveyors and blockages at the wash plant which forces the operations at the wash plant to be periodically stopped. This leads to losses in production. Fines also increase the risk of coal dust explosions. As reported by Raghavan et al. (2014), coal dust also reduces visibility along haul roads which can lead to accidents. Coal fines create consolidation problems as they tend to stick to the surfaces and surrounding particles which leads to blockages in the coal flow during processing and at the power plant. Moreover, long periods of exposure of mine workers to coal dust generated during mining could result in lung diseases like silicosis and coal worker's pneumoconiosis (Meijers et al., 1991; Attfield and Morring, 1992; Vallyathan, 1994; Porter and Fittipaldi, 1998). Fines generation also affects the environment in terms of air quality, vegetation, and soil degradation. Fine coal dust particles which settle on the soil affect the quality and pH of the soil. Dust deposition on the leaves of plants decreases photosynthesis (for example, chloroplast content and stomatal blockage) and affects the colour of the leaves and plant growth (Bhuiyan et al., 2010; Zhengfu et al., 2010).

Besides mechanical factors, other researchers have studied fines generation considering coal lithotypes, microlithotypes, minerals and chemical elements present in coal (Terchick et al., 1963; Sciezska, 1985; Falcon and Falcon, 1987; Spero, 1990; Spero et al., 1991; Huggins, 2002; Hutchings, 2002; Sykorova, 2005; Nie et al., 2016; Bai et al., 2017). MCM has suffered penalties from some customers because of high fines content in the coal supplied to them. The fines generated has also led to blockages in the tail end of conveyors which results in production delays. This study attempts to determine the quantity of fines generated in MCM, a coal mine in Botswana.

In addition, the economic and environmental impacts of fines generated are also studied, and the measures taken to address the problem are elaborated.

1.1. Mine Case Study

Morupule Coal Mine (MCM) is located along the Serowe-Palapye road in central Botswana with coordinates 22.5071 ºS, and 27.0264 ºE (Fig 1). The Morupule area comprises Karoo sedimentary rocks which form the eastern margin of the greater Karoo basin developed to the west of Morupule. These sedimentary rocks consist of shale, coal, and sandstone of the Middle and Lower Ecca Group. Botswana has significant reserves of coal on the east side of the country, including the Morupule deposit, with 40 million tonnes of recoverable reserves that are proven (Machete, 2012).

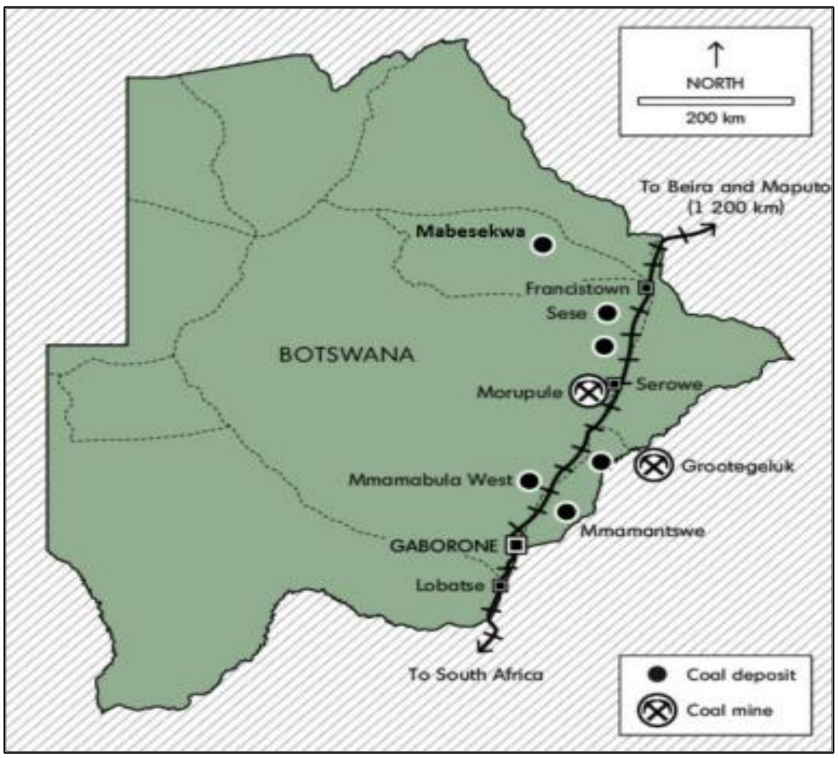

Figure 1. Location of Morupule Coal Mine, central Botswana (Makoba et al., 2020).

MCM is an underground mine which employs room and pillar mining method to extract coal. Continuous miners are used for cutting the coal and loading it into shuttle cars, which haul the coal and dump it into feeder breakers which crush the coal into smaller sizes before it is transported to the surface by conveyor belts. The mine produces metallurgical and thermal coal. After the screening process, coal with fines goes to the wash plant, where the separation between coal and gangue takes place based on the differences in their densities. Medium to large-sized coal goes through the comminution and sizing processes. The primary consumers of thermal coal are Botswana Power Corporation (BPC), Botswana Ash and the Namibian power utility company (Nam Power). BPC requires coal products ranging from 3.35 mm to 32 mm and only allows up to 32% fines (-3.35 mm) in the final product for easier handling at the power plant.

2. METHODOLOGY

Several types of tests were performed on coal collected from the MCM. Four samples, weighing 20 kg each, were obtained from the four mining sections namely, South Main 3/1, SM4/8, SM 4/5, and East Main 1/1 (Fig 2). Eight samples of 20 kg each were also collected, three from conveyor belts (CB1 from 18-114, CB2 from 18-113, and CB3 from 18-102), two from the lowest transfer points (LTP1 from 18-114 and LTP2 from 18-108), and two from highest transfer points (HTP1 from 18-102 and HTP2 from 18-101). In addition, one sample of 20 kg was taken from the run-off-mine (ROM) stockpile.

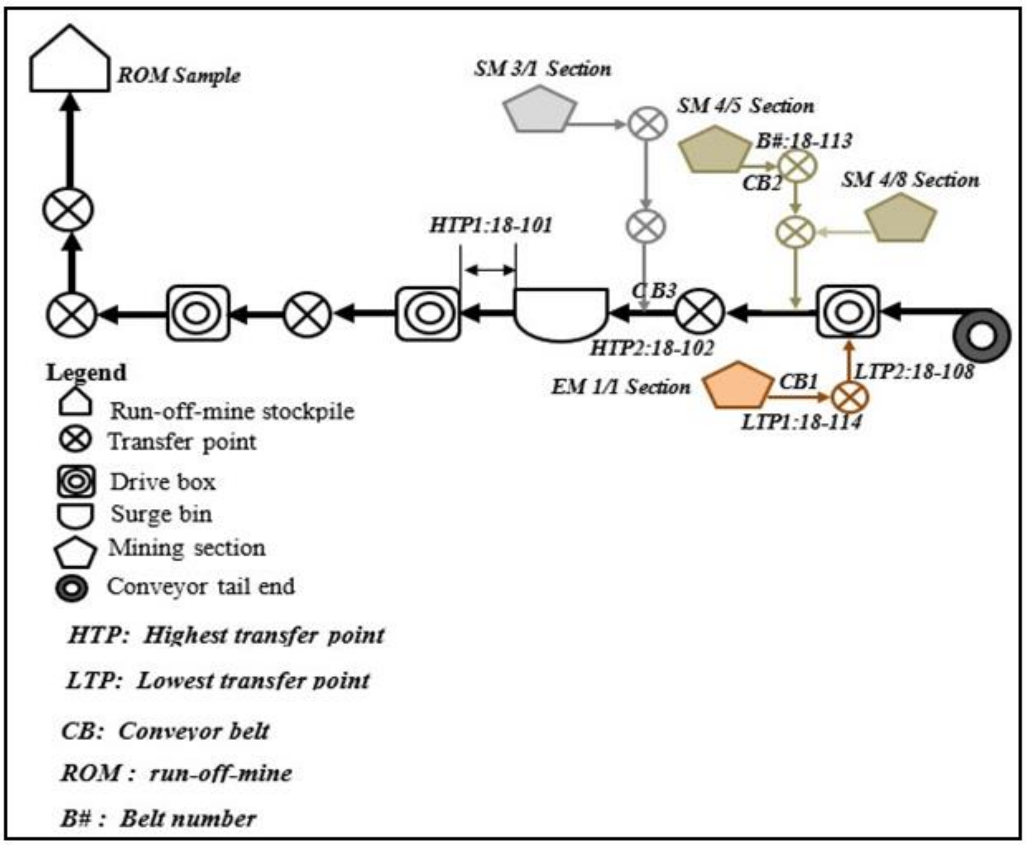

Figure 2. Location of sample points at Morupule Coal Mine.

The wash plant's production losses were determined through an examination of missed deadlines, stoppages due to tail-end blockages, and conveyor belt breakdowns using the company's reports. Data on coal dust concentrations was also obtained from the mine. The flow chart for the methodology is shown in figure 3.

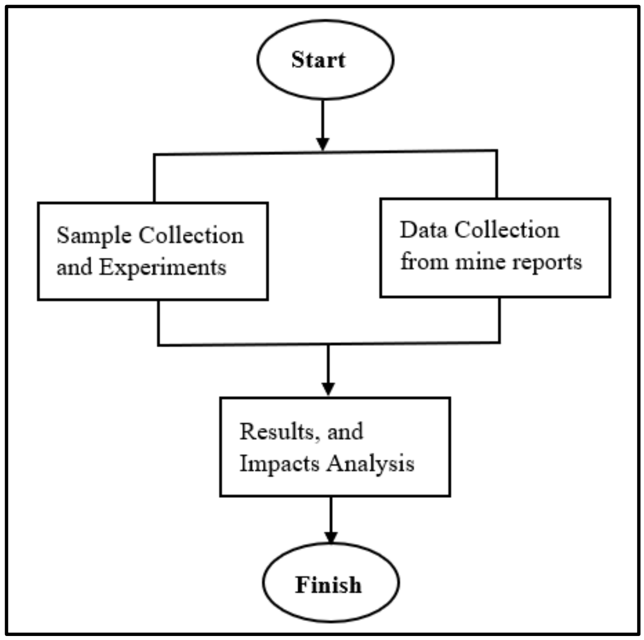

Figure 3. Flow chart for the methodology.

The relative influence of feeder breakers, belt speeds and transfer points on fines generation at the run-off-mine (ROM) stockpile based on particle size distribution is evaluated by the cosine amplitude method (Yang and Zhang, 1997). This method is used to obtain similarity relations between various parameters. The strength of the relation between the dataset is given by equation (1):

$$r_{ij} = \frac{\sum_{k=1}^{m} XikXjk}{\sqrt{\sum_{k=1}^{m} X^2ik \sum_{k=1}^{m} X^2jk}} \quad \text{------------------------- (1)}$$

Where, Xi and Xj are the input and output datasets respectively, with ***m*** being the dataset number.

3. RESULTS AND DISCUSSION

3.1. Nature of Coal and Fines Generation

The curves on the particle distribution and concentration of fines show that more fines were produced from SM 3/1 (≈ 12.65%) section compared to the other sections (Fig 4A and B). SM 3/1 coal is the most friable (≈ 31.25%) of all the sections while SM 4/5 coal is the least friable (about 2.81%) (Fig 4C).

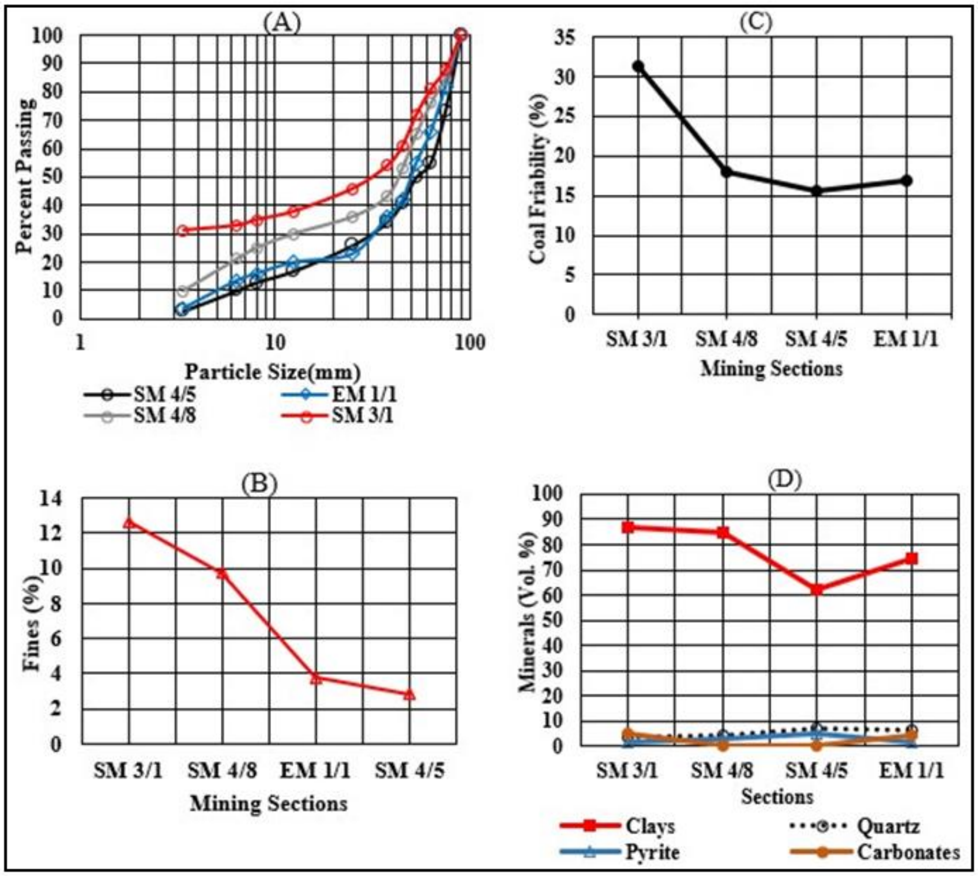

Figure 4. Coal samples from the MCM: (A) Particle Size Distribution curve, (B) Fines (%), (C) Friability (%), and (D) Minerals present in four sections (Vol.%) (Saubi et al., 2022).

The fines generation at mine sections and the friability test results compare well with mineral matter (Fig 4D) where quartz and pyrite are the most dominant in the SM 4/5 coal compared to the other sections. The average particle size distribution (PSD) of coal after sampling from the ROM stockpile shows that the average quantity of fines generated by the system is < 3.35 mm (Fig 5). Figure 6 shows the relative influence of feeder breakers (FB), belt speeds (BS) and transfer points (TP) on fines generation at the ROM stockpile based on particle size distribution is evaluated by the cosine amplitude method (CAM).

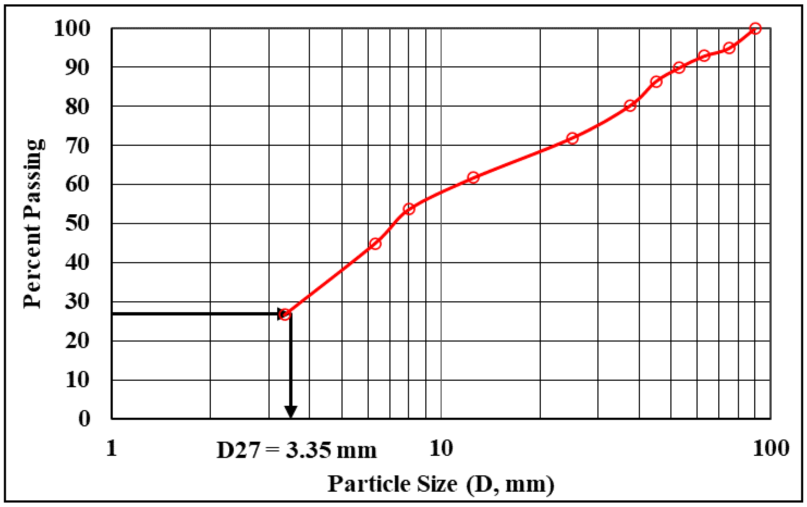

Figure 5. PSD of Runoff Mine Stockpile Coal at the MCM. D27 is the size of the sieve from which 27% of the coal is passing.

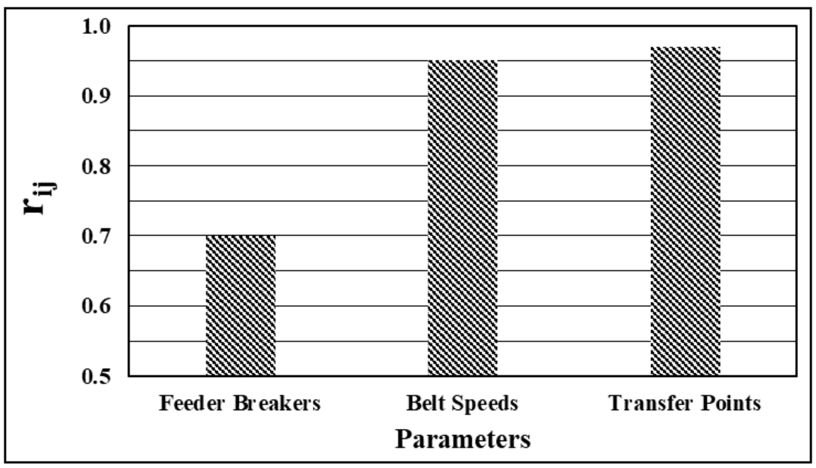

Figure 6. Sensitivity Analysis Using CAM at the MCM.

According to strength values obtained from the application of the CAM, (Fig 6) feeder breakers have the least influence, followed by the speed of conveyors, and finally, transfer points (height) is the most influencing parameter on fines generation at the run-off-mine stockpile (ROM). The production in tonnes and percent of coal fines generated at the wash plant (Fig 7) shows that fines generation is one of the significant factors that accounted for the production targets of the mine not being met at the wash plant for most of the months. This suggests that a significant amount of coal gets washed away as waste in the form of fines at the wash plant. Most customers accept coal products with a limited percentage of fines. When the proportion of fines in the stockpiles is more than 20% of the overall stockpile, then the targets cannot be met at the wash plant, as fines should make only 0.5% of the coal feed into the plant. For example, BPC requires coal products with less than 32% fines. On average from January to December 2019, the fines contributed 0.9% of coal fed into the Wash Plant at MCM which is higher than the acceptable limit of 0.5% per year (Fig 7). The anomalies occurred in August and November 2019 when more fines were generated while less coal was produced. This is due to a relatively weak seam that was encountered during mining in those months from the SM 3/1 mining section.

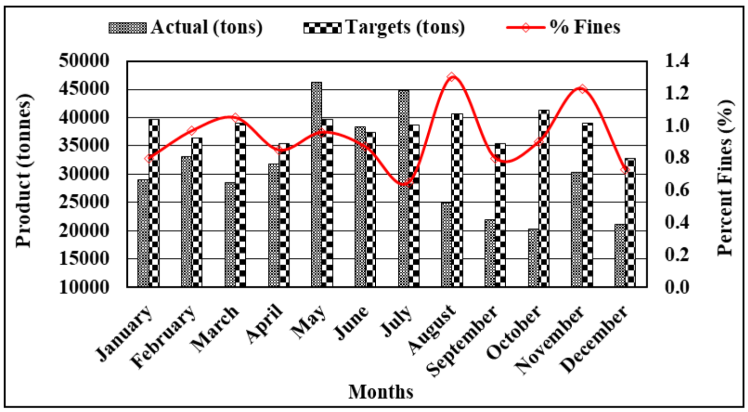

Figure 7. Coal Wash Plant Product at the MCM.

The downtime due to blockages recorded at individual conveyor belts (Fig 8) shows that the main conveyor belts (i.e., 18-108, 18-111, 18-112) had higher downtimes than section conveyor belts. The main conveyor belt 18-103 has the highest downtime of 18.22 hr per month. This is because belt 18-103 is connected to the tail-end of the conveyor belt system at the MCM. Hence, fine coal particles tend to clog or accumulate at the end of the pulleys resulting in severe blockages.

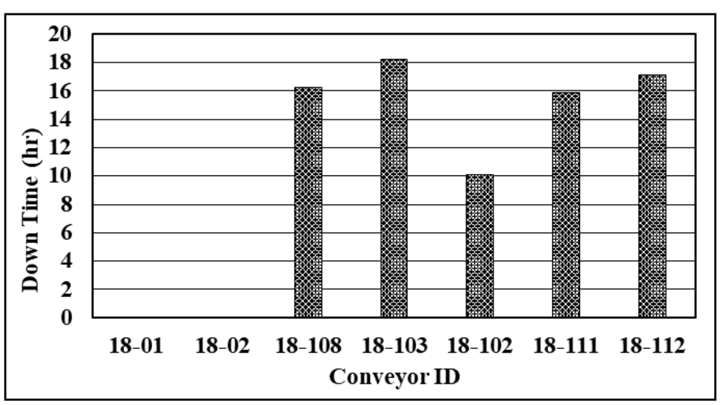

Figure 8. Blockages for Individual Conveyors at the MCM.

3.2. Economic Impacts

Fines generation leads to blockages at the tail end of conveyors, which forces operations to stop resulting in delays and production losses. The performance of the conveyor belts at the MCM (Fig 9) indicates that conveyor belt blockage is the major cause of delays than other conveyor belt problems. These blockages result from the generated fines. The cumulative delay from the conveyors is 77.57 hours every month, that is, an average of 3.37 hr/shift. The average coal production at the MCM in an 8-hour shift is 4,100 tonnes. Therefore, the delays due to conveyor belt blockages led to a production loss of 575 tonnes per shift.

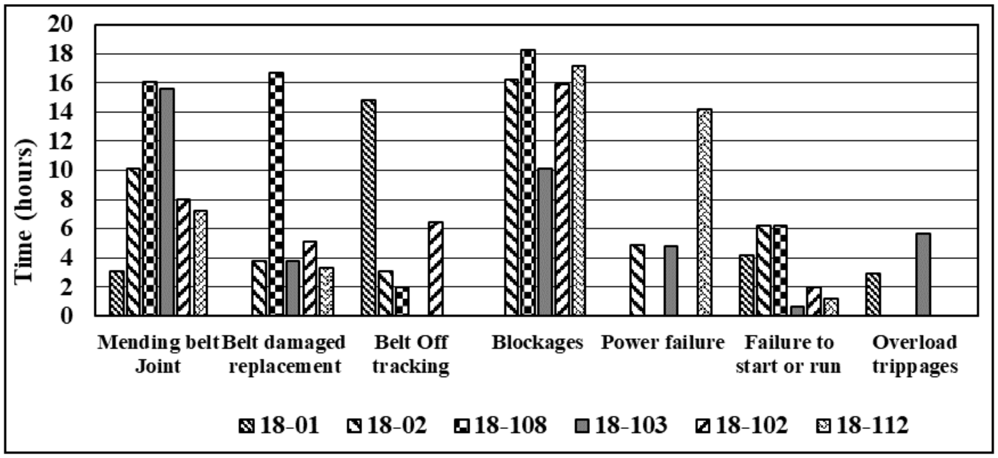

Figure 9. The MCM Conveyor Belt Performance.

The production losses versus breakdown times (Fig 10) show that production losses are directly proportional to breakdown times. This was the general trend in all the months. The leading cause of conveyor breakdowns was tail-end blockages due to fines accumulation.

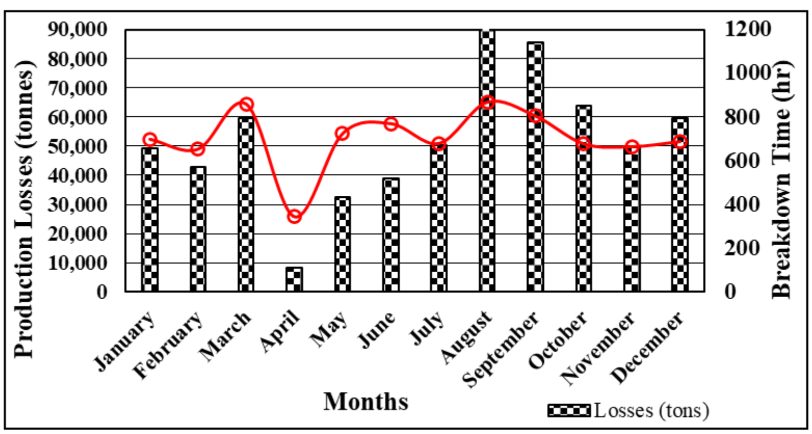

Figure 10. Relation between Production Losses and Conveyor Breakdowns at the MCM.

The total monetary loss is calculated based on the following observations:

Coal Price = BWP 650/tonne

Actual Output (wash coal) = 370,060 tonnes in a year

Fines (wash plant) = 11.11% in a year

Acceptable Limit = 0.5%/monthly × 12 = 6% in a year

Loss (Fines) = 11.11% - 6% = 5.11%

Production Loss = 575 tonnes/shift

Economic Loss from Production = P650/tonne × 575 tonnes/shift = BWP 373,750.00/shift

$$\text{Economic Loss from Wash Plant} = \left(\frac{\frac{\text{P650}}{\text{tonne}} \times 5.11\% \times 370{,}060\ \text{tonnes/year}}{\frac{12\ \text{months}}{\text{yr}} \times 23\ \text{shifts/month}}\right) = \text{BWP}44{,}534.57/\text{shift}$$

The total monetary loss per shift is BWP 373,750 + 44,534.57 = BWP 418,284.57.

3.3. Environmental Impacts

An assessment of the environmental impact of dust generation is carried out with the use of a Leopold matrix as shown in table 1 as an impact identification tool. This also includes evaluating the impact significance of dust generation on the health and safety of workers and equipment.

Table 1. Leopold Matrix for impact identification.

Valued Components	***Coal Handling Operations***			
	Cutting of CM	***Hauling by Shuttle Cars***	***Transporting Coal by Belts***	***Stockpiling Coal***
Human Health	3 / 9	3 / 6	2 / 6	6 / 9
Machinery	2 / 8	3 / 8	2 / 5	2 / 5
Air Quality	3 / 6	2 / 7	3 / 7	8 / 9
Total	61	56	43	136

In the Leopold matrix, the magnitude for cutting of the continuous miner is low since this activity only affects the area where the CM is cutting at the section. Loading and dumping of shuttle cars have low magnitude as well since they involve only specific areas where loading and dumping operations are done. The magnitude is also low for haulage by conveyor belts because it only affects the locations around transfer points where fines are generated. Stockpiling of coal has the highest magnitude since it is done on the surface, and the coal dust gets dispersed into the atmosphere over a large area around the mine. The importance of all the activities is directly linked to human health as coal dust has detrimental effects on human health, leading to severe diseases such as black lung and lung cancer.

The magnitude for cutting of the CM, loading, and dumping by shuttle cars in the Leopold matrix is low because it only affects the machines. Still, the value or importance is high since these machines are critical to coal mining and handling and any breakdown or delay from the CMs causes serious production losses. The magnitude for conveying by belts (on the surface) and stockpiling of coal in the Leopold matrix is high since these activities are exposed to the atmosphere and affect a more significant area around the mine. Its value is very high since the coal dust in the atmosphere has effects on human health, soil and vegetation in the mine and surroundings.

Summarising the impact significance shown by Leopold matrix, human health is affected by all activities in coal handling operations. However, activities such as conveying coal by belts and stockpiling have the most significant impacts on air quality around the mine. Coal handling operations of high magnitude (extent of impact) have led to more impact significance (product of magnitude and value). Stockpiling of coal being an activity with the highest impact significance.

Coal screening, stockpiling, and conveying are the primary sources of particulate matter (coal dust) dispersion at collieries. MCM monitors the air quality of its underground operations as well as above ground for occupational reasons. The results of the coal dust monitoring taken above the surface are shown in figure 11.

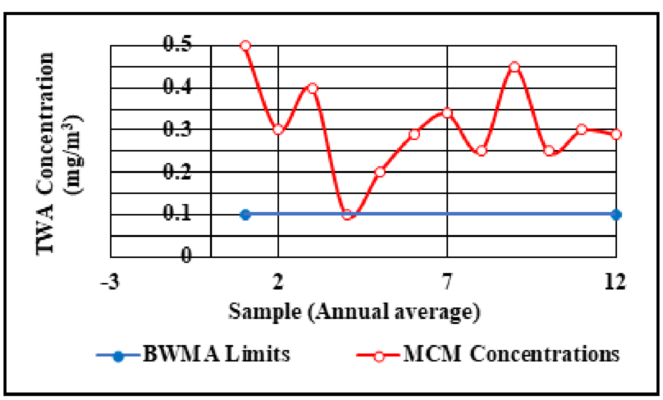

Figure 11. Surface Coal Dust Concentration in MCM.

Figure 11 shows that the air quality around the mine is 0.30 g/m^3 and that the Botswana Waste Management Act limits for particulate matter of 0.1 g/m^3 based on the annual averaging period were also exceeded. The conveyance by belts (on the surface) and stockpiling of coal are exposed to the atmosphere. Therefore, other factors such as wind play a role in dispersing the fines over a large area thus affecting a more significant area around the mine. As a result of this, fine coal dust particles settle on the soil and affect the quality and pH of the soil. Dust deposition on the leaves of plants decreases photosynthesis in the plants and affects the colour of the leaves and plant growth. It was observed that the leaves of the vegetation around the area had dull green colour and most plants had stunted growth (Fig 12).

Figure 12. Pictures showing the impact of coal dust on vegetation in the MCM area.

3.3.1. Mitigating Environmental Impacts

Engineering controls in the mine are the principal methods used to reduce exposure to respirable coal mine dust. Engineering control measures include diluting the dust generated by providing adequate ventilation at the coal face, controlling the respirable dust created and entrained (with improved shearer drum design of the CM), and suppressing the dust generated utilizing water. Machines such as continuous miners and roof bolters are not significantly affected by coal dust since they are designed with dust collection systems. In cases where dust collectors of the roof bolters show accumulations of dust between the filters and blower, the dust is removed by backflushing the system with compressed air. The continuous miner is remote-controlled in most cases to enable the operators to avoid dusty areas and remain in fresh air to minimise their dust exposure. The CMs are also equipped with sound non-clogging water filtration systems to avoid cases where dirt and dust particles in the water line clog the spray nozzles. Regular bit replacement and routine inspections of the cutting drum are done to minimise fines generation. As shown in (Fig 13), the dust level concentrations are kept within the acceptable limits in the mine as the dust concentrations underground were all < 2 mg/m^3. The MCM ventilation standards which comply with the Mines, Quarries, Works, and Machinery Act Chapter 44 of Botswana limits the dust concentration underground to 2 mg/m^3.

The mine workers wear approved personal protective equipment and uniforms that are laundered each day. The protective clothing is inspected and maintained to preserve its effectiveness. The concentration of respirable coal dust is determined as a time-weighted average (TWA) by collecting samples over an 8-hour shift for up to a 40-hr work week.

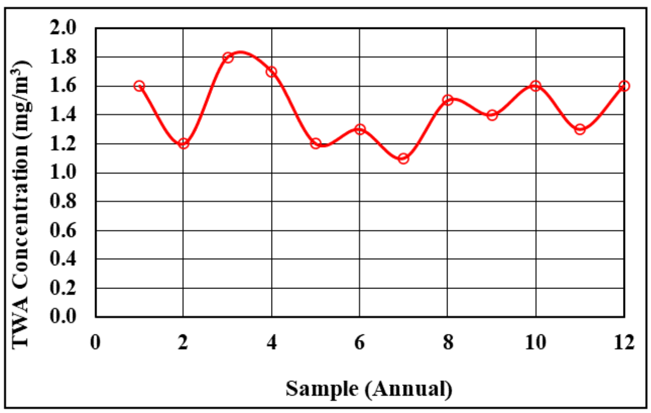

Figure 13. Underground coal dust concentration in MCM.

When it is observed that the respirable dust concentrations exceed the recommended exposure limit (REL) for respirable coal dust, workers wear respirators for protection until adequate engineering controls or work practices employed return the atmosphere to normal levels. Due to these strict measures at the mine to prevent coal dust dispersion and inhalation by mine workers, there has not been any reported cases of coal worker's pneumoconiosis.

4. CONCLUSIONS

In this study, an attempt is made to quantify fines generation in MCM and determine the economic and environmental impacts. It is found that the overall haulage system from the working face to the run-off-mine stockpile generates about 27% fines of the coal produced monthly. The total monetary loss per shift considering losses from production and the wash plant is about BWP 418,285. Fines generation is kept within acceptable limits underground due to strict engineering control measures, while the coal dust concentrations on the surface exceed the required limits as the coal is exposed to the atmosphere and it is difficult to control the influence of wind on it. Therefore, the dispersion of coal dust has affected the vegetation in the mining concession.

5. ACKNOWLEDGEMENTS

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6. CONFLICT OF INTERESTS

The authors declare no conflict of interest regarding this work.

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