



School of Earth Sciences and Engineering

Department of Mining Engineering

**EVALUATION OF MORUPULE COAL MINE'S
BLOCK 2 MORUPULE MAIN SEAM FOR THE
PROSPECTS OF NEW COAL MINE
DEVELOPMENT AND COAL PRODUCTION**

by

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BEng. in Mining Engineering

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November 2024

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ABSTRACT

The coal mining industry plays a crucial role in global energy production, and the need for accurate and updated information about coal deposits is essential for effective resource management. This study focused on the re-evaluation of the Morupule Coal Mine block 2 (MCM2) that was initially evaluated over 50 years ago. The aim was to utilise the change in methodologies and advancement in technology over the years, leading to more accurate and reliable results. By re-evaluating the MCM2 coal block and incorporating the advancements in methodologies and technology, this study provided an updated understanding of the coal deposit focusing on the Morupule main coal seams' potential and feasibility for future mining. Findings rendered the project both technically and financially feasible at the current economic condition based on the estimated coal resource and cost estimates, respectively. The overall in-place coal resources of the Morupule main seam were estimated to be 812 million tonnes (Mt). This resource was further broken down as 715 Mt Measured Resource and 97 Mt Indicated Resource. Mining method anticipated is open cast mining using a dragline in combination with drill and blast techniques, roll-over mining where progressive rehabilitation is conducted as mining takes place. The proposed opencast mine has a production capacity of 3 million tonnes per annum, requiring capital investment of US\$57 million and targeting a coal selling price of US\$100 per tonne, with a potential net present value of US\$1.094 billion.

DEDICATION

This thesis report is dedicated to my lovely mother Dr. Zodwa Gcinaphi Nxumalo, my dear brother Phinda Kono Mngomezulu, and my late father Lucas Mkhathazi Mamba. To myself, always remember not to give up on the person you are becoming!

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ABBREVIATIONS AND ACRONYMS

3-D	3 dimensional
ADT	Articulated Dump Truck
AHP	Analytic Hierarchy Process
Bcm	bank cubic meter
BPC	Botswana Power Corporation
Bt	billion tonnes
BOTASH	Botswana Ash
DGS	Department of Geological Survey
IEA	International Energy Agency
IRR	Internal Rate of Return
Km	Kilometre
km ²	square kilometre
M	Meter
MCDM	Multi Criteria Decision Making
MCM	Morupule Coal Mine
MCM2	Morupule Coal Mine block 2
Mm	Millimetre
Mt	million tonnes
Mtpa	million tonnes per annum
MW	Megawatts
NPV	Net Present Value
PP	Payback Period
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
ROI	Return on Investment
ROM	Run of Mine
SADC	Southern African Development Community
SAMREC	The South African code for the reporting of exploration results, Mineral Resource, and mineral reserves
SCOLBOT	Shell Coal Botswana

CHAPTER 1

INTRODUCTION

1.1 Chapter Overview

This chapter presents the overview of coal mining followed by the context of the Botswana coal sector, the history of coal mining is highlighted and the current status of coal mining in Botswana. It also has the purpose and context of the study, the problem statement, and the objectives of this research work. Methods of data collection and reconciliation that were used as well as the research framework applied in the study, are also presented.

1.2 Overview of Coal Mining

Coal mining is commercialised in over 60 countries and utilised in over 70 countries. Due to the Coronavirus pandemic, the global consumption of coal dropped by an estimated 7% between 2018 and 2020, which pushed the total coal demand down to 7.63 billion tonnes (Bt) (IEA, 2020). The fall in coal consumption was attributed to the drop in the demand for coal to produce electricity which reflected a low electricity demand due to the stronger contributions from renewables and lower natural gas prices. The pandemic not only affected the demand for coal but the supply as well. Regardless of this decline in both demand and supply, a 2.6% rebound was forecasted for the global demand of coal and by the year 2025 the demand is forecasted to even out at approximately 7.4 Bt (IEA, 2022).

Electricity supply from renewable energy has proven undependable thus coal is foreseeable to stay in demand for electricity generation in the near future (IEA, 2022). Goodman (2016) claims that power generated from coal stands above as hydro-electricity is constrained by the scarcity of water in some regions while nuclear-energy is unfavourable due to it being capital intensive reaffirms the importance of coal dependence for energy supply. Industrial processes contribute to the enormous volumes of coal used as there are no practical substitutes for coal in these processes.

Changes have occurred regarding how coal exploration is conducted and with regards to the Collection and interpretation of geological data has changed radically in coal exploration practices; with advances in research on theoretical and practical coal exploration techniques

and the development of new integrated coal exploration systems for the identification and quantification of coal resources have availed an opportunity for updating data obtained from previous exploration (Wang *et al.*, 2021). Xiao *et al* (2016) also alluded that data from previous exploration can be aligned with the current technologies and economic classification systems such as the distribution of associated coal resources in coal strata, as well as multi resource coordinated exploration of coal.

Computer programmes such as Datamine, Techbase, Minex, and Surpac, have increased access to the gathering and elucidation of data for the accurate determination of the location and extensions of mineral deposits or ore bodies which is crucial in the estimation of the quantities, deposit thickness, and grade distribution. That is why in recent times these computer applications have been widely used for visual interface depiction and simulation on models of topography, ore body, and 3-D mine designs. Such advances are ideal for improving the accuracy of previously obtained results and for the improved authenticity of findings on the area of study (Erarslan, 2005). Innovations and incorporating modern technology make it easier to find new coal deposits, which in turn facilitates the exploitation of entirely new types of deposits and leads to the decline of the costs of mining and coal processing (Sanchez and Hartlieb, 2020). Studies by Wang *et al* (2021), Unver (2018), and Xiao *et al* (2016), provide more evidence supporting the use of technological computer applications in mineral exploration. The studies show that mining research and development has led to new technologies that not only reduce the costs of production but also enhance the quality of the coal commodity produced while reducing the environmental impacts brought about by coal mining.

1.2.1 History of Botswana's Coal Mining Industry

Coal exploration in Botswana began in the early 1930s. The results of exploration and coal analysis indicated that coal bearing deposits formed in two distinct Groups: The Palapye-Serowe Group and the Artesia-Dibete Group. Early geological surveys and later detailed exploration by Anglo American Corporation and by Shell Coal Botswana (SCOLBOT) revealed that the Morupule area contained enormous resources of bituminous thermal coal of low ash content and high calorific value (Machete, 2012). A mining licence was granted to Anglo American Corporation in 1966 by the Government of Botswana resulting in the development of Morupule colliery. After completion of geological work on the Morupule

coalfield, approval of the mining plan to mine coal was received, and exploitation commenced in 1972. Morupule colliery was opened and has been active since then.

In 1983, the Government of Botswana and SCOLBOT signed a joint venture agreement defining the terms and conditions under which a new thermal coal export mine would be developed at Kgaswe near Serowe. Feasibility studies were conducted on all aspects affecting coal mine development and associated infrastructure. The study showed that the project was technically feasible but economically unattractive, thus Shell withdrew from the project in early 1985 (Amstrong, 1984). Though exporting coal then seemed far-fetched, the importance of the Morupule coalfield was expected to grow due to increased world consumption of fossil fuel and the favourable global trends towards coal (Machete, 2012). This was covenant with the forecasts that alluded to the diversification of Botswana's economy by venturing into coal mining as a key prospect for economic growth through coal export from four commercially significant coal deposits at Morupule, Mmamabula, Sese and Mmamantswe coalfields which were extensively explored to a point where it was conceivable to conclude that an export industry of at least 36 million tonnes per annum (Mtpa) growing to as much as 90 Mtpa is possible (Grynberg, 2012).

1.2.2 Current Status of Coal Resources in Botswana

Coal production plays a crucial function in sustaining the security of the global energy mix. In Botswana, coal is the only energy resource identified to exist in quantities large enough to have a major impact on the country's energy balance. Coal currently provides 29% of Botswana's primary energy and it is forecasted to remain a major contributor to the energy mix due to its relatively large quantity and low production cost (Maatla Energy, 2018). According to Ukwazi Mining Studies' 2017 report for Shumba Energy, there are prospects for coal providing a basis for reducing the country's dependency on energy imports as well as coal eventually being the major export commodity for Botswana. This is in accord with African Energy's 2018 report on power generation and coal export project development, which highlighted that the total energy consumption in Botswana will increase steadily putting coal in a predominant position, thus availing a market for increased production of coal.

Botswana is a country with abundant, largely untapped resources of high quality sub-bituminous coal in several locations in the country (Machete, 2012). It has an estimated

212,868 Bt of coal resource, constituting 50% to 60% reserves, making Botswana the second largest coal resource site in Africa, after South Africa (Botswana Investment and Trade Centre, 2016). Ten areas in Botswana have been identified to contain coal deposits; although the coal quantity and quality vary for each area; generally, the calorific values are high, ash contents are low, and volatility is medium to high (Kabelo, 2018).

The Botswana coalfields are sparsely spread, covering areas such as Dukwi, Foley, Serule, Bobonong, Morupule, Moiyabana, Mmamabula, Mmamantswe, Letlhakeng, Dutlwe and Nconjane (Figure 1.1). The shallow coal seams are spread along the eastern side of the country, while the western side has deep coal seams. Interest has been concentrated on the Morupule, Mmamabula and Kgaswe coal fields which all contain thermal coals which can be directly fed into a power generating plant or for increased quality can be washed and sold onto the international thermal coal markets (Baruya and Kessels, 2013). Three coal mines are currently in operation: the long serving Morupule Coal Mine (MCM), Minergy Limited which started mining operations in 2019, and the Motheo project opencast coal mine in Morupule which was commissioned in 2022.

Morupule Coalfield

The Morupule coalfield is a 425 km² lease area that is divided into three blocks, namely, MCM1 block, MCM2 block, and MCM3 block. The total inferred coal within the MCM lease area is approximately 12 billion tonnes of semi-bituminous coal resource (Morupule Coal Mine, 2020). Since inception of the Morupule colliery, mining activities have been focused on the MCM1 block operating an underground bord and pillar coal mine, currently mining at 85 m below the ground. Mining on this block was expanded between 2008 and 2011 to increase the run-of-mine (ROM) coal production capacity from 1.2 Mtpa to the current rate of 2.8 Mtpa (Morupule Coal Mine, 2020).

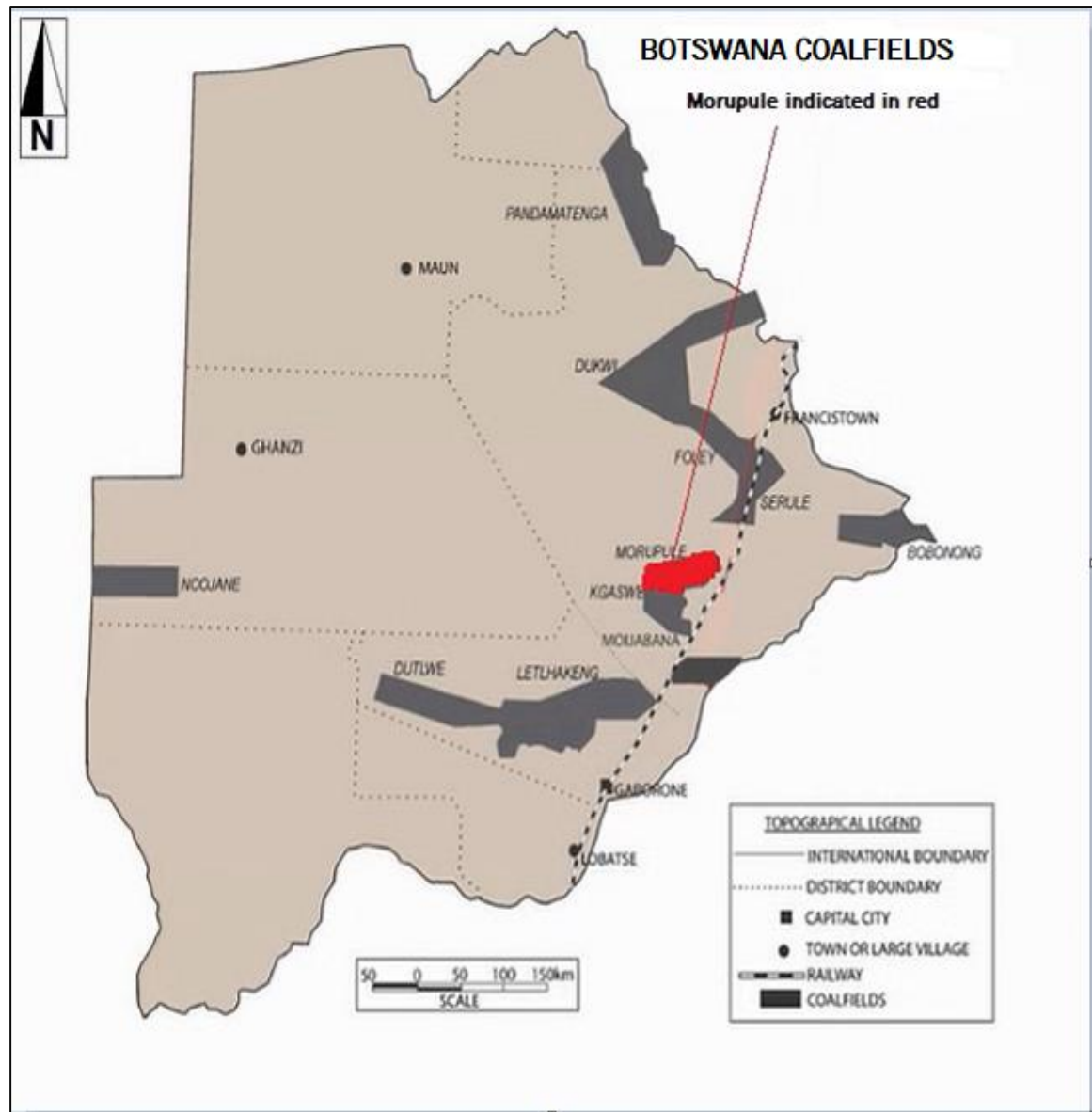


Figure 1.1 Botswana Coalfields (Modified after: Kabelo, 2018).

Considering the state of the coal market and the possibilities of increasing production, MCM has been exploring the other resource blocks to be exploited within the lease area. The latest expansion plans led to the operation of an open cast coal mine on the MCM3 resource block which produces 2 Mtpa into the regional market, which was commissioned in 2022. To the north of the MCM1 block is the MCM2 block, the focus area of this study, which is still untapped but has known prospects of being a viable and minable block (Figure 1.2).

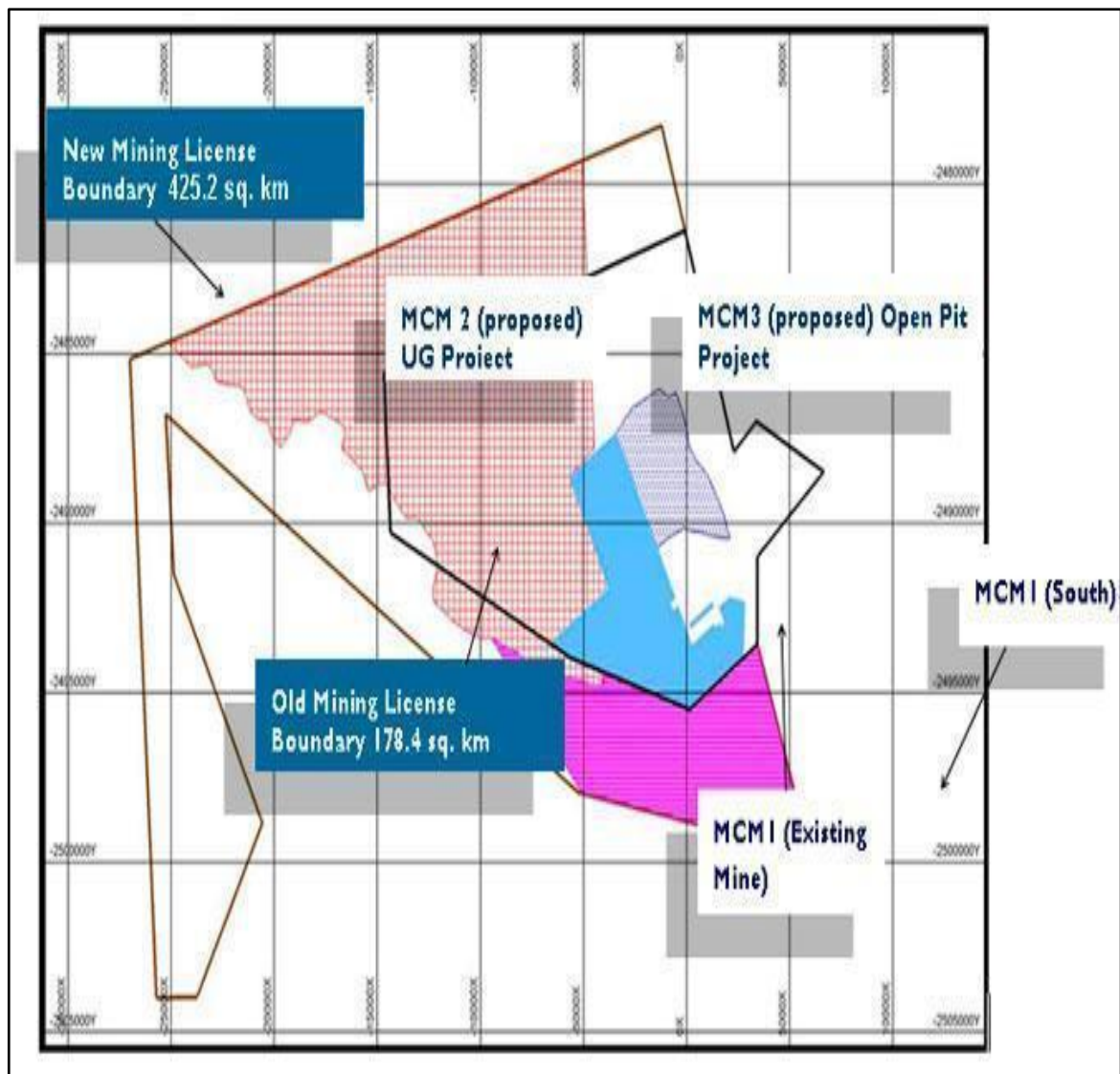


Figure 1.2 Study Area Location Map

Part of the MCM2 block was explored by SCOLBOT and the results of their feasibility study indicated that the project was technically feasible but economically unattractive at that time resulting in Shell withdrawing from the project in early 1985 (Armstrong, 1984). This is the area this study focused on, the main objective being to assess its viability for coal mining, the development of a new coal mine under the current economic conditions as well as considering all environmental regulations currently applicable. This study thus aimed to obtain current coal resource estimation data on the MCM2 resource, as well as assess the prospects of it being a potentially feasible mining area for coal production.

1.3 Purpose of the Study

The purpose of the research study was to provide an updated estimation of the MCM2 coal block, provide cost estimates for commencing a new coal mine project as well as assess the technical and economic feasibility of a new coal mine development.

1.4 Problem Statement

The coal industry has witnessed significant advancements and changes over the past 50 years, including advancements in mining technology, environmental regulations, and market dynamics. As a result, it becomes crucial to re-evaluate and reassess the findings and conclusions of a coal block evaluation study conducted five decades ago. The main mandate being determining the current status and potential of the coal block in light of these changes, ensuring accurate and up-to-date information for decision making.

The MCM2 block has an economic potential that has not been looked at since the mid-1980s, when then Shell Coal Botswana (Pty) Ltd (SCOLBOT) jointly undertook feasibility studies with the Government of Botswana in a project called “Kgaswe Project Feasibility Study” (Armstrong, 1984). A thorough assessment was done up to feasibility level envisaging a 5 Mtpa coal export operation that could be expanded to twice that capacity. Production would come from 3 room and pillar underground mines, located at various parts of the Kgaswe area.

The problem lies in the out-of-date nature of the previous coal resource estimation, which relied on methodologies that may no longer align with the present mining landscape. This made it imperative to re-evaluate the coal resource estimation, mining parameters, economic feasibility, and environmental considerations associated with the coal block. This research relooked at this area to determine if it can be the next frontier in the development of MCM coal resources, specifically targeting an export market that requires a genuine Grade A coal (26.5 - 28.0 MJ/kg) that cannot be produced from other MCM blocks. In fact, most coal fields in the world have exhausted this type of coal and more and more inferior qualities are produced out of necessity (IEA, 2022). During this time when coal is facing the serious headwinds of a “decarbonising” world, it is important to find and economically extract those resources that give the highest energy per unit of production, therefore affording reasonable transportation cost for energy and the best chances for carbon neutrality when one must factor other sources of energy that the government may be looking at implementing.

This study addressed several key questions. Are the previously estimated coal resources accurate? Have advancements in mining technology impacted the potential production capacity and extraction methods? How have environmental regulations and sustainability concerns influenced the viability of the coal block. By conducting a comprehensive re-evaluation, incorporating updated data, and utilizing advanced mining software and methodologies, this study provided a current assessment of the coal block's potential, its economic viability, and environmental considerations. The outcomes of the study facilitate informed decision making regarding the future development and utilization of the coal block.

1.5 Objectives of the Study

Three objectives were considered in conducting the coal resource evaluation for the MCM2 block for coal mine development. These objectives were:

1. Study and evaluate all geological data used for coal resource estimation to determine the geologic context of the study area, shape and spread of coal deposit and the resource classification.
2. Generate appropriate coal mine design plan through the determination of mine boundaries, determination of mining method and planning of production schedule based on selected mine life; and
3. Study the financial feasibility of the project through the calculation of coal mining investment costs.

1.6 Methodology

Advanced analytical techniques, modelling software, coal resource estimation codes, regulations, and cost estimation techniques were applied to determine the most suitable method and scale of mining. Figure 1.3 illustrates the methodology framework utilised in the study. It shows procedures of the main data analysis components of the study.

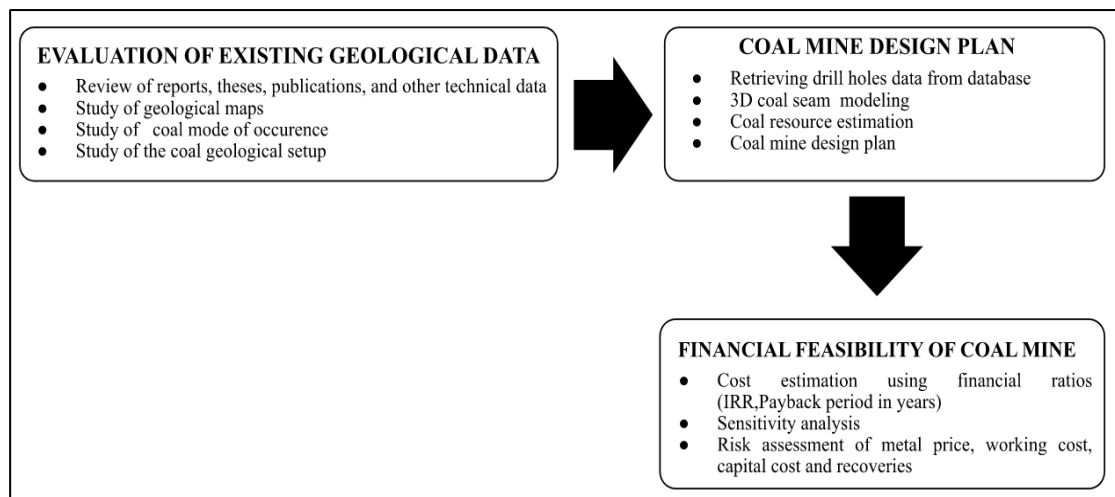


Figure 1.3 Methodology Framework

1.6.1 Evaluation of Existing Geological Data

This involved gathering all available information pertinent to the study area, including published and unpublished scientific papers and theses, geological maps, reports, and coal mining feasibility studies. The quality and reliability of the data was reviewed and assessed to identify any gaps or limitations.

1.6.2 Coal Mine Design Plan

Mine designs from previous feasibility studies and those of similar mine operations were evaluated and analysed to identify areas of improvement. Mine planning software (Geovia Surpac and Minex) were utilized to develop optimised mine designs that maximise coal recovery and minimize operational costs. Geotechnical constraints and safety requirements were considered during the mine design process hence advanced geostatistical methods were utilised to estimate the coal resource. Producing a realistic geometrical (3-D) modelling of the coal seam was the first step in the coal mine design, incorporating data from drilling programs, coal quality analyses, and geological models to develop a dependable resource model. Factors such as coal seam thickness, depth and quality were considered to determine the economically extractable resources.

1.6.3 Financial Feasibility of Coal Mine

Proving the presence of coal resources is motivated by the prospects of making profits from coal mining. It is a known occurrence that resources may not be of economic significance at a given time but there are chances they may gain economic significance at a later stage

with changed economic and technological conditions (Kumar and Kumar, 2015). Financial parameters and capital budgeting techniques were applied to assess the financial feasibility and sustainability of the coal mine. Financial parameters evaluated include Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period, as well as sensitivity analysis on capital budgeting parameters.

1.7 Significance of the Study

Despite being the longest exploited coal field in Botswana, the Morupule coal resource is so far not extensively exploited. While much exploration data is available, computer-aided geological modelling has not been executed. This study provided an updated and more accurate understanding of the coal block's geology, considering advancements in geological mapping techniques and data analysis. This helped in better identifying and delineating coal resources. By applying modern geostatistical methods, the study provided more reliable estimates for coal resources. This information was crucial for effective mine planning and investment decisions. The findings of the study will guide future planning and development of the coal block, including mine design optimization and operational requirements. It supports long-term decision making and maximizes the value and potential of the MCM2 block.

1.8 Limitations of the Study

Obtaining reliable and comprehensive historical data from over 50 years ago was challenging. Some data was incomplete, outdated, and lost, making it difficult to accurately compare and validate previous findings. Technological advancements in data collection, analysis, and modelling techniques introduced variations in the interpretation and estimation of coal resources compared to the methods used previously. Regulatory requirements and environmental standards have evolved significantly, resulting in the need for additional studies, assessments, and compliance measures that were not previously considered. Any evaluation study involves uncertainties and assumptions, and re-evaluating data from 50 years ago introduces an additional layer of uncertainty. Assumptions made during the study may affect the accuracy and reliability of findings.

1.9 Delimitations of the Study

The study focused specifically on re-evaluating the findings from 50 years ago and does not account for more recent developments in changes in the coal block since then. The study

was limited to the data that is available from 50 years ago. Missing or incomplete data restricted the comprehensive analysis with current conditions. The study was limited by resources such as time, budget, and workforce which had an impact on the depth and breadth of the re-evaluation. This resulted in a more focused analysis and the need to prioritize certain aspects over others. The study focused specifically on the coal resource estimation and does not include broader aspects of geotechnical analysis and modelling, or intensive environmental impact assessments. These may be addressed separately or as part of subsequent studies.

CHAPTER 2

BACKGROUND INFORMATION

2.1 Background on the Prospects of Coal Resource Development in Botswana

Botswana is an administratively stable country with an estimated population of 2.30 million (2019 estimate). It is a landlocked country covering 581,730 km², located in southern Africa. Botswana shares boundaries with South Africa, Zambia, Zimbabwe, and Namibia. In 1966, diamonds were discovered and this made Botswana one of the fastest growing economies in the world, thus the country entered the ranks of upper-middle income countries in the past five decades. The significant growth in Botswana's economy is attributed to substantial mineral prosperity, good governance, judicious management of the economy, and small population (Ghebremusse, 2018).

The main objective of the Botswana government regarding the mining or mineral sector is to establish maximized economic remunerations from mining (Bertelsmann, 2022). The limited exploitation of the large coal deposits has been a worrisome issue to policy makers. In that essence, policies have been put in place that encourage coal deposit prospecting, new coal mine development and the promotion of opportunities for linkages to expand value added activities (Grynberg, 2012). It is for this reason that policies for the economic and legal framework for mineral exploration, mining and mineral processing continue to be incessantly reviewed to make it more competitive and attractive to coal mine investors (Ghebremusse, 2018).

The government developed a coal road map in 2009 which provided a coal marketing strategy incorporating improvements in the mining of coal and coal generated electricity sectors and identifying potential candidates and investors to implement the ideal strategic plans (Lewin, 2011). In addition to that, the government also explored alternatives to build rail lines to be used for coal export to the seaborne market (Baruya and Kessels, 2013). Coal experts suggest that policy makers must continue to promote coal export as it is evident that investment in infrastructure for the coal industry could contribute significantly to the revenue of the coal producing countries (Tate *et al*, 2021). The current mineral policies in

Botswana encourage more private sector involvement for the proposed expansion of the supply of coal to the international seaborne market.

Improved regional stability avails an opening for Botswana's policy makers to consider alternative export facilities and ports that will expedite the development of coal deposits (Ghebremusse, 2018). This therefore means the failure of Botswana coals to penetrate the export trade market can no longer be attributed to the long distance to seaports but rather factors that hold back the expansion of the coal export industry need to be determined objectively (Fichani, 2003). The role and significance of distance in the costs of transporting coal by rail, therefore, needs to be considered as similar to that of coal producers and exporters with similar hauling distances in other world regions hence eliminating the limitations of haulage distance for the export of Botswana coals. Botswana has a worthy standing in foreign investor dealings and is a known prosperous mining country. The most significant investor opportunity in coal production and export is the existing joint venture partnership with the international corporations of South Africa which puts the country at an advantage and a better position to minimise the entry barriers into the international thermal coal trade (Grynberg, 2012).

2.1.1 Overview of Botswana Coal Mining Economy and Coal Mining Prospects

Botswana has a diverse economic system encompassing private fractions in conjunction with economic planning and government regulations. Botswana's economy has been steadily growing since independence due to financial buffers and policies that have played a vital part guarding the economy (Lewin, 2011). The restrictions of Botswana's diamond led economic development model have however, been more evident, as economic growth is dawdling, economic inequality still dominant, and creation of jobs being constrained in the diamond mining sector (Harvey, 2015). The findings of an analysis brief conducted by Bertelsmann (2022) indicated that the coronavirus pandemic had exacerbated existing growth challenges leading to the economy contracting by an estimated 8.9% in 2020 as the coronavirus lockdown and other government restrictions due to the pandemic constrained economic activity.

Development within Botswana's mining sector lies with coal due to its large untapped resource. This untapped resource has been assessed to have the prospects of significantly ramping up coal production in Botswana, targeting the export market (Grynberg, 2012). The

prospect of large-scale coal production is aligned with the Government's plans to branch out from metal mining and focus on coal as a strategic prospect for Botswana's future economic growth (Baruya and Kessels, 2013), mainly so because the Government has recognised coal as a tactically significant article of trade with the capability of receiving foreign revenue and adding value to the economy. Given that coal production presents a major growth opportunity in Botswana and since the country suffered from the decreasing demand in diamonds, the Government is providing incentives and has designed a coal roadmap to exploit from the estimated 212 billion tonnes coal deposits in the country (Harvey, 2015).

Considering the economic prospect of coal in the country, there is a strong need to expand mining operations to satisfy coal demand. MCM has made plans to increase its production to satisfy the requirements of local and international market. The attention has been on exploring for new coal resources to exploit in order to increase coal production. It will also allow for the development of new and efficient coal mines operating at low marginal costs.

2.1.2 Types of Mineral Licences in Botswana

Botswana's mining laws classify licences for mineral exploration and exploitation into three categories: prospecting licence, retention (reconnaissance) licence and mining licence. These are defined in the Mines and Mineral Act Chapter 66:01 as follows:

- **Prospecting Licence:** This is authorisation approved by the Government to an individual or company permitting the search for mineral deposits within a demarcated area not exceeding 1,000 km², to determine the amount and economic value of all the minerals specified in the licence area. Validity period of the licence is an initial three-year period with the option of two renewals, each not more than two years.
- **Retention licence:** This is permission that gives tenure over land before progressing to obtaining a mining licence, for a three-year period. This licence is permitted for three years, renewable once for a further three years.
- **Mining licence:** This is a legal contract granting rights for the extraction of a mineral or other valuable deposit, granted under predetermined conditions of time, price, rental or royalties. A mining licence can be permitted for a period not exceeding twenty-five years, with indefinite renewal periods not exceeding twenty-five years each.

Morupule coal mine holds exclusive rights to prospect and mine coal on the lease area comprising a mining licence granted for coal mining. MCM has mining rights of the area issued by the Department of Mines granted under licence number ML 4/76, first issued in 1976, and further extended for another 25-year period in 2001 to 2026. The mining lease area was extended to cover a larger area including areas which previously fell in the exploration area in 2011 which had been previously explored by the government and SCOLBOT venture. MCM operates in an area situated under the jurisdiction of the Ngwato Land Board and has a lease agreement with the authority. Conditional surface rights were granted by the Ngwato Land Board for the mining area as there are still some land-users within the area who must be consulted.

2.1.3 Exploration of the Morupule Coalfield

In the late 1960s, the Anglo-American Corporation explored the eastern part of the Morupule area extensively and confirmed the presence of coal of adequate quantity and quality to support a coal mine (Hancox, 2016). Between 1974 and 1984, SCOLBOT held prospecting licences for part of the Morupule coalfield (Kgaswe area). During this period, regional exploration was conducted where wide spaced diamond boreholes were drilled over the Serowe-Palapye area and later the drilling was detailed and focused on a smaller area.

Between 1974 and 1980, Shell conducted an exploration programme which included photogrammetry, surface mapping, ground geophysics, drilling, and wireline petro-physical logging (Amstrong, 1976). In 1983, the Government of Botswana and SCOLBOT signed a joint venture agreement defining the terms and conditions under which a new thermal coal export mine could be developed at Kgaswe near Serowe. The Geological Survey of Botswana flew an aeromagnetic survey of the area. By 1984, a total of 201 boreholes had been drilled in the lease area, at an average density of one borehole per 0.97 km². Figure 2.1 shows some of the exploration boreholes drilled on the MCM2 block.

Since 1984 to date, there are no records of any company conducting exploration in the MCM2 block, although it is included in the MCM lease. The escalating oil and energy prices since 1970's however, drew interest into the coal resource of Botswana, attracting several companies which led to major parts of the country being studied. Botswana Government hence embarked on a journey since independence which focused on an aggressive nationwide geological and geophysical mapping using high resolution aeromagnetic and gravity survey (Sefemo, 2021). This survey covered 90% of the land area in the northern part, central part, and the Molopo farms areas, therefore, contributing to the current total geological mapping which has covered 48% of the country. Other than the work conducted by Shell, there is no record of historic and systematic coal exploration in the area.

2.1.4 Royalties and Tax

In Botswana, a mining licence holder is legally obligated to pay royalties monthly to the Government. Royalties are calculated as a percentage of the overall market worth of the mineral commodity, defined as the trade value receivable at the mine gate in a transaction devoid of discounts, commissions, or deductions (Sefemo, 2021). Royalties are as follows for different commodities: 10% for precious stone; 5% for non-precious metals and 3% for other mineral/mineral products. Coal falls under the category of other minerals, incurring 3% royalties. Additionally, mining companies are required to pay tax to the government. Equation 2.1 is used to calculate tax due for mines of coal and coal products.

$$\text{Annual tax rate} = \left(70 - \frac{1500}{x}\right) \% \quad (2.1)$$

where: x is the taxable income or gross income

2.1.5 Environmental Liabilities

Section 65 of the Botswana Mines and Minerals Act requires the possessor of a mining licence to conduct prospecting and mining operations whilst ensuring that there is minimal impact on the environment. The Act also requires the mining licence holder to restore to the natural state its licence areas timely during mining, as well as at the termination of the prospecting and mining operations. The Environmental Assessment Act of Botswana further requires the holder of a mining licence to seek consent from the Department of Environmental Affairs of Botswana prior to conducting activities or any activity where there is unanticipated, irreversible, and probable adverse environmental impact.

2.2 Morupule Coalfield Accessibility, Local Resources, Topography, Vegetation and Climate

The accessibility, the available local resources, and the type of vegetation in the Morupule coalfield was studied in numerous exploration and assessment studies.

2.2.1 Accessibility

Botswana's transportation network is well developed with quality tarred (or paved) roads and gravel roads which provide access to different areas in the country. The Morupule mine area is accessed by a tarred road from Palapye towards Serowe on the A14 highway. Areas of mining activity within the mine are reached by means of a combination of secondary roads, four-wheel drive track, logging roads and farming footpaths. Access to the MCM2 block is possible throughout the year. During the rainy season, however, secondary gravel roads become muddy although the smaller sandy tracks remain drivable as the rainwater quickly seeps into the sandy soil.

2.2.2 Local Resources and Infrastructure

Coal mine development requires the availability of adequate water and transport infrastructure. Morupule is located near the main rail line that links many parts of Botswana as well as some neighbouring countries. Its location facilitates both domestic and regional supply of coal. A coal-fired power station known as Botswana Power Corporation operates nearby and it consumes about 66% of the MCM's annual production.

The Morupule area is a mature mining area where mobile phone communication is accessible; there are established roads, trails, power lines, and railroads, as well as the attainability of both skilled and unskilled local personnel. This area also has conveyors, coal storage facilities and surge capabilities, crushing and screening plant, washing plant, administration buildings, workshops, central control room, fire station, clinic, laboratories, etc. Surface rights secured over the lease area provide adequate space for the location of the mine infrastructure. Some of the existing infrastructure is shown in Figure 2.2.

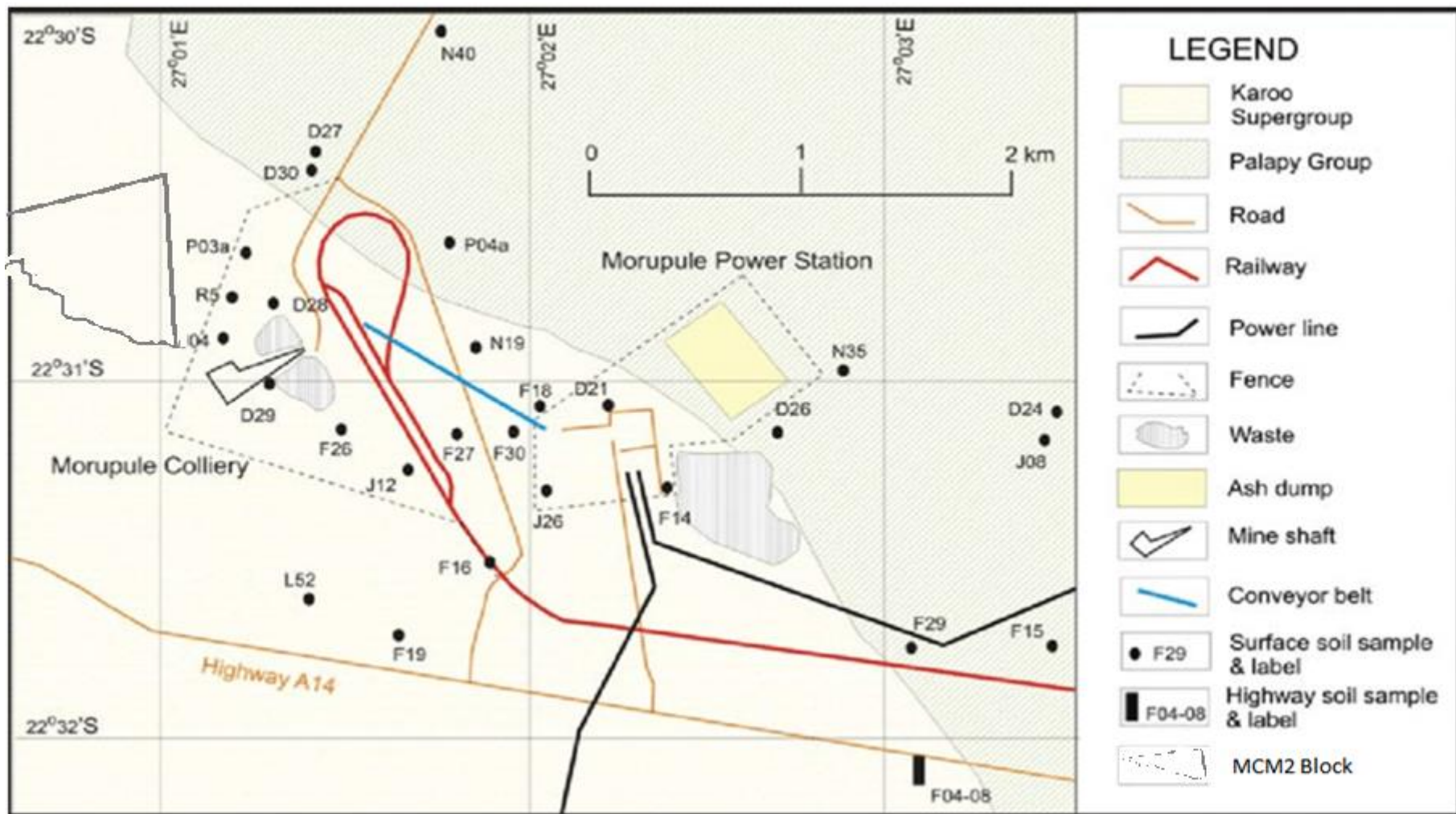


Figure 2.2 Existing Infrastructure in Morupule Area (Source: Zhai *et al.*, 2009).

2.2.3 Topography, Climate and Vegetation

The Morupule area is generally flat with the main landscape variations being that of the Tswapong Hills lying 12 km southeast of the operating coal mine site. The land is at an elevation between 900 m and 1,100 m above sea level. Low relief plains and thorn-velds dominate the area. There is easy access to water including groundwater and rivers. The Morupule and Lotsane rivers drain the lease area.

The climate of the Palapye area is typical of a semi-arid region with relatively cold, dry winters and hot, wetter summers. Temperatures show large seasonal and daily variation with average temperature ranges between 2.65 °C in winter and up to 41.35 °C in summer (Statistics Botswana, 2019). The rainy season runs through the summer months, i.e., between October and March and the dry season commences in mid-April until September. It is hot and dry for the better part of the year, rainfall tends to be erratic, unpredictable, and regional. In Palapye the annual average rainfall recorded is usually a minimum of 300 mm. Winds are generally light but become breezy and strong as the end of winter approaches. The prevalent wind direction is northeast.

The typical vegetation in the Morupule area consists of tree savanna and arid sweet bush veld containing a tree and shrub layer and a grass layer. The vegetation supported by the riparian environment differs from the surrounding vegetation as larger trees tend to be found in that area. In the neighbouring area the land is predominantly used for subsistence farming and grazing of livestock. There is extraordinarily little wildlife present except for the birdlife and game in the privately owned Tuli block area. In the surrounding area species such as impala, wild beasts, kudus, zebras, and warthogs are abundant.

2.3 Geological Setting of Morupule Coalfield and Mineralisation

An extensive geological, geotechnical, and hydrogeological study was undertaken by SCOLBOT on the Morupule coal field to determine the geological setting of this coalfield.

2.3.1 Regional Geology

Botswana contains coal bearing deposits within the Eccle series of the Karoo Supergroup/system. These coals form part of the vast Permian Gondwana coals of the Karoo Basin, which is found throughout southern Africa, originating from the late Carboniferous to the early Jurassic period (Ukwazi Mining Studies, 2017). The Karoo Supergroup

underlies approximately 60% of Botswana (shown in Figure 2.3), and is predominantly composed of a succession of shale and mudstone with subsidiary amounts of siltstone, coal, sandstone and tillite (Van Deventer, 2017). Major coal seams and sandstones occur within the Karoo sedimentary rocks.

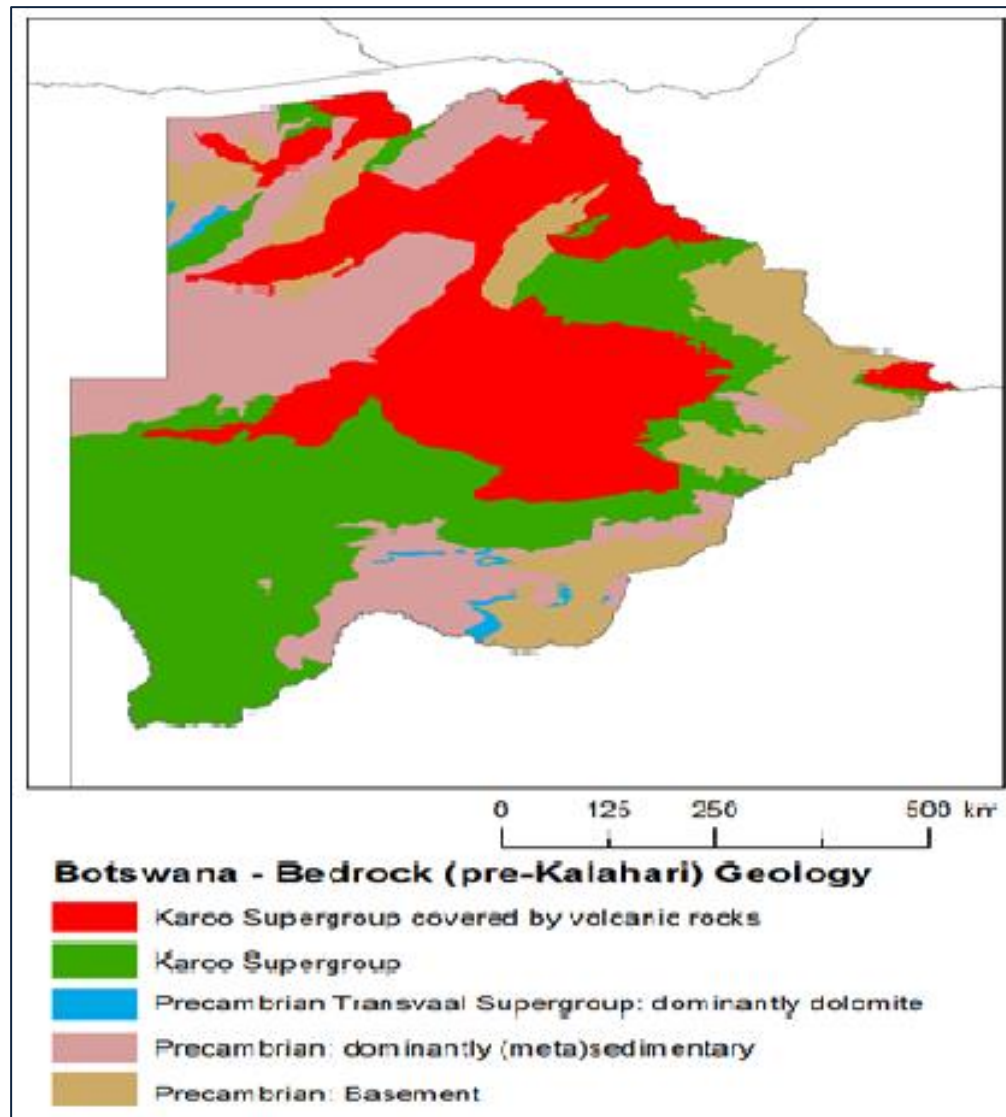


Figure 2.3 Regional Geology of Botswana (Source: Hydrogeology of Botswana, 2022)

The Morupule lease area lies on the southern side of the west-northwest trending Makoro Trough. This trough is a 60 km fault bounded structure of Middle Precambrian age, adjoining with the Kalahari Basin to the west (Armstrong, 1984). Both the Trough and Kalahari Basin are in-filled with clastic and mafic volcanogenic strata of the Karoo Supergroup. The Karoo strata have a maximum thickness of more than 500 m within the Makoro Trough. The Karoo strata rest unconformably on red and green shales and flaggy

quartzite of the Waterberg system which sub-crops to the east. The Waterberg system is of Precambrian basement which lies within the Limpopo belt - a structurally deformed belt which has been active since early Precambrian times. Karoo sedimentary rocks are developed to the west of Morupule, and they form the eastern margin of the major Karoo Basin (Ukwazi Mining Studies, 2017).

Typically, the Karoo Supergroup in the area are overlain by a blanket of up to 30 m of Kalahari beds consisting of sand, unconsolidated and semi-consolidated pebble beds and gravels, calcrete and ferricrete which have a variable thickness and often contain calcrete bands of varying thickness and lateral extent (Chisenga *et al*, 2016). Below the Kalahari sediments there is a 20 to 30 m layer of shales and siltstones; this layer contains a few thin coal seams.

The Morupule area is underlain by strata from the Dwyka, Beaufort, and Eccca Groups respectively, of the Karoo Supergroup. Sediments of the Beaufort Group are characterised by the Tlhabana formation comprising a thick suite of non-carbonaceous grey silty mudstones. Dolerite dyke and sill intrusions occur in some parts of the lease area. These are post-Karoo dykes trending in the west-north-west direction. The width of the dykes' ranges from less than a meter up to 50 m; the grain sizes on these dykes range from medium to coarse grain (Armstrong, 1984). The sills on the other hand appear to often intrude at the contact between the Tlhabana and Serowe Formations.

Sediments of the Eccca Group underlie the strata of the Beaufort Group. The major coal seams develop within the Eccca Group, and these are the coal seams that are being mined presently by MCM. This Group consists of four formations comprising the Makoro, Kamokata, Morupule and Serowe Formations. The Makoro Formation is represented by argillaceous mudstones and siltstones, and fine-grained sediments deposited in broad lakes which developed after the retreat of the Dwyka ice sheet (Hancox, 2016). The Karoo strata were laid down in the Makoro Trough after tectonism that affected the Limpopo Mobile Belt.

The top of the Karoo Supergroup contains the Dwyka Group which is represented mainly by shales, diamictites, pebbly mudstones, siltstones, and sandstone of the Dukwi formation (Van Deventer, 2017). The Dukwi formation comprises rounded pebbles, quartzite and

shale with granite gneiss and dolerite set in a grey-green muddy to coarse grained sandy matrix. These pebbles occur as outcrops along the Lotsane River to the south of the coal mine, together with elements of the Tswapong Formation.

2.3.2 Morupule Lease Area Geology

Geological structures present in the lease area include the Serowe syncline, a large west-northwest trending dyke/sill complex occurring on the southern limb of the Serowe syncline and high angle faults forming a graben complex (Armstrong, 1984). Apart from the west-northwest fault direction, there are also east, northwest, and northeast trending faults. The east-northeast trending faults conjugate with the west-northwest set. The northeast trending faults are the least developed occurring along the southern limb of the syncline. These geological structures are illustrated in Figure 2.4 as interpreted from drilled boreholes data. The faults were interpreted as normal dipping at 70°. Throws vary along the length of the faults, the common variation being from 5 m to 20 m. The lease area is remarkably free from dolerite intrusions.

The bedrock in the lease area is mostly covered by Kalahari sands with a depth between 2 m to 27 m (averaging 12 m). Thus, Karoo succession outcrops are rare. The Karoo succession in the lease area, as constructed from drillhole data, is made up of three major units: the upper, middle, and lower units (Figure 2.5).

- Upper unit - consists of up to 110 m of non-carbonaceous, clastic material and mudstone with weak and slaking horizons.
- Middle unit - is made up of 50 m of clastic mudstones and coal with subordinate siltstones and mudstones. This unit consists of the three potentially mineable coal seams, namely, Serowe bright, Lotsane and Morupule main. In this unit there is also a 40 m wide and 12 m thick 'Channel Sandstone' lying 1 m to 10 m below the Lotsane seam.
- Lower unit - consists of 100 m of sandstones and siltstones sediments that are underlain by tillite.

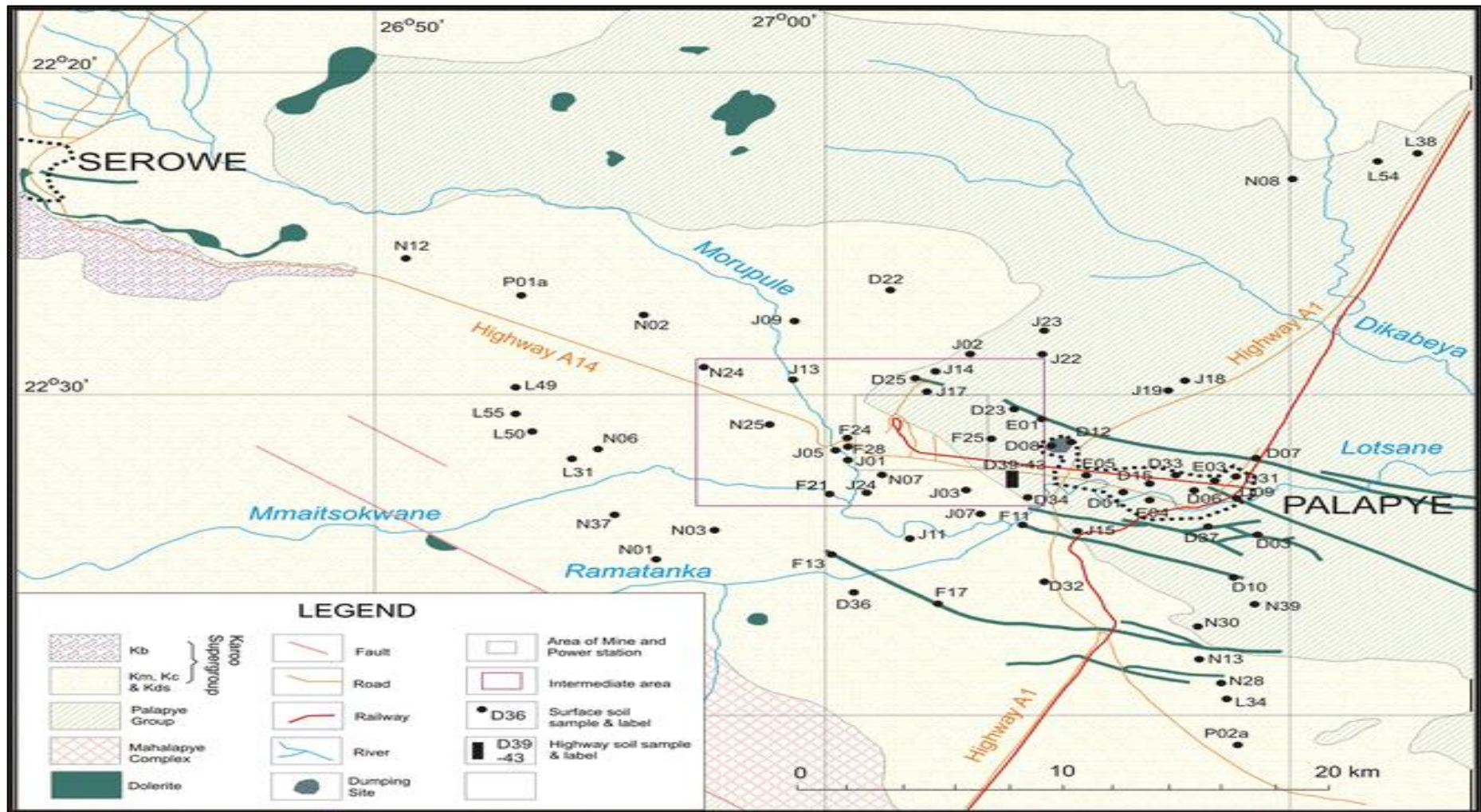


Figure 2.4 Geological Map of the Morupule Area (Source: Zhai *et al.*, 2009)

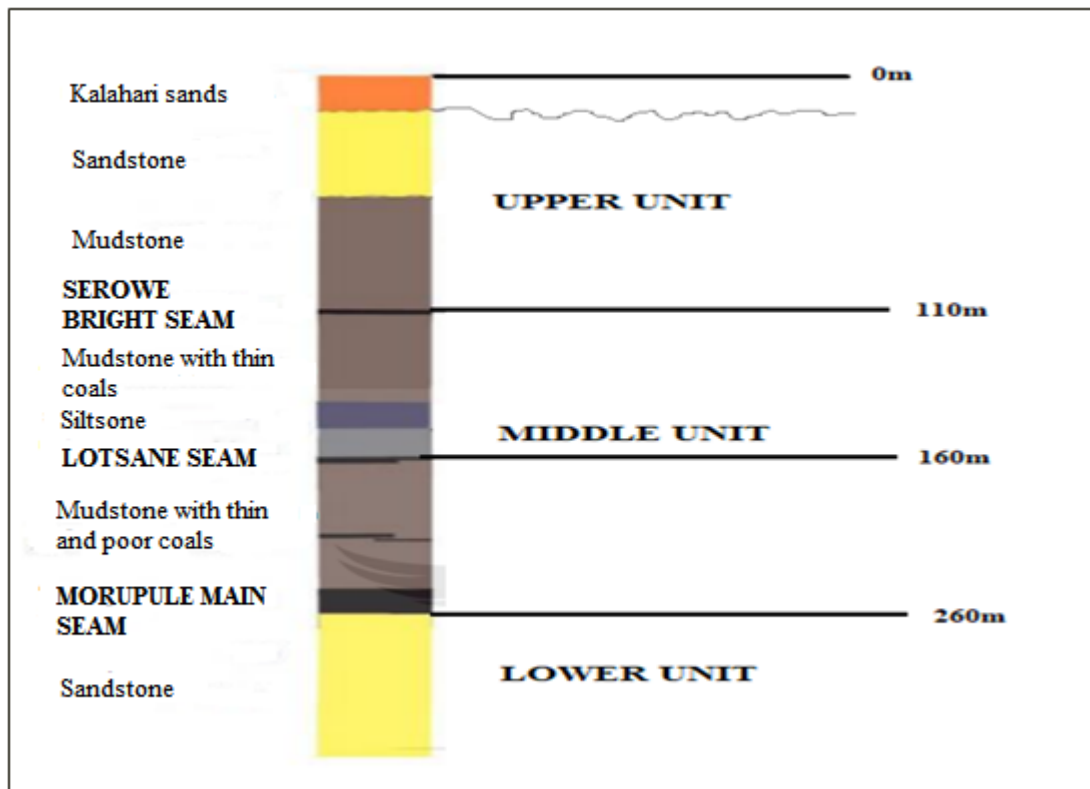


Figure 2.5 Stratigraphic Sequence of the Morupule Coalfield

2.3.3 Geology of Coal Seams in the Morupule Coalfield

Three coal seams having an average gradient of 1.15° exist within the Morupule coalfield. These are Serowe bright seam, Lotsane seam, and Morupule main seam. From the ground going vertically down, the first seam intercepted is the Serowe bright seam consisting of a laterally resolute siltstone marker horizon which is partly covered by 30 m of carbonaceous mudstone, siltstone, and coal (Hancox, 2016). The Serowe bright seam averages a thickness of 1.8 m and comprises two or three bands of primarily bright coal separated by thin mudstone horizons (Amstrong, 1984). The sub-crop of the Serowe bright seam forms just outside the lease area on the eastern boundary. The seam comprises an upper and lower leaf, separated by 0.2 m thick silty mudstone parting. The lower leaf quality is superior to the upper leaf, both decreasing in quality and thickness towards the northwest. The seam has a carbonaceous, silty mudstones roof and floor strata. The coals in this seam are developed poorly near the uppermost part of the seam, having possible economic importance (Zhai *et al.*, 2009).

The Lotsane seam, located about 60 m below the Serowe bright seam, has a complex structure. The seam comprises three leaves of coal which are irregularly distributed and

locally thicken into carbonaceous mudstones (Van Deventer, 2017). It varies in thickness from 1.9 m - 2.5 m with greatly varying proportions of the coal and inter-bedded waste partings. Over most of the lease area, this seam is too shaly for commercial onset consideration; however, at the coalescence of two or more leaves, the seam possesses potential coal mineability as is in the northwest and southeast parts of the lease area and the roof of the seam is mudstone with wash-out structures in-filled with sandstone (Amstrong, 1984).

The lowest seam, the Morupule main seam lies 50 m below the Lotsane seam. This seam thickens towards the southeast and east, with frequent limestone partings, up to 0.3 m thick towards its top (Chisenga *et al*, 2016). The seam floor comprises of sandstone and siltstone, with some aquifer water, while the roof is a gradational mixture of carbonaceous mudstone and inferior coals. The seam thins in the extreme southeast direction where the roof comprises of sandstones and siltstones infilling partial washouts of the seam. A physical description of the seams is given in Appendix 1.

2.3.4 Coal Qualities of the Morupule Coalfield Coal Seams

NQ wire-line equipment (diamond drilling system using a core diameter of 47.6 mm) was used to core most of the boreholes. Core for geotechnical testing was sourced from thirteen individual boreholes, three clusters of 10 large diameter boreholes, and a further 3 single large diameter bores, each providing 150 mm core which was used for bulk core sampling. The coal geological database found in the Department of Geological Survey (DGS) contains information from the drilling work done such as, boreholes geological logs, geophysical logs, analytical results, and some relinquished reports.

Wardell Armstrong in collaboration with SCOLBOT calculated the resource estimates for three seams with area limitations of the eastern and western lease boundaries; the major graben complex extending across the northern sector of the lease; the dolerite dyke/sill complex and the limit of devolatilized coal, extending across the southern sector of the lease. A minimum thickness cut-off of 1.5 m was used for each seam without using any coal quality criteria to define the resource. The in-situ potentially mineable resource was estimated at 1,812 Mt, with an inherent moisture content of 4%. Of this total, 1,378 Mt (76%) lies in the Morupule main seam, 108 Mt (6%) lies in the Lotsane seam, and 326 Mt (18%) lies in the Serowe bright seam (Amstrong, 1984).

SCOLBOT defined the in-situ geological resource in the Kgaswe area (including the MCM2 block) as the tonnages which lie in seams with thicknesses greater than 1.5 m, where coal had a raw ash content of less than 30%, and a washed product sulphur content of less than 2%. Average coal qualities for this area were reported at a float density of 1.3 on a dry basis (see Table 2.1). The coal resource estimates reported on the project area need to be in line with set coal resource reporting codes thus the need to re-evaluate the resource estimate.

Table 2.1 Average Qualities in Coal Seams in the Morupule Lease Area (Source: Armstrong, 1984)

	Serowe Bright Seam	Lotsane Seam	Morupule Main Seam
Cover Depth (m)	55 to 110	120 to 160	160 to 300
Thickness (m)	0.1 to 1.9	0.6 to 3.85	1 to 12.35
Ash (%)	26	22	21
Volatile Matter (%)	31	30	24
Sulphur (%)	3	3	1
Calorific Value (MJ/kg)	23	22	25

The range of the raw coal quality and ultimate analyses of the three seams indicated a comparatively small variation within the seams. The Morupule main seam comprises a dull coal similar in petrography to the coal seams of the Middle Ecca age in South Africa (Ward, 1998). The Serowe bright seam and Lotsane seams have similar petrography to those of the carboniferous coals of North Europe consisting of bright coals (Hancox, 2016). However, the sulphur content of the Serowe bright and Lotsane seams is low, showing significant variations to those of the carboniferous coals of North Europe. There has been no coal production from the MCM2 deposit so far.

CHAPTER 3

LITERATURE REVIEW

3.1 Chapter Overview

This chapter presents the theoretical background of concepts applicable in coal exploration as well as the data obtained during exploration. The coal market was analysed considering productivity, thermal coal prices and identifying gaps in the coal market.

3.2 Coal Exploration

Coal exploration is the premise of coal mining, providing adequate resource estimation to ascertain the sustainable development of coal mines as well as the discovery of reliable geological information that guarantees that coal mining is efficient and safe (Dearman, 2013). Coal exploration involves the evaluation of new and known deposits for the quantification and ascertaining the quality of coal contained within those deposits, as well as defining geological aspects that influence the recovery and utilization of the coal (Ward, 1998).

The coal resource evaluation process involves delineating the mineralisation and estimating the resource to provide information for coal mine design (Rupprecht, 2004). A database is created and managed to ensure retrieval of data when needed. Use of these techniques and data collected assist in the design and operation of effective systems of coal mining, coal preparation and utilisation. The geological data are assimilated using computer database and resource modelling systems which are then utilised to develop a 3-dimensional (3-D) illustration of the deposit for mine planning (a base for the evaluation of the in-situ, recoverable and marketable coal resource).

3.2.1 Geological Data Acquisition Techniques

The techniques used in coal exploration to obtain geological data include field mapping, interpreting air photos and satellite images, and conducting airborne and ground geophysical surveys (Cao *et al*, 2011). Coal exploration programmes typically involve the following components: evaluation of readily available geological evidence and gathering apt base maps, conducting surface exploration (e.g. mapping, geophysics, etc.), gathering

environmental baseline, and compiling information to evaluate coal resources and mining factors (Wang *et al*, 2021). None of these techniques and programmes is unaffiliated to the other but the fundamental to all of them is the geology of the deposit.

Geological information is assimilated using computer databases and modelling systems such as Geomine and Geovia Surpac. The results of the geological data assimilation are used; to develop a 3-D model of the deposit using mine planning software, to evaluate the in-situ, recoverable and saleable coal resources, and to aid in assessing the environmental effect of any planned mining. In the past years, the introduction of micro-electronics-based technology has changed how exploration is conducted, particularly data collection, data analysis and presentation. Micro-electronic based technology enables the handling of innumerable information and maintaining consistency, resulting in improved data acquisition standards that was impossible using only traditional exploration techniques (Thomas and Thomas, 2013).

3.2.2 Geotechnical Data Acquisition Techniques

The geological complexity of the geology of the study area determines the amount of geotechnical data required which determines the level of accuracy possible for the particular study area (Hanson *et al.*, 2005). The geotechnical data required includes; interpreted geological sections and level maps, hanging wall and footwall, characteristics of the joint sets in the orebody, intact rock, fracture and fault shear strength of the country rock (s), and the hydrologic conditions of the study area.

Level maps and interpreted geological sections are prepared to indicate the major rock types, and major structures such as faults and veins. These maps are prepared using the same scale as the mining plan with the investigating area extended horizontally beyond the boundary of the orebody (Rupprecht, 2004). Major structures are considered independently in the mine design and included in the geological map. The structural geology of the orebody studies the major structures and rock fabric. Joints and faults with high occurrence frequency are considered in the study of rock fabric.

Rock shear strength, fracture shear strength, and fault gouge shear strength are the rock strength data required for characterizing the different country rocks. The recommended number of specimens for a representative rock strength test is from 3 to 6 samples per rock

type (Rupprecht, 2004). Hydrogeological conditions are also considered to investigate the effect of groundwater on the rock strength, essentially because pressure is induced on surfaces when groundwater is in a slope, resulting in high potential of failure which could decrease the stability of the mine (Hanson *et al*, 2005). Hydrologic condition inspection is therefore, for the purpose of knowing the water table level, water resource's location and the setting of water-bearing geological structures.

3.3 Coal Market

Coal production governs the generation of power as it presently fuels 37% of the world's electricity and this percentage is projected to be constant over the next 30 years (Budeba *et al.*, 2015). Coal contributes about 25% of the world's primary energy needs; this contribution has been expanding at a cumulative annual progression rate of 1.7% over the 1990 to 2030 period (EIA, 2020). Many countries need to import energy resources to meet their energy needs as they do not have natural energy resources that are adequate to cater for their energy needs. Coal importation is further prompted by the lack of native coal supplies, the need to procure particular types of coal, as well as importing coal for quality and logistical reasons.

The global coal market is enormous and varied, having numerous diverse producers and consumers from every continent. Coal's biggest market is in Asia, consuming about 50.5% of the coal sold on the global market. The supply of coal is decentralised as it comes from suppliers that are spread throughout the world and coal is traded internationally. This eliminates the dependence of consumers on the security of the supplier and stability of one region. An overlap in the markets tends to occur when coal prices are high, and supply is abundant.

3.3.1 Global Coal Production and Demand

China, the United States of America (USA), India, Russia, and South Africa, are the current top five producers of coal. Most producers of coal use it within the country and only a small percentage is directed to the international coal market. In the year 2030, the global coal production is forecasted to reach 7 Bt, China being the leading producer over this period (IEA, 2020).

According to the 2020 IEA report, coal production has increased greatly in Asia while there has been a decline in Europe's production. In 2020, the global coal demand experienced its largest drop since World War II, falling by 5% from 2019's level. This decline in demand was attributed to the restrictions that were put in place to slow the transmission of the coronavirus. Low natural gas prices caused an uncommon drop in electricity demand in the first half of 2020, this drop in demand affected the use of coal for power generation. The demand for coal-for-energy is however, expected to increase significantly nationally, regionally, and internationally ever since the containment of the coronavirus.

Before the pandemic, coal market studies had anticipated that the global demand for thermal coal would continue to grow strongly as domestic demand in several key countries outstripped supply (Investor Factsheet, 2016; Maatla Energy, 2018). Demand was mainly expected from countries which rely on power generated from coal like those in Southeast Asia and other developing countries (see Figure 3.1). Coal will make up 40% of the global electricity generation, hence it will remain the largest sole source of electricity generation through to 2030 (IEA, 2020).

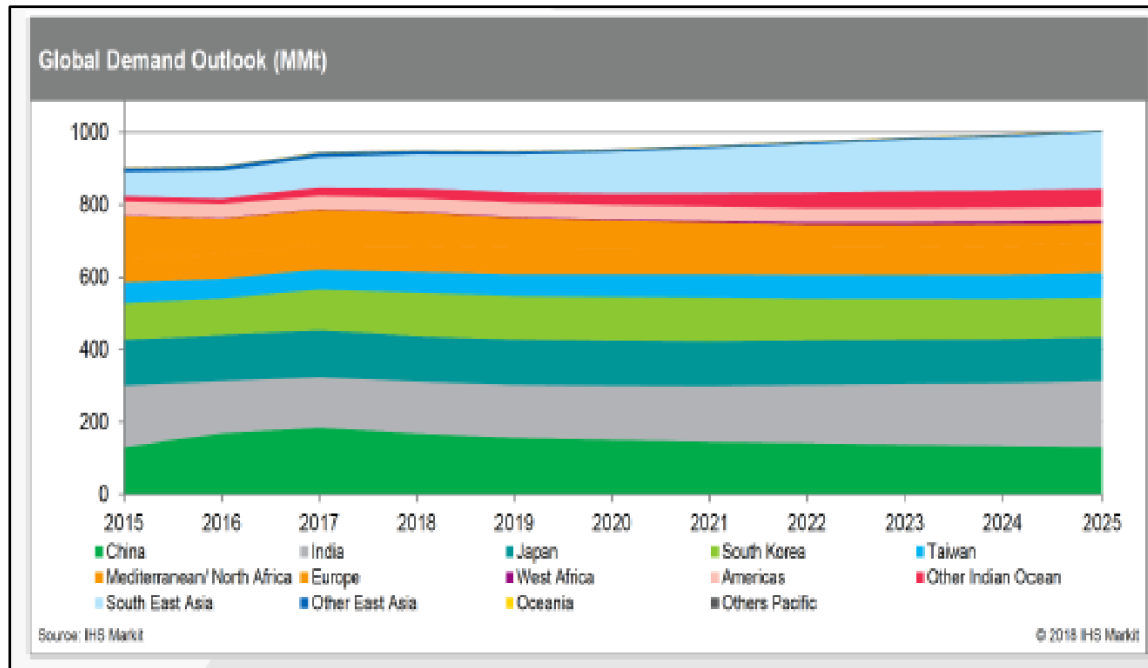


Figure 3.1 Outlook of the Global Demand for Coal (Source: Maatla Energy, 2018)

3.3.2 Global Thermal Coal Prices

The prices of thermal coal vary by region also contingent on the grade and quality. The rebound in thermal coal prices began in 2018 and ended mid-2020, and the price was virtually constant up to the end of 2020, then it increased exponentially from the beginning of 2021 to about mid-2022 (as shown in Figure 3.2). Within the first eight months of 2019, the price of thermal coal declined steadily as a result of expanded supply within the thermal coal market as producers reacted to higher costs in 2017-18 periods (Tate *et al.*, 2021). Import limitations in China within the fourth quarter of 2019 also added negative pressure to coal prices as they declined, making production less profitable. After adjustment of costs within the starting of 2020, Covid-related demand concealment pushed prices down. The price of thermal coal hovered around US\$50 per tonne in late 2020, rising to over US\$ 100 per tonne in early 2021 and in late 2021 trading closer to US\$300 per tonne which is over 50% increase from the price in 2020. The thermal coal price had a rebound in April 2022 to trade at slightly above US\$250 in late 2022.

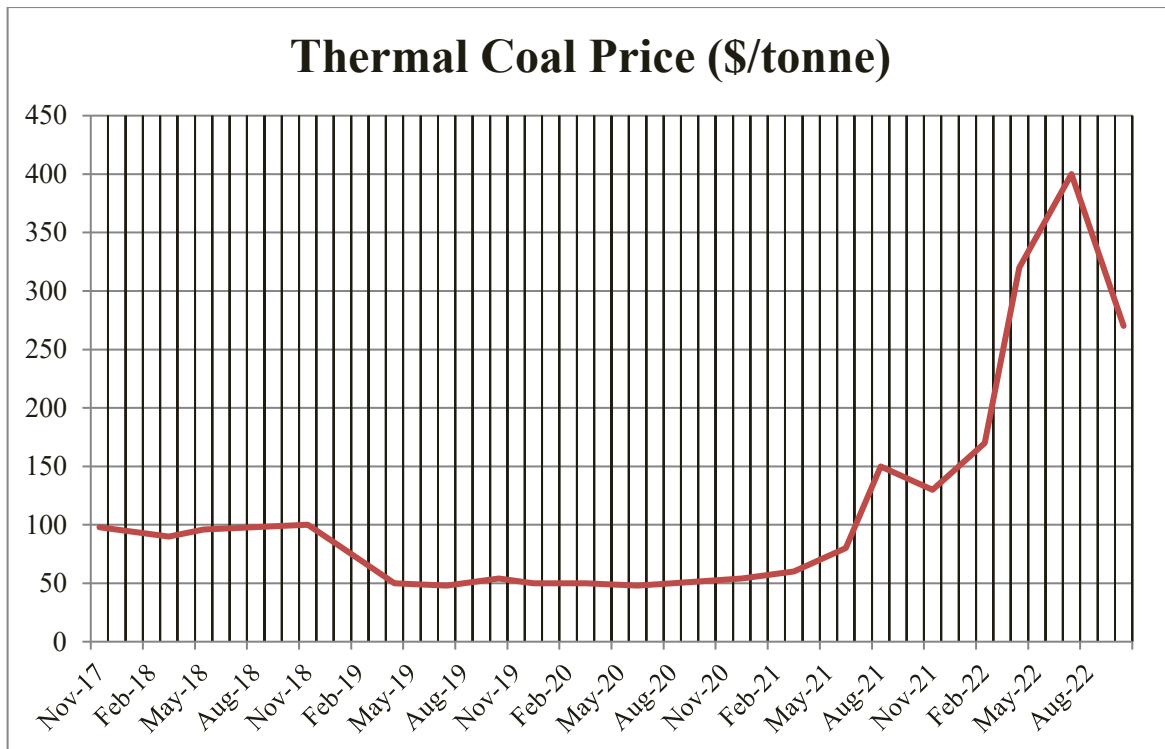


Figure 3.2 Coal Price 5-Year Performance from 2017 to 2022 (Source: Trading Economics, 2022)

3.3.3 Coal Power Shortage in Selected Countries in the SADC Region

In the African region several countries have been investigating ways to increase coal production due to the prospects of international trade of coal, emphasizing the necessity of increasing coal production of currently operating coal mines as well as opening new coal mines to upsurge the coal supply (IEA, 2022). Existing and potential coal producing countries like Botswana are re-evaluating their energy plans considering the magnitude and location of markets for their coal resource. With the surging increase in oil prices, coal resources turn out to be more reasonable as a source of energy to energy importing countries.

Botswana, Namibia, South Africa, Zambia, and Zimbabwe are five countries that are part of the Southern African Development Community (SADC) region utilising coal powered electricity with known deficits of coal power supply. Figure 3.3 shows the chronic power shortages that exist in each of these countries. There is a total estimated 24,650 megawatts (MW) of power deficit in these five SADC countries combined, the largest deficit being in South Africa. This deficit was attributed to the high growth rate in the South African economy coupled with the tapering investments in new power sources leading to severe power shortages in Southern Africa's major generating utility the Electricity Supply

Commission's (ESKOM). Supply is inadequate to meet the increasing demand and end users are looking for alternate supply outside ESKOM (Department of Public Enterprises, 2019). This validates the prediction made by Pollet *et al* (2015), of an emerging coal power deficit in South Africa with a probable shortfall of up to 32,000 MW by 2030.

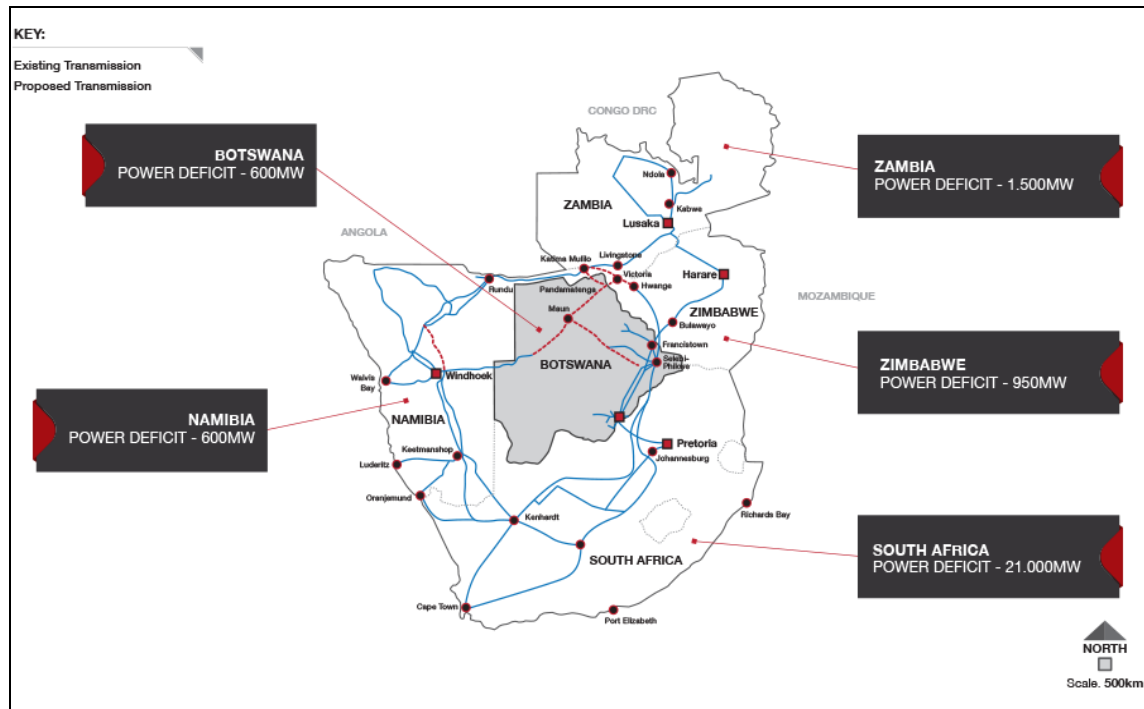


**Figure 3.3 Status of Coal Power Shortage in Five Countries in the SADC Region
(Source: African Energy, 2018)**

The Integrated Resource Plan of 2019 conferred that by 2030 nearly 60% of electricity in South Africa would still be coal powered, indicating a reduction from the existing 77% of electricity generated from coal. If no new power stations were being built during that period in South Africa and the other SADC countries, Botswana is poised and adept to supplying coal to the Southern African power generation market. In addition, the Asian coal industry has planned for increased production to meet the growing demand from steel production. Amplified coal production, however, requires the availability of extensive coal resources and strategies to avoid the depletion of this resource; exhaustion of resources can be counteracted by the location of additional resources which can be achieved through systematic geological exploration.

3.3.4 Botswana Coal Sales

Presently, thermal, and washed coal from Morupule mines is retailed to nearby countries and exported to the trade markets. Botswana Power Corporation expends 89% of the unwashed thermal coal, 10% goes to Botswana Ash, and the remaining 1% is sold to other buyers locally. About 79% of the washed coal is being exported and the residual 21% of the washed coal is utilized by the Government, parastatals, food industry and others locally (Sefemo, 2021). As of 2019, datasets obtained from the Department of Energy Affairs outlined that 85% of the thermal coal trade (washed coal export) goes to South Africa, followed by Zimbabwe expending 10%, Zambia with approximately 1% and 4% goes to other nations.

Figure 3.4 shows that thermal and washed coal sales from Botswana have been steadily increasing over the years since 2010. Coal sales have increased steadily from less than 0.5 Mt in 2010, to over 2.5 Mt in 2019, and the sales have continued to increase since then. In the years 2020 and 2021, the total coal sales hovered around 3 Mt (Morupule Coal Mine, 2021).

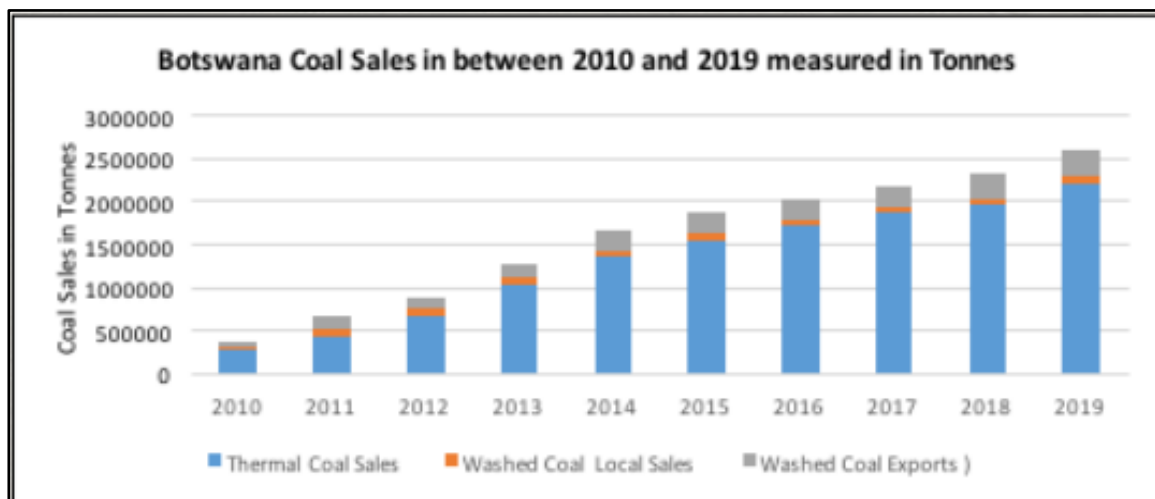


Figure 3.4 Botswana Thermal and Washed Coal Sales from 2010 to 2019 (Source: Sefemo, 2021)

3.4 Coal Mining Investment Cost

Upon the positive evaluation of a coal deposit, determination of its economic potential is undertaken to ascertain if it is feasible to mine at a profit and whether the operation is sustainable. The economic evaluation of a coal deposit involves cost estimation which is a

critical practice for the commencement of a new coal mine operation. It is important because it influences both the profitability and competitiveness of a new coal mine. Costs are estimated using information from exploration work done on the deposit. These cost estimates measure the coal mines' competitive position in making profit from sales in comparison to other producers and suppliers of coal.

The understanding of the deposit's characteristics, economic variables, and environmental regulations is imperative as these factors have an influence on the cost estimation for a new coal mine regardless of whether the production is for export, domestic consumption or both markets. Budeba *et al.* (2015) concluded that geological conditions mainly influence the costs of coal mining, also highlighting the variation of these costs from country to country. The investment cost breaks down the project's financial standing in each period, in relations of the start-up capital required, the profits attainable, as well as the performance of the project measured using financial ratio indicators (Azis *et al.*, 2020). Most coal estimation studies are conducted in a similar manner; firstly, the coal resource in the ground is estimated for the determination of the grade and quality of mineralisation. Then the current market prices are applied for the determination of an in-situ gross value to attain the potential net value of the coal resource.

Several studies have discussed the varying costs of coal mine operations as well as the main factors influencing these costs. The crucial aspect of value creation for coal producing operations is the reduction of costs related to extraction and transportation while ensuring low-cost production of high-quality coal. Another significant contributor to the variation of the investment cost estimate is the selected estimation approach, whether top-down or bottom up (Sullivan *et al.*, 2012). The bottom-up approach utilises details of the desired output (production capacity) that are defined clearly whilst the top-down approach utilises historical data from similar projects. It has been made evident by Kumar and Kumar (2015), Huang *et al.* (2018), Unver (2018) and Ghadernejad *et al.* (2019) that the success in producing precise results of the coal mining investment cost is dependent on accurate identification of the coal deposit, establishment of its geological features and of the surroundings, as well as appropriate scaling of coal production.

Mohutsiwa (2015) identified the non-existence of broad-spectrum estimations of costs of opening coal mines in South Africa. The research indicated that in South Africa, on average,

the capital costs for developing an open cast coal mine for truck and shovel type of operation, could be estimated at US\$ 32 million for 3 Mtpa of coal production and processing, which is like the findings of Dipu (2013)'s estimate of investment costs for surface coal mines in India. These cost estimation for open cast coal mines was founded on a stripping ratio of 4:1 and apt changes could be implemented to justify lower or higher stripping ratios. For South African underground coal mine establishment on the other hand, for room and pillar type of operations, costs could be estimated at US\$ 32 million for 7 Mtpa of coal production and treatment capacity, pertinent to coal mines within 150 m depth mined with semi-mechanized bord and pillar mining method. However, there are a limited number of such studies due to limitations in prices and cost availability, as well as determining cost estimates of desired accuracy (Sullivan *et al.*, 2012).

CHAPTER 4

METHODOLOGY

4.1 Chapter Overview

This chapter presents the research methodology used in this study. The data required and used were discussed as well as how this data was applied in coal resource estimation processes and coal mine design. It also describes the applicable capital cost estimation techniques for coal resource economic evaluation.

4.2 Coal Resource Estimation

A coal resource is coal mineralisation of economic importance with desired quality and quantity for equitable forecasts for economic mining (Lomberg and Rupprecht, 2017). Geological data obtained from exploration drilling on the MCM2 block was the basis for the estimation and interpretation of geological characteristics of the resource, such as the quantity, grade, and continuity of mineralisation. The resource estimation process, studies in detail all accessible geological and geophysical data consideration given to uniformity of the thickness of the coal seam and its quality. The review of the coal properties of the deposit was crucial because this has an influence on estimating the coal mineralisation since these properties do not merely guide the mining and processing methods but correspondingly define coal uses as well as extraction and processing costs.

Factors taken into consideration when estimating mineable resources of a coal deposit include; the thickness of the overburden which determines the coal seam extraction method, geological information relating to the continuity and slope of the seams, conditions of the floor and roof, the presence of any partings between the seams, stress condition in coal seams and rocks, and the physical and chemical properties of coal seams which impact the coal processing methods (Kumar and Kumar, 2015). These factors in turn have an influence on the applicable technology and selection of needed equipment. The consideration of the mineability of coal resources puts focus on the quality of the coal enclosed in the geological body containing the coal.

4.2.1 Evaluation of Existing Data

A geological/ore body model and quantification of the accuracy of data is mandatory when developing resource estimates. Geological maps, topographic maps, cadastral maps, scientific papers and reports, theses, land records, aerial photographs and satellite imagery, and geotechnical data applicable to the study area were collected and revised as well as the existing well logs, seam analyses and history of production as part of the secondary data used for resource estimation. This information was used to ascertain the geological setting of the study area, topography, water supply, and land access.

A special note was made on the history of coal exploration, including information of the companies that were involved. Precise consideration was taken on the basis on which coal quality data was referenced. Existing data evaluation required the maintenance of continuous familiarity of new development on coal mining research, especially the coal geology and exploration technology, coal analysis, and coal utilisation. This research provided opportunities to improve the understanding, application and analysis of the geological exploration data utilised in the study.

4.2.2 Modelling of Ore Body

Orebody modelling commenced with the collection and analysis of drill holes data. Unver (2018) summarised the steps that can be followed when conducting coal seam modelling on three coal basins with varying geological and structural conditions. The main data utilised in the coal seam modelling includes drilling data, lithological logging, sampling and analysis of diamond core holes, drill holes collar information, known intercepts of coal seams and coal quality data.

The database and geological cloud computing platform based on the exploration data of the MCM2 block was established and geological data analysis was conducted to guide coal mines' design work. This information base contained remote sensing information, drilling data, geophysical exploration, and analytical and testing data accrued by the coal resource exploration. The database was also founded on data acquired from lithological logging, sampling, and analysing diamond core holes. The data included collar information of the drill holes, description of lithology, coal seam intercepts, and coal quality information. The data provided a summary of the number of drill holes, the total length drilled, minimum depth, maximum depth, and average drill holes spacing.

The data were presented in Microsoft Excel comma separated values (.csv) format and entered into a merged Microsoft Excel database. The data were revised and authenticated by double checking geological logs and analytical results against downhole geophysical logs. Microsoft Access® Database was utilised for the validation of the geological data: checking for missing units, duplicates, as well as organising the data to be loaded into the Geovia Surpac mining software application for coal seam and block modelling purposes. Ensuring the authenticity of the data used was crucial thus several checks were performed to identify incorrectly entered data. These checks included calculating a summary of statistics for each quality variable and drawing a histogram; reviewing outlier values based on the histogram plots; checking to see whether the sum of the coal attributes values was 100%; checking excessively large depths; drawing scatter diagrams between quality variables and observing for incorrectly entered values and removing them from the database.

Creating a Geological Database

In Geovia Surpac, a geological database was created which consisted of four tables (geology, sample, survey, and collar) each containing various kinds of data pertaining to the exploration drilling that was conducted. Each table contained a given number of fields, had many records with each record containing data fields. Two mandatory tables were required within the database, i.e., collar and survey tables. The collar table contained information describing the location of the collars of the drill holes, the maximum depth of the holes, the date when the holes were drilled, and the type of drill holes. The survey table on the other hand contained drill holes survey information that was used to calculate drill holes trace coordinates. Mandatory fields in this table were the maximum down holes depth of each drill hole, the dip, and the azimuth of the drill holes. Data from the tables were used to create the geological database which could be displayed with down holes information that was plotted in Geovia Surpac user interface graphics.

The next step then was to create colour display styles for the lithology and assays data. These styles were used in displaying drill holes to show the different rock lithologies in each drill hole as well as the coal seam depths. The addition of styles enabled the creation of sections graphically, digitizing of the ore outline, flagging of an interval table to conduct statistical analysis on the data for determining sample populations and using composited data to estimate the block model, and determination of the grade of a digitized segment.

Based on the coloured lithology, a visual check was conducted on each drill hole to ascertain the coal thickness and the depth at which coal seams occurred.

Creation of String Files

A string file from the given drillhole set indicated the depths in the drill holes which were considered as ore for the creation of sections. Firstly, the drill holes were displayed, and colour constrained in terms of the geology and labels selecting the parameters of cut-off grade. The boreholes were sectioned in the north-south direction (because the spread direction of the coal seam was in the southern direction) at 300 m interval and were digitised using the section method to form ore strings which were further connected in a series to cover the entire deposit. The creation of sections was done for all the drill holes row sets using data imported from the geology data table. A total of 14 sections were created; sections were taken at a step distance of 300 m on either side of the section line. The sections were combined to generate a string file.

Compositing

Once the ore strings were created, they were composited to find basic statistics of the deposit. This enabled the proper solid modelling, creation of a block model, ensuring proper coal resource evaluation and determining the resource estimate using the nearest neighbour method estimation technique. The process of compositing entailed combining the assay values of adjacent samples from the drill holes to determine the assay values of longer drillhole intervals. Compositing was performed with respect to the intercepted contacts rather than the entire hole, on all samples contained within the drill hole.

An appropriate composite length for this coal resource estimation was selected; this length was equivalent to the average sampling length of the core samples. The chosen composite length ensured that dilution was minimized as well as avoiding over smoothing due to compositing. Each composite sample was allocated a rock code corresponding with the mineralized solid in which it occurred, and each composite was used for grades interpolation onto the block within the individual solid by only placing additional constraints on the model.

Statistical Analysis

Statistical analysis checked the presence of high-grade outliers and a binomial distribution (two non-adjacent peaks) on the composite data presented in histograms. The reason for checking for outliers was that extreme grades (whether low or high) can bias the calculation of averages towards the extreme value especially in cases where there are few samples. This effect is even greater when the distribution is positively skewed. Histogram plots and cumulative probability plots of the composite data were also used to determine the degree of skewness and the coefficient of variation for the data set.

Spatial Analysis

A spatial analysis shows how values change over distance and direction. Variograms were used to illustrate the sample differences (variance) against distance (lag in meters) for the various coal qualities data. According to Souza *et al* (2014) the impact of error during coal seam modelling is taken care of by relying on robust variogram as a dependable variogram also ensures the accurate estimation of the coal resource. Based on the composited data files, an experimental variogram was created from the population data then afterwards fitted a variogram model. Several directional variograms were drawn to ascertain the direction of anisotropy of the deposit for the different coal qualities.

The variograms were aligned with three parameters which are the nugget, the sill, and the range. The nugget indicated the differences in value of samples taken at a separation distance of 0 m. The sill on the other hand indicated the value at which the variogram model flattened out, indicating a point where the difference between sample values becomes negligible. Points below the sill indicated a positive correlation while those above it represented a negative spatial correlation. The range indicated the corresponding horizontal distance in meters at which the sill was attained. It indicated the maximum distance to which samples were not correlated (auto correlation is zero); before attaining the range, samples are correlated (i.e., the difference between samples continues to increase), but beyond the range samples are not correlated.

Coal Seam Modelling

In Geovia Surpac, a 3-D coal seam model in the form of a surface digital terrain model (DTM) was generated using the created ore string files. The ore strings were oriented in the clockwise direction for the strings that were digitised in an anticlockwise direction. Then,

ore strings were triangulated to form a wireframe model of the deposit using the function of triangulation inside a segment and triangulation between segments for the extreme two section strings. After triangulation, the wireframe model was validated to check for the presence of invalid edges, triangles, repetition of edges, etc. Once validation was completed and accepted, the wireframe model was set to solid to form a 3-D coal seam model of the Morupule main seam. Then the volume of the solid model was generated.

4.2.3 Block Modelling

Block modelling is used to design mine operation plans and to predict coal run of mine quality parameters. A block model was formed from the spatially referenced geological database created in Geovia Surpac that provided the means to model a 3-D solid from drill holes sample data. A block model was created to report an estimate of the volume, tonnage, and average grade of the coal block. In Geovia Surpac, wireframes were used to constrain composite values chosen for grade interpolation and the coal blocks reported in the 3-D coal seam model. The size of the block was selected based partially on the average drill holes spacing (borehole spacing), composite assay length, the tentative mining method, as well as the projected minimum bench height achievable on the coal mine area.

Individual blocks of size $50 \times 50 \times 50$ m were chosen to make up this block model based on the known volume of mineralization. At the scale of the sample deposit, this provided a block size reasonable for grade distribution analysis, but still big enough not to mislead when considering a higher cut-off grade within the same model. The extents of the block model were a circumstance of the concession boundaries and the geometry of the mineralized solid. The block model itself was created encompassing the known areas of coal mineralisation using the minimum and maximum x, y, and z coordinates of the 3-D Morupule main seam coal model.

Kriging

The concentration of the different coal qualities across the block model was estimated using ordinary kriging algorithm. The surrounding data points were used to calculate the estimated concentration in a particular grid location. Kriging parameters defined the grid and search window and determined how the kriged estimates were calculated. Data was processed in Geovia Surpac in order to determine the search ellipsoid dimensions. The search ellipsoid dimensions were determined using results obtained from the spatial analysis.

4.2.4 Coal Resource Estimation Based on 3-D Coal Seam Model

After the generation of an empty block model, the initial attribute field requirements like the rock type, ore class and type of material in each square of the block were interpolated. The prior generated 3-D solid model was merged with the block model to form a constraint block model. Constraints were added to the empty block model to control the blocks from which interpolations were made, i.e. restricting influence from surrounding samples through interpolating grades according to solid precedence. By integrating the solid model to the overall block model, the extra blocks available in the area which fell outside the 3-D coal seam model were removed for a better estimation of the coal resource. An overburden model and a surface topography model were intersected with the block model to exclude blocks that extended above the bedrock surface.

The constraint models were saved as individual constraints models for rapid reuse or for use as components for other constraints. The constraints were then applied to the block model with codes assigned to the attribute fields that denoted the different rock types, ore classes or material types. Graphical display of the constraint model was used to visually inspect the results of the constraints application as well as to ensure that the constraints models produced the desired results.

Interpolation of coal cut off grades (calorific values) onto the block model was completed using the available estimation technique supported by Geovia Surpac, i.e. the nearest-neighbour estimation method. Coal prices, reasonably assumed mining costs, metal recoveries and grades (used for comparable deposits in the region), are some of the several factors that were considered in determining the appropriate cut-off grade. Attribute values were added to the constraint block model. These were the coal qualities values (i.e., calorific value, ash content, carbon content and sulphur content), specific gravity, air, waste, and rock type. All blocks with a percent greater than zero were assigned coal grades, also flagged with a lithology code. Blocks within the model with grade values less than the cut-off grade were considered waste (i.e., blocks where no parts of a mineralized solid were captured, and no grades assigned), while those with values above the cut-off grade were considered as ore. The tonnage of the coal mineralisation was reported to ascertain the tonnes of coal present.

Coal Resource Classification

Coal resource estimation was conducted in accordance with the South African guide for systematic evaluation of Coal Resources and Coal Reserves (SANS10320:2004), as well as the South African Code for Reporting of Mineral Resources and Mineral Reserves Code (SAMREC 2016). In the resource estimation process, all available geological data were reviewed in detail considering the consistency of the coal seam thickness and coal quality over the MCM2 Morupule main coal seam. Coal resources were reported on an in-situ density basis as stated in both the SAMREC Code (2016) and the SANS Code 10320. The Apparent Relative Density of 1.3 g/cm^3 verified in the laboratory was applied in the resource estimations hence the coal qualities were reported on an air-dried basis.

Coal resource categories were assigned based on the following criteria:

- Measured Resource- blocks were classified as measured if the interpolation results were based on input from 1 drill hole and a minimum of 2 composites within the specified search radius
- Indicated Resource- blocks not assigned to the measured category were assigned to the indicated category if the interpolation results were based on a minimum of 3 drill holes, 6 or more reporting composites, and the average distance to the nearest reporting composite was less than 30 m.

Dassault Systems Geovia Minex's (version 6.5.1) general growth algorithm method was utilised to generate smooth surface that replicated the regional trends of the geological data. The seam thickness, roof, and floor elevations of the coal seam, and all the coal quality data were gridded using the Minex algorithm. Grids were all limited to within the coal resource area with an extrapolation of 200 m beyond any known last point. A search radius of 2000 m was applied in order to determine the influence of points on any specific points that were unknown. This model was validated through a comparison between the model data and the borehole point data by reporting grid statistics on the model and also by checking the gridded data at the borehole position. This examination provided a sufficient level of confidence in the mine source data as well as the geological model in support of the coal resource classification.

4.3 Coal Mining Design Plan

Understanding the nature and disposition of the coal seam plus the structure and content of the coal geological resource model was imperative to provide a significant mine design. The first step was to select a suitable mining method; this was followed by the selection of the appropriate mining equipment. After the equipment selection, the mine design outline was created. The next step was to create a production schedule that outlined the mining sequence and production rates. Lastly, it was important to consider the potential environmental impact of the mine and develop strategies to mitigate any negative effects.

4.3.1 Selection of a Mining Method

The selection of the best mining method for exploitation of the Morupule main seam on the MCM2 deposit required the analysis of other factors besides the anticipated productivity using the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) technique. This technique involved identifying the relevant mining method selection criteria and weighting them according to their importance. PROMETHEE then evaluated each mining method against the criteria and generated a preference ranking, which allowed the selection of the most appropriate mining method.

The first step was to select the criteria that was used to evaluate the mining methods. The criteria included the production rate, recovery rate, operating costs, safety, and environmental impact. The next step was to weight the criteria according to their importance (weighting was arbitrary based on engineer's experience). This was done using a pairwise comparison matrix, where each criterion was compared to every other criterion and assigned a weight based on their relative importance. The matrix had the same number of rows and columns as the number of criteria being evaluated. Each cell in the matrix represented the relative importance of the criterion in the corresponding row compared to the criterion in the corresponding column. The matrix was constructed by considering each criterion in turn and using a scale of importance that ranges from 1 (equally important) to 5 (extremely important). The choice of weights for each criterion was based on a combination of expert knowledge from the MCM mining department, data driven insights and alignment with the goals and context of the study for increasing production with safe mining operations and minimal environmental impact as main priorities.

The next step was to evaluate each mining method against the criteria. This involved assigning a score to each mining method for each criterion based on how well it meets the criterion. PROMETHEE was then used to generate a preference ranking, which allowed the selection of the most suitable mining method based on the criteria and their weights. The preference ranking was then calculated by comparing each mining method to every other mining method and determining its relative preference level based on the scores assigned in the previous step. To evaluate each method, a score was assigned to the method for each criterion, based on how well it meets that criterion. The scores were on a scale from 0 to 1, where 0 means that the method performs poorly on the criterion, and 1 means that the method performs very well on the criterion.

The final step was to use preference ranking to select the most suitable mining method. After obtaining the scores for each method and criterion, PROMETHEE was used to compare each method to every other method and determine its relative preference level based on the scores assigned in the previous step in order to generate a preference ranking. The preference ranking was calculated based on the net flow of each method, which was the difference between its positive flow and its negative flow. The preference ranking allowed the selection of the most suitable mining method based on the criteria and their weights. The method with the highest preference ranking was considered to be the most appropriate for the given set of criteria.

4.3.2 Mine Equipment Selection

Mining equipment selection was based on the size and depth of the mine, the type of ore to be mined, and the production capacity required. To facilitate this process, the PROMETHEE multi-criteria decision-making (MCDM) method was employed. MCDM methods help evaluate and compare various alternatives based on multiple criteria and provide a systematic approach to decision-making. The process commenced with clearly defining the objectives of the equipment selection process; this included factors such as productivity, cost-effectiveness, safety, reliability, maintenance requirements, and environmental impact. Next was the determination of the criteria that was used to evaluate and compare different equipment options; these criteria aligned with the defined objectives and included factors such as production capacity, power requirements, operating costs, maintenance costs, environmental impact, safety features, availability of spare parts, and technological advancements.

Relative weights were then assigned to each criterion based on their importance in achieving the objectives. The weights were determined through employing the Analytic Hierarchy Process (AHP) mathematical technique; it involved pairwise comparisons between the criteria. A scale of 1 to 9 was used, where 1 indicates least importance and 9 indicates extreme importance of criterion. The assigned weights reflected the relative importance of each criterion in achieving the objectives. The choice of weights for each criterion was based on the expert knowledge from the MCM mining department and production managers.

A list containing potential equipment alternatives suitable for the chosen mining method was compiled, considering factors such as equipment types (excavators, haul trucks, loaders, etc.), manufacturers, models, sizes, and specifications. Each equipment alternative was then assessed against the identified criteria. This was done by gathering relevant data and information from equipment suppliers, reviewing technical specifications, and consulting with subject matter experts. Each equipment alternative system was evaluated and assigned a score or rating on a scale of 1-10 for each criterion, where 1 means that the equipment performs poorly on the criterion and 10 means that the equipment performs very well on the criterion. The scores represent the performance of the equipment option in relation to the specific criterion. A higher score indicates better performance or alignment with the criterion.

A rating or scoring system was further developed to quantify the performance of each alternative for each criterion. PROMETHEE was applied to compare and rank the alternatives. To apply the PROMETHEE method, each equipment option was evaluated against the criteria and assigned a preference value between 0 and 1, where 0 means that the equipment option performs poorly on the criterion, and 1 means that the equipment option performs very well on the criterion. The preference values indicated the relative superiority of each equipment option over others for a specific criterion. Higher values indicated a higher preference or better performance. A sensitivity analysis was then performed to examine the robustness of the results obtained from the PROMETHEE MCDM method. The sensitivity analysis evaluated how changes in criteria weights or alternative evaluations affected the final rankings. This analysis facilitated understanding the stability and reliability of the selected equipment alternatives.

4.3.3 Coal Mine Design Layout

Coal mine design involves several components and details that are essential for safe and efficient mining operations. This includes designing the pit layout, determining the optimal pit parameters, and creating a plan for the placement of waste material. Geovia Surpac provided intuitive mine planning tool for designing mine features, allowing the creation of optimal pit designs as well as establishing the overall mine layout. Surpac's pit optimization module was utilised to determine the most economical pit shell and the ultimate pit limit. Section plans of the mine layout design were then generated.

Pit Design Parameters

Pit design parameters were determined having analysed the geotechnical data of the MCM2 block. This geotechnical data was sourced from SCOLBOT's exploration study where they analysed 16 NQ slim line boreholes (6 inclined and 10 vertical); 3 large diameter boreholes (150 mm diameter core) and 6 sites where 150 mm diameter auger holes and test pits were sunk for soil testing. This assessment provided critical information on the strength and stability of the rock mass. It also provided key parameters for input into the slope stability analysis, such as groundwater conditions.

Soils investigation: Six sites widely spaced across the MCM2 area were selected by the team of exploration geologists and engineers for collecting test samples of Kalahari sands to determine their engineering properties. Thicknesses of the Kalahari sands were between 6.3 m and 15 m consisting of moderately to highly consolidated sands containing calcrete lenses of up to 2 m thick at 0.5 m to 9.3 m below the surface. Bedrock below the sands consisted of weathered mudstones and siltstones except in the western part of the MCM2 area where the bedrock consisted of sandstone.

Rock strength: Laboratory tests were conducted to determine the engineering properties of the strata in the MCM2 area. Such tests included uniaxial compressive strength, tensile strength, and intact cohesion; slake durability, Hard grove grind-ability index, abrasiveness, modulus of elasticity, and Poisson's ratio. These engineering properties were determined from the immediate roof/floor (within 1.5 m of the seam) and the intermediate roof/floor (from 1.5 m to 6 m of the seam). Sandstone has an average cohesion of 30 mega Pascal and an internal angle of friction of 40°, while the mudstone has cohesion of 5 mega Pascal and an internal friction angle of 25°. The laboratory results revealed that the engineering

properties of these coal seams indicated coals that are hard, abrasive, and dull relatively free of joints and fractures. The floor materials were found to be very durable while the roof materials were of variable strength depending on the lithology.

Hydrogeology: Five piezometers were installed in slim line boreholes at seam intersections after a piezo-metric surface was determined across the MCM2 area during a hydro-census. Packer permeability tests were conducted in three large diameter boreholes to measure the hydraulic conductivity and transmissivity of six potential aquifers. The estimated seepage of water into seam workings was 120 m³/day in Morupule main seam.

The pit dimensions were further determined based on the coal resource size, coal seam thickness, the selected mining method, and the production requirements. These dimensions provided sufficient space for coal extraction and accommodation of required equipment and infrastructure. The mine design was selected based on the size of the selected mining equipment, which require adequate space for manoeuvring and efficient loading and hauling operations.

Slope Design

The slope angle was chosen to ensure stability while allowing effective blasting and excavation. A comprehensive slope stability analysis was performed to evaluate the stability of various slope angles. This analysis involved assessing factors such as the rock mass strength, slope geometry, groundwater conditions and potential failure mechanisms. The Slope Stability Analysis software was used to calculate the factor of safety and identify critical failure surfaces. The analysis considered the strength properties of the country rock layer, the interlayering of coal seams, and the potential failure mechanisms. Appropriate design parameters were then determined based on the geotechnical assessment and slope stability analysis; this included selecting a target factor of safety considering the geotechnical properties of the rock mass and incorporating any site-specific constraints. Different slope design options were evaluated based on the slope analysis results and design parameters, considering factors such as the overall slope angle, bench widths, and catch bench configurations. The slope design was optimised to minimize excavation volumes while maintaining stability and safety.

4.3.4 Production Schedule

Geovia Surpacs' scheduling tools were utilised to create production schedules for the mine. This involved determining the sequence and timing of mining operations considering the coal quality, equipment available and production targets. A production schedule outlined the anticipated annual production rates. This helps to ensure that the mine can meet its annual production target. The production schedule was based on the location and size of the ore body, the capacity of the equipment, the production capacity required, and the environmental and safety considerations. It was important to have a well-planned production schedule to ensure the efficient use of resources and the timely completion of the mining operations.

4.3.5 Mining Schedule

The mining schedule outlines the sequence of mining activities over time. The mining schedule was developed in Geovia Surpac by using the optimal pit design, incorporating the production schedule to determine the order of mining blocks and the extraction rate of each area. The mining schedule was optimized for the block model and cut-off grade and considering economic optimization. The software was further used to analyse the feasibility and efficiency of the proposed schedule, this allowed a scenario analysis and optimization adjustments to minimize downtime, reduce costs and optimise resource utilization.

4.3.6 Environmental Considerations

Potential environmental impacts associated with mining activities were identified. Numeric values were assigned to quantify the projected magnitude of these impacts on the MCM2 block and surrounding areas. Each impact was assigned a numeric value ranging from 1 to 5 to represent the magnitude of the impact, with 1 indicating minimal impact and 5 indicating extreme impact. Suitable mitigation measures were then identified to be incorporated in the operational plans to minimise these environmental impacts.

4.4 Coal Mining Investment Cost

Finally, a cost analysis was conducted to determine the overall cost of the mining operation. This included considering the cost of equipment, labour, and materials. Determination of the economic potential of the estimated coal resource was undertaken to ascertain if it is feasible to mine it at a profit and the operation is sustainable. The investment cost estimate

was formulated using a blend of first principles using budgetary quotes to avoid using general industry factors.

Assumptions were made due to the deficiency of available engineering information; therefore, the accuracy of the cost estimate could not be guaranteed. The target accuracy of the estimate was $\pm 20\%$. To calculate the financial value of the MCM2 mining project, data related to the cash inflows and outflows were required. Projections of information pertaining to mine production rates, construction schedules, and forecasts of resulting cash flow were contained in these estimates. Factors like achieving the anticipated mine production rates at the assumed grades and the ability to acquire major equipment or skilled labour on time may cause the actual results during operations to diverge from those presented in this report.

4.4.1 Analysis of the Business Situation

Bench marked coal mine data provided the database needed to determine the financial feasibility of the project. The data included the projected annual tonnes of coal to be produced, the average price of coal, sales revenue, and operating expenses. It is from this data that the depreciation expense was calculated using the straight-line depreciation method.

The economic assumptions and parameters considered in assessing reasonable prospects for eventual economic coal extraction were:

- Producing coal products of better quality to those produced from Masama Coal Mine and MCM3 block, currently fetching prices in the region between US\$70/tonne and US\$100/tonne free on truck.
- Capital costs for starting a medium sized coal mine at MCM2 are anticipated to be similar to what it was at Masama Coal Mine and the MCM3 opencast mine and was estimated to be in the region of US\$50 million.
- Operating costs for this medium sized coal mine are anticipated to be similar to those in the SADC region and based on quotes received is expected to be in the vicinity of US\$15/tonne of coal.

4.4.2 Capital Costs

Capital costs for coal mining projects customarily consist of costs of land, capital equipment and infrastructure to support the mining and milling process. These costs may also take account of capitalized expenses for permissions and approvals needed for mining to commence. With most mining projects, the costs of equipment dominate the overall project costs; therefore, equipment selection is at the core of determining the capital costs. Investment capital, interest rate, coal price and product's price were collected from market study or calculated assumptions were made.

4.4.3 Financial Evaluation

It was vital to assess whether the project's financial performance is feasible or not. The total cost and expenses were compared to the expected revenue to be gained through selling the final coal product and by products. Financial evaluations were calculated using capital budgeting techniques, such as the payback period (PP), net present value (NPV), and internal rate of return (IRR). Financial evaluation also encompassed sensitivity analysis; this assessment was conducted to determine and analyse variables with potential significant impact on the project's financial performance.

Annual cash flow estimates were conducted based on an economic model developed specifically for this project. Before-tax estimates of the project costs were set for reasonable purposes, after-tax estimates on the other hand were drawn up to give approximations of the true value of investment. The tax estimates, however, involved several complex variables that can only be accurately calculated during operations. This study, hence, contains inventive information of the estimated mine production rates, construction schedule and projections of resulting cash flows. Factors such as the ability to obtain major equipment as per the schedule, getting the required skilled labour, as well as achieving the presumed mine production rates at the presumed grades, may cause the tangible outcome to differ from that presented in this economic analysis.

Net Present Value

The expectation when making an investment is to get returns on the money spent. A decision to invest or not is made based on the determination of the net present value. The net present value is calculated as the difference of the present value of cash inflows and outflows in a specific time period (equation 4.1). The net present value was calculated by subtracting the

initial investment amount from the present value of the investments' cash inflows discounted at a rate (Rangel *et al*, 2016). Investment was acceptable if the net present value was greater than zero. Investment was therefore ideal when the present value of the cash flow generated by the investment exceeds the cost of making the investment, meaning a positive NPV.

$$NPV = \frac{CF_t}{(1+i)^t} - C_o \quad (4.1)$$

where: CF_t = the net cash inflows-outflows during a single period t in US dollars

C_o = the total initial cost of investment in million US dollars

t = the number of time periods in years

i = the discount rate or the return that could be earned as a percentage

Internal Rate of Return

This is the discount rate at which the present value of the cash inflows is equal to the initial investment amount (Rangel *et al*, 2016). It indicates the interest that will be earned on investment when receiving the given cash inflows. This rate was calculated by equating the net present value to zero (equating 4.1 to 0). Investment was allowed when the value of the internal rate of return was greater than the cost of capital (i.e., $IRR > i$).

Payback Period

The payback period is the time lapse necessary to recover the initial investment made on the project, based on the cash inflow. This period was determined by dividing the initial investment amount by the annual cash inflow, without considering the time value of money (Bierman and Smidt, 2007). Given a cumulative cash flow (i.e., summation of the cash flows from year 0 to year 20 for example), the year when a positive value was obtained was noted; this information was then used for calculations or substitution into 4.2 to calculate the payback period. The payback period is acceptable when its value is less than the concession period (life of mine).

$$PP = \frac{P - N}{P + N_y} \quad (4.2)$$

where: N_y = the number of years after the initial investment at which the last negative value of the cumulative cash flow occurs.

N = the value of the cash flow at which the last negative value of the cumulative cash flow occurs.

P = the value of the cash flow at which the first positive value of the cumulative cash flow occurs.

4.4.4 Sensitivity Analysis

The sensitivity analysis showed how changes in value of variables with potential substantial impact on the project's financial performance affected the economic value of the project itself. It ascertained the strength of the decision to invest in a project when there were changes in the variables that impact the financial performance of the project. The sensitivity analysis was conducted by firstly identifying the key variables that had significant impact on the economic analysis. The variables with potential significant impact considered for this project were the coal price, discount rate, production volume, and cost of capital.

A baseline scenario was set with initial assumptions for each key variable. Then, alternative scenarios were created by varying one variable at a time while keeping other variables constant. The independence of each variable was verified using the same percentage range of variation, from -20% to +20%. Financial evaluations were then performed for each scenario by calculating the three key financial metrics i.e., NPV, IRR, and PP. The sensitivity of the metrics was assessed by comparing the results across the scenarios. Variations in the financial metrics were analysed across scenarios to determine the variables with the most significant impact on the project's profitability. Scenarios that yielded the best and worst outcomes in terms of financial performance were identified.

CHAPTER 5

DATA ANALYSIS

5.1 Chapter Overview

This chapter presents the data analysis. The purpose of data analysis was to develop a graphical representation of the coal deposit from borehole data, provide a computation of the Morupule main seam coal resource and estimate its grade distribution to ensure improved coal resource evaluation, for cost effective mine design plan and cost analysis.

5.2 Modelling of Orebody

Data analysis was conducted based on borehole exploration drilling information for the MCM2 block sourced from the MCM database. Data used was that of information attained from drilling, lithological logging, core sampling, and the descriptions of stratigraphic sections measured in the field. The data tables used are in Appendix 2. The geological data were reviewed and verified as being accurate.

5.2.1 Geological Database

Based on the drill hole information available, a geological database was created to model the deposit. The database comprised data for 68 out of the 81 exploration holes drilled in the MCM2 block by SCOLBOT. The data in the Microsoft Excel (.csv) files was imported into Geovia Surpac version 2022 (x64). Figure 5.1 shows the location of boreholes in the MCM2 block based on their collar and survey file information.

Compositing

The sample database used contained a total of 190 assay samples representing 889.77 m of core. Using the down hole compositing method, compositing resulted in a total of 694 composite samples. Of the total assay population, approximately 22% were 1.1 m or less with approximately 78% of the samples being between 1.2 to 1.5 m in length.

5.2.2 Statistical Analysis

Reports of the histogram plots for the various coal qualities from within the mineralised domains are presented in Table 5.1. The coefficient of variation for the different coal qualities was less than 0.5, except for sulphur which was 1.03, indicating that the spread of data values was low relative to the mean. Skewness was negative for the calorific value and carbon dataset, indicating that the mean was less than the median in these datasets. Skewness was, however, positive for the ash, moisture, and sulphur data set, indicating datasets where the mean is greater than the median. The coal qualities datasets had no outliers.

Table 5.1 Histograms Reports of the Drill Core Sample Data

Variable	Calorific Value (MJ/kg)	Carbon (%)	Ash (%)	Moisture (%)	Sulphur (%)
Minimum	19.08	23.01	7.79	1.59	0
Maximum	30.85	66.9	35.4	7.7	3.03
Mean	26.05	54.54	15.39	3.8	0.43
Median	26.5	57.17	14.18	3.81	0.31
Variance	3.34	34.02	21.63	0.69	0.19
Standard deviation	1.83	5.83	4.65	0.83	0.44
Coefficient of variation	0.07	0.11	0.30	0.22	1.03
Skewness	-2.38	-1.39	2.08	0.44	3.79
97.5 Percentile	28.53	62.22	30.38	5.68	1.6

5.2.3 Spatial Analysis

Variograms were drawn at 0° dip, 0° azimuth with 90° spread, creating a spherical variogram. The results on variogram fitting for the coal qualities of the Morupule main seam are shown in Figure 5.2. The nugget, sill, and range values were indicated on each variogram depicting the spatial analysis of the sample data for the different coal qualities. Larger sill values relative to the nugget values in all the variogram plots for all the coal qualities indicate that there was enough correlation between the sampling data points. In all the variograms models for the coal qualities, none had a nugget value greater than the sill, meaning that there was good correlation between the data points. The ash showed the highest nugget value of 3.93 compared to all the other coal qualities nugget values that ranged between 0.01 and 1.3. The larger nugget value indicates a higher level of variability

in the ash content occurring at exceedingly small scales and influenced by local factors that were not captured by the sampling design or spatial interpolation methods.

All the variogram models indicated a rapid increase in the spatial correlation until the range was attained, beyond which correlation becomes constant. This indicates that the coal seam qualities exhibit a limited spatial continuity within a specified range. The spherical variogram also suggest that nearby locations have similar coal qualities, but the correlation diminishes beyond a certain distance. These variograms indicated that the Morupule main coal seam has coal qualities that were sampled at closely spaced data points therefore indicating low variability in the coal qualities throughout the coal seam.

5.2.4 3-D Coal Seam Model

The Morupule main seam was geometrically modelled as illustrated in Figure 5.3. The coal deposit was modelled as near horizontal, strata bound coal deposit where the coal distribution was controlled by topographic highs. The reported surface area and volume of the Morupule main coal seam based on the 3-D model were 108,599,811 m² and 624,575,820 m³ respectively.

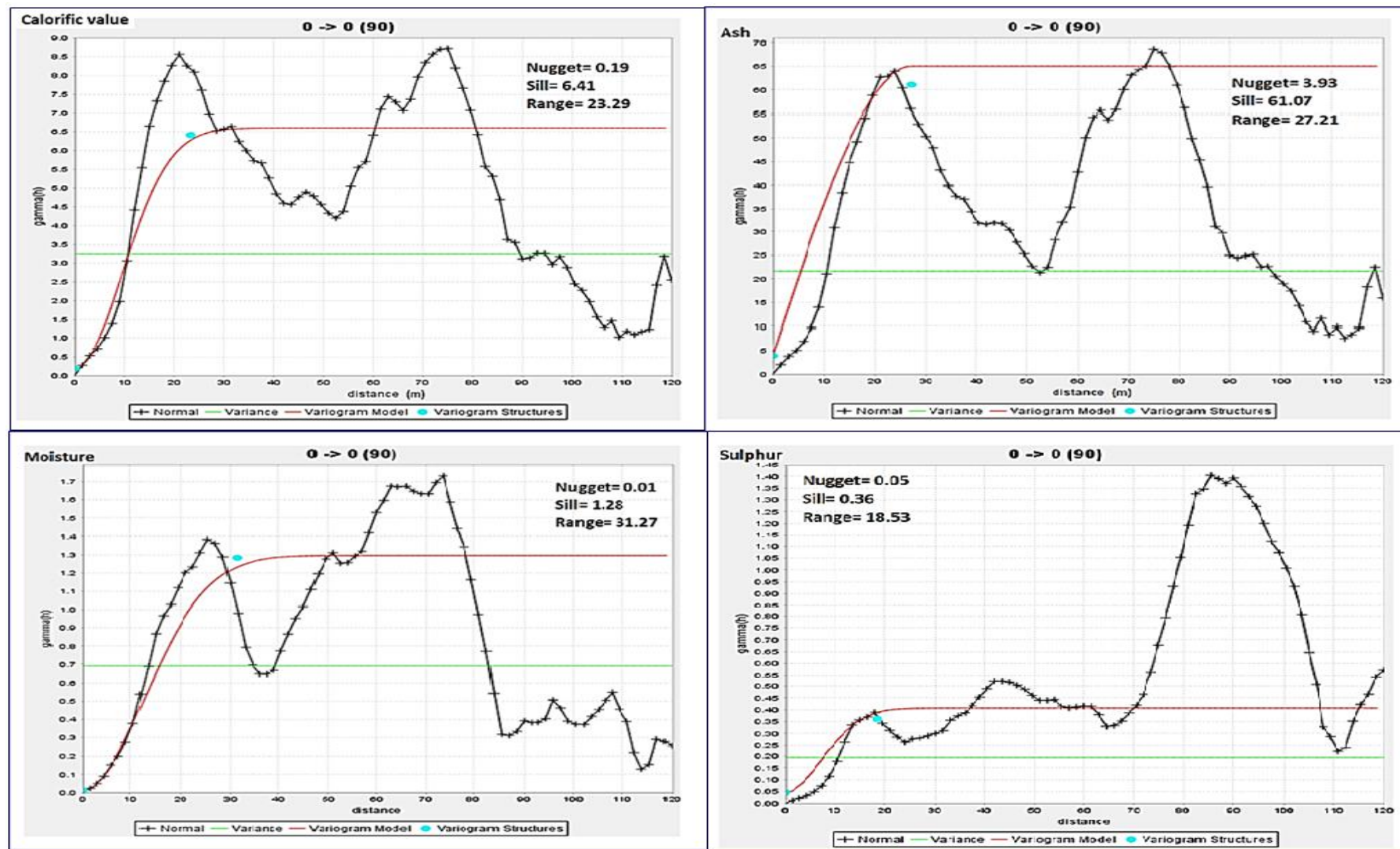


Figure 5.2 Sample Length Variograms for Coal Qualities at 0° Dip End, 0° Azimuth with 90° Spread

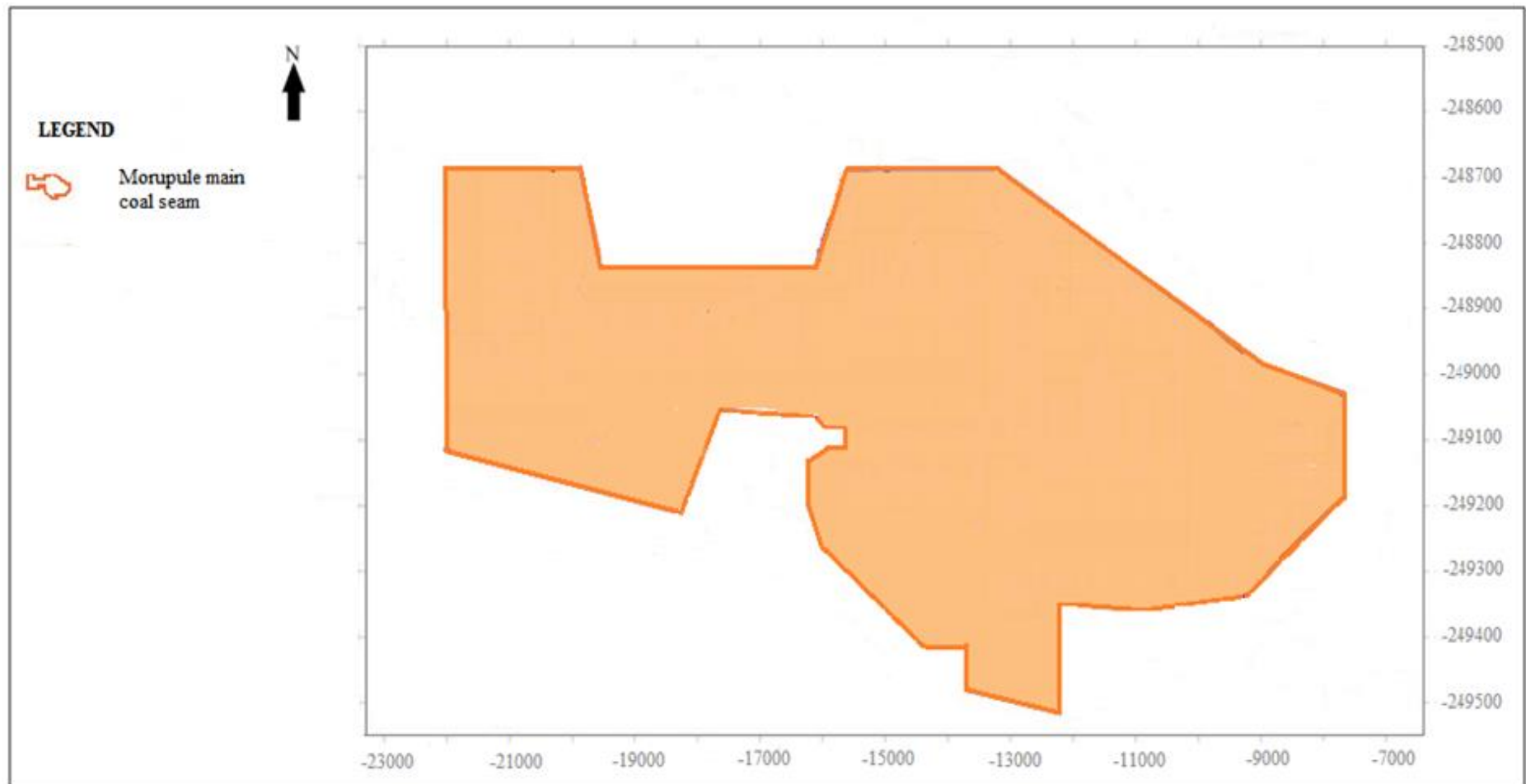


Figure 5.3 Solid Model of the Morupule Main Coal Seam

5.3 Block Modelling

Geological data was further used to develop an updated coal seam geology model for the MCM2 block for the purpose of resource estimation. The extents of the block model (see Table 5.2) were a factor of the concession boundaries and the geometry of the mineralized solid which occupied a volume of 624,575,820 m³. For the block size dimensions for x, y, and z, 50, 50, and 50 m are defined, respectively.

Table 5.2 Block Model Geometry

Origin	-22597.352° E
	-2493183.000° N
	337.798 m elevation
Size of 1 block (m)	50 X
	50 Y
	50 Z
Rotation	0°
Total number of blocks	127,379

Kriging

Kriging application was run for the coal seam thickness and the coal quality parameters; calorific value, ash content, Sulphur content, and moisture content (Figure 5.4- Figure 5.8). The best fitting spherical model occurred in the minimum lag distance interval of 740 m. The search ellipsoid dimensions were taken in x, y, z directions as 740 m, 380 m and 100 m, respectively to include all values of quality parameters of coal and put them in estimated blocks.

Coal seam thickness: Figure 5.4 shows the spatial distribution of coal thickness in the Morupule main coal seam. It was noted that the seam thickness reveals significant variations in thickness across the Morupule main coal seam, with localised regions of high thickness and with a region of very low coal thickness on the eastern part of the coal seam.

Calorific value: The analysis of the ordinary kriging for calorific value estimation reveals promising accuracy, with a low mean error of 0.25 MJ/kg, indicating a minimal bias between the estimated and the measured value. The root mean square error of 1.10 MJ/kg

suggests good precision in the estimates, with most points falling within a reasonable range of the true value. The coefficient of determination (R^2) of 0.78 indicates a strong correlation between the estimated and measured calorific value. The spatial distribution analysis (Figure 5.5) reveals a consistent pattern of increasing calorific value towards the central portion of the Morupule main seam. However, a localized anomaly of low calorific value is identified in the northern and north-western part of the coal seam, potentially indicating an area of lower coal quality.

Ash: The analysis of the ordinary kriging results for ash content estimation reveals satisfactory accuracy, with a mean error of 1.2%, indicating a slight over-estimation of ash content in the estimated values compared to the measured data. The root mean square error of 2.5% suggests reasonable precision, with the majority of points falling within an acceptable range of the true values. The coefficient of determination of 0.68 indicates a moderately strong correlation between the estimated and measured ash content. The spatial distribution analysis (Figure 5.6) reveals relatively uniform ash content across the Morupule main coal seam, indicating consistent coal quality for ash.

Moisture: The analysis of the ordinary kriging results of moisture content reveals mixed findings. The mean error 1.5% indicates a slight over estimation of moisture content in the estimated values compared to the measured data. However, the root mean square error of 2% suggests good precision, with most points falling within an acceptable range of the true values. The coefficient of determination of 0.72 shows a reasonably strong correlation between the estimated and measured moisture content. The spatial distribution analysis (Figure 5.7) indicates significant variations in moisture content across the Morupule main coal seam. Higher moisture content is observed in the eastern region, likely due to potential groundwater influence. In contrast, the western part displays lower moisture content, likely due to drier hydro-geological conditions.

Sulphur: The analysis of the ordinary kriging results for sulphur content estimation shows satisfactory accuracy, with a mean error of 0.1%, indicating a minimal bias between estimated and measured values. The root mean square error of 0.5% suggests good precision, with most points falling within a reasonable range of true values. The coefficient of determination of 0.85 demonstrates a strong correlation between the estimated and measured sulphur content. The spatial distribution analysis (Figure 5.8) reveals significant

variations in sulphur content across the Morupule main coal seam, with localised regions of high and low sulphur content.

5.4 Coal Resource Estimation Based on 3-D Coal Seam Model

The block model was filled with the following attribute values; coal quality values (calorific value, ash content, carbon content and sulphur content), specific gravity, air, waste, and rock type. Interpolation of coal grades (calorific values) onto the block model was completed using the nearest neighbour estimation technique. The total volume and tonnage of the Morupule coal seam was estimated as shown in Table 5.3.

Table 5.3 Total Estimated Coal Resource

Ore volume (m³)	Density (tonne/m³)	Ore Resource (tonne)
624,575,820	1.3	811,948,566

5.4.1 Coal Resource Classification

In accordance with the SAMREC 2016 Code the MCM2 Coal Resources were categorised as Measured, and Indicated Resources as shown in Figure 5.9. The borehole densities together with data consistency within the boundaries of the coal resource area were the key factors considered in the Resource classification. A discount of 8% and 12% was applied respectively to Measured and Indicated Resources to justify unanticipated geological losses. The coal resource classification as well as the discount rate applied was determined in view of the database integrity, geological interpretation, type of seam deposit, the resource estimation and modelling techniques utilised, and the consistency of the physical coal parameters and quality of coal.

No blocks were classified as Inferred in the current resource estimate due to deficient drill hole spacing over most areas. The minable tonnes in-situ coal resource estimation was prepared on an air-dried basis and discounted for potential geological losses. The resource statement is presented in Table 5.4, including raw coal qualities and relative density on an air-dried basis and at the indicated moisture content.

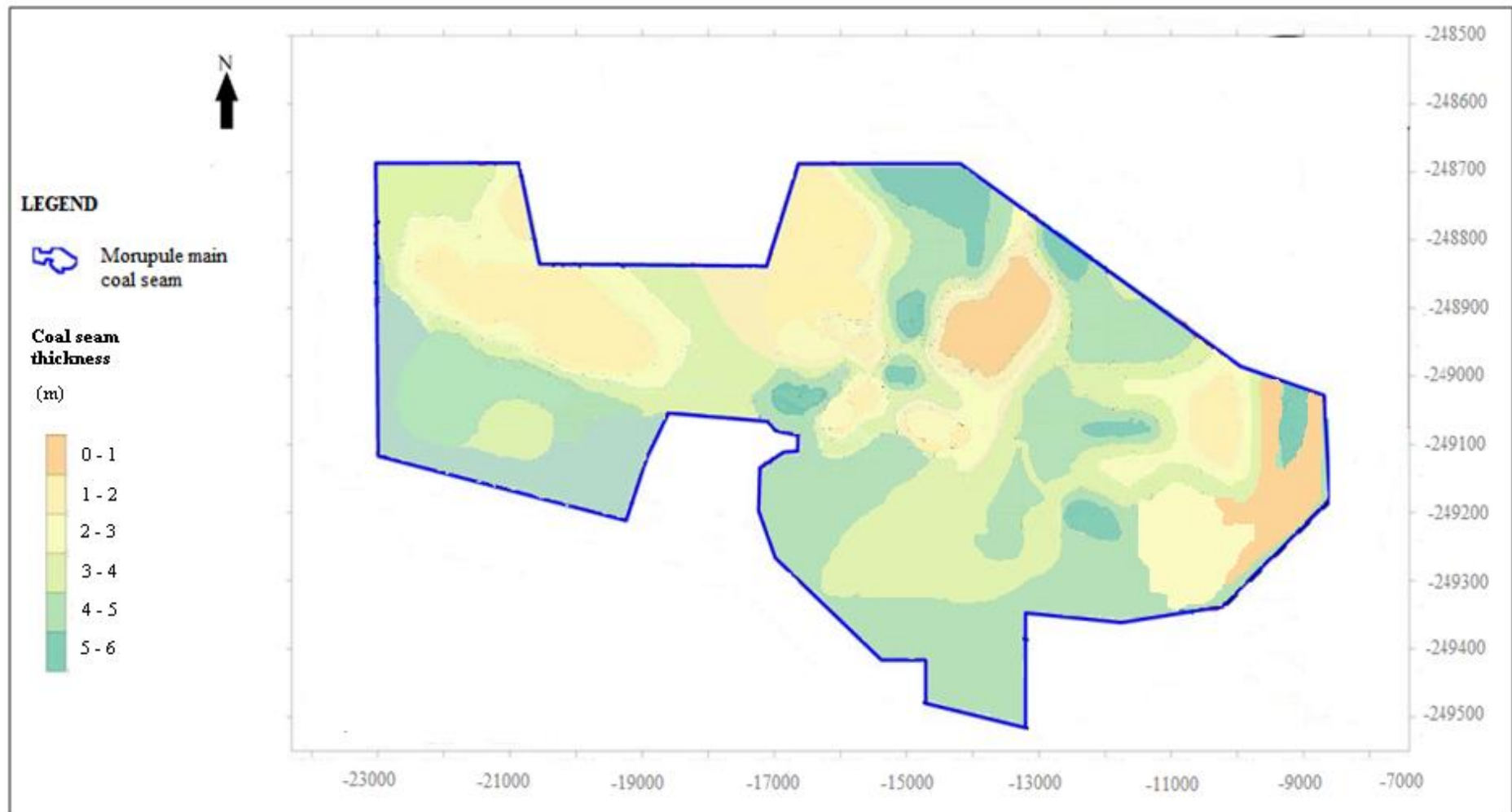


Figure 5.4 Spatial Prediction Map for the Ordinary Kriging of Thickness (m) Map of Morupule Main Coal Seam

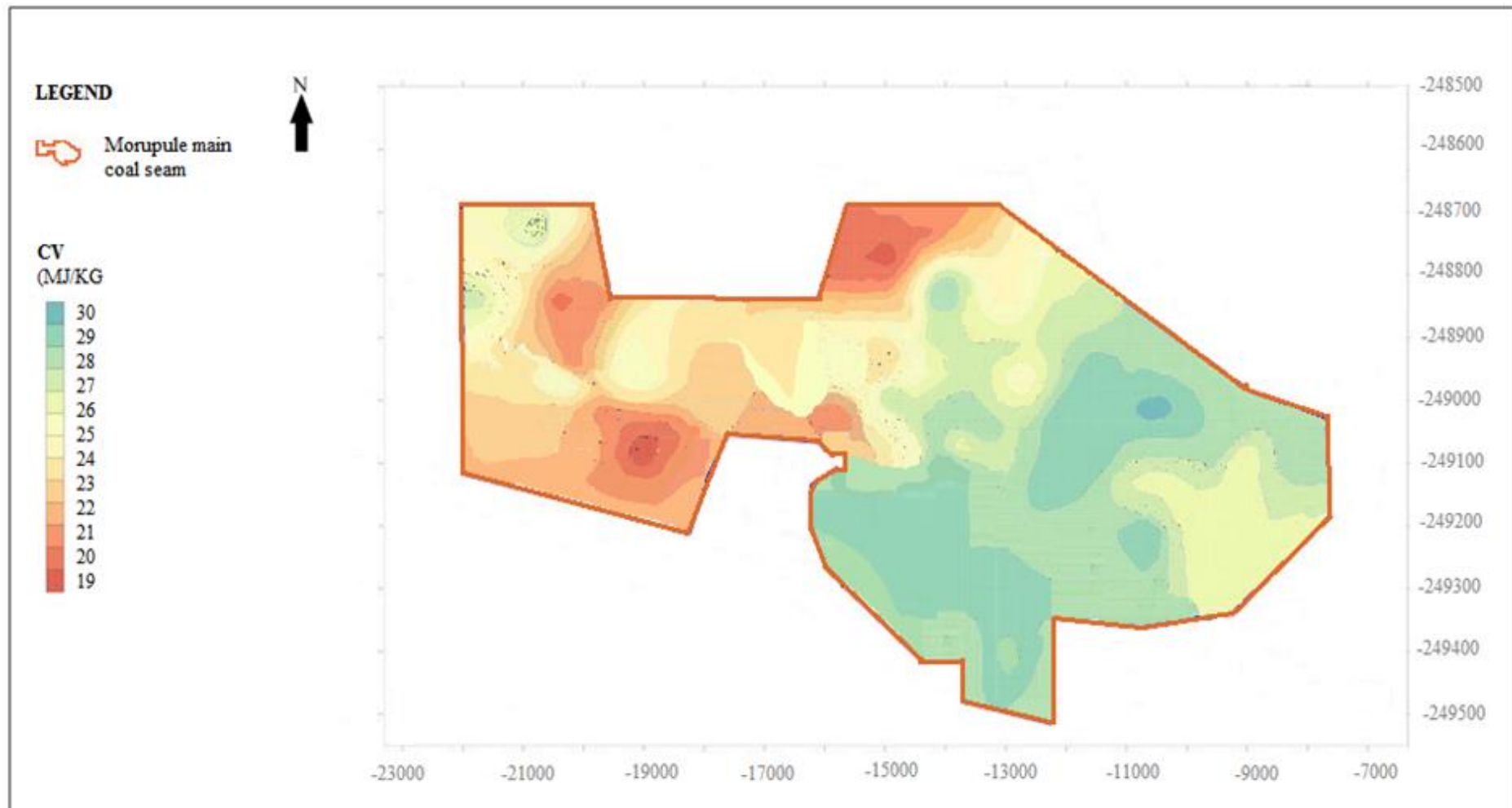


Figure 5.5 Spatial Prediction Map for the Ordinary Kriging of Calorific Value (MJ/kg) Map of Morupule Main Coal Seam

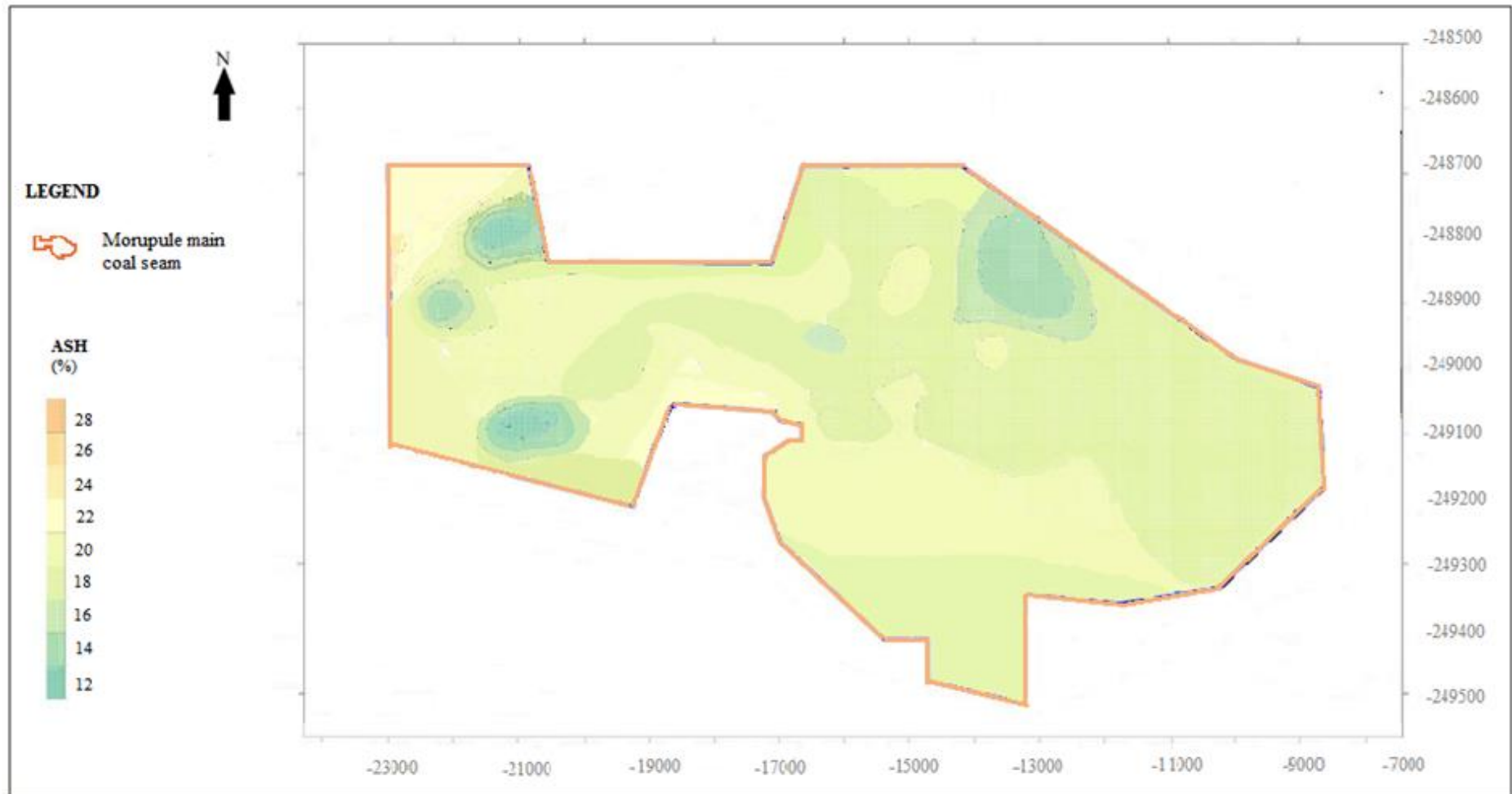


Figure 5.6 Spatial Prediction Map for the Ordinary Kriging of Ash Content (%) of Morupule Main Coal Seam

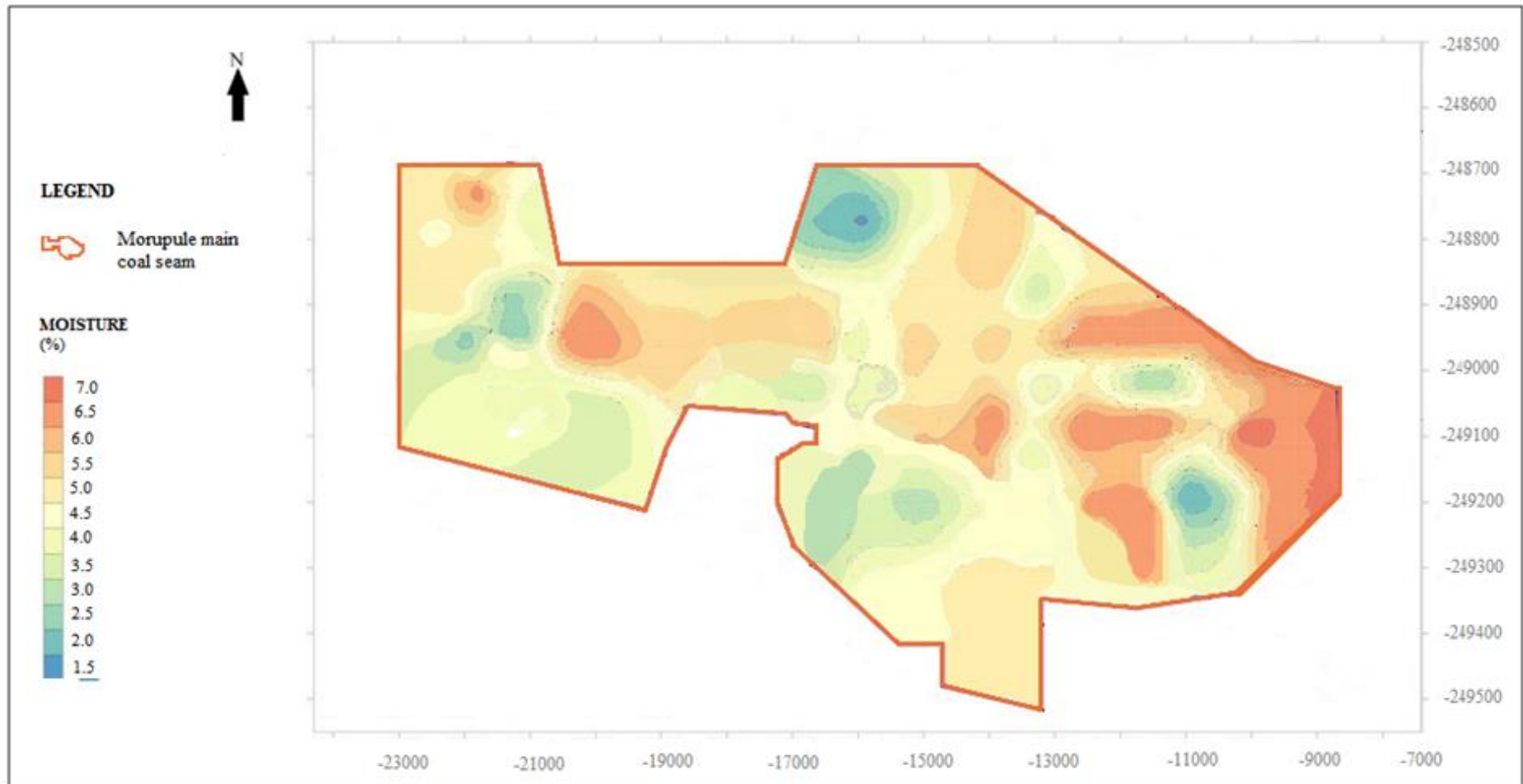


Figure 5.7 Spatial Prediction Map for the Ordinary Kriging of Moisture Content (%) of Morupule Main Coal Seam

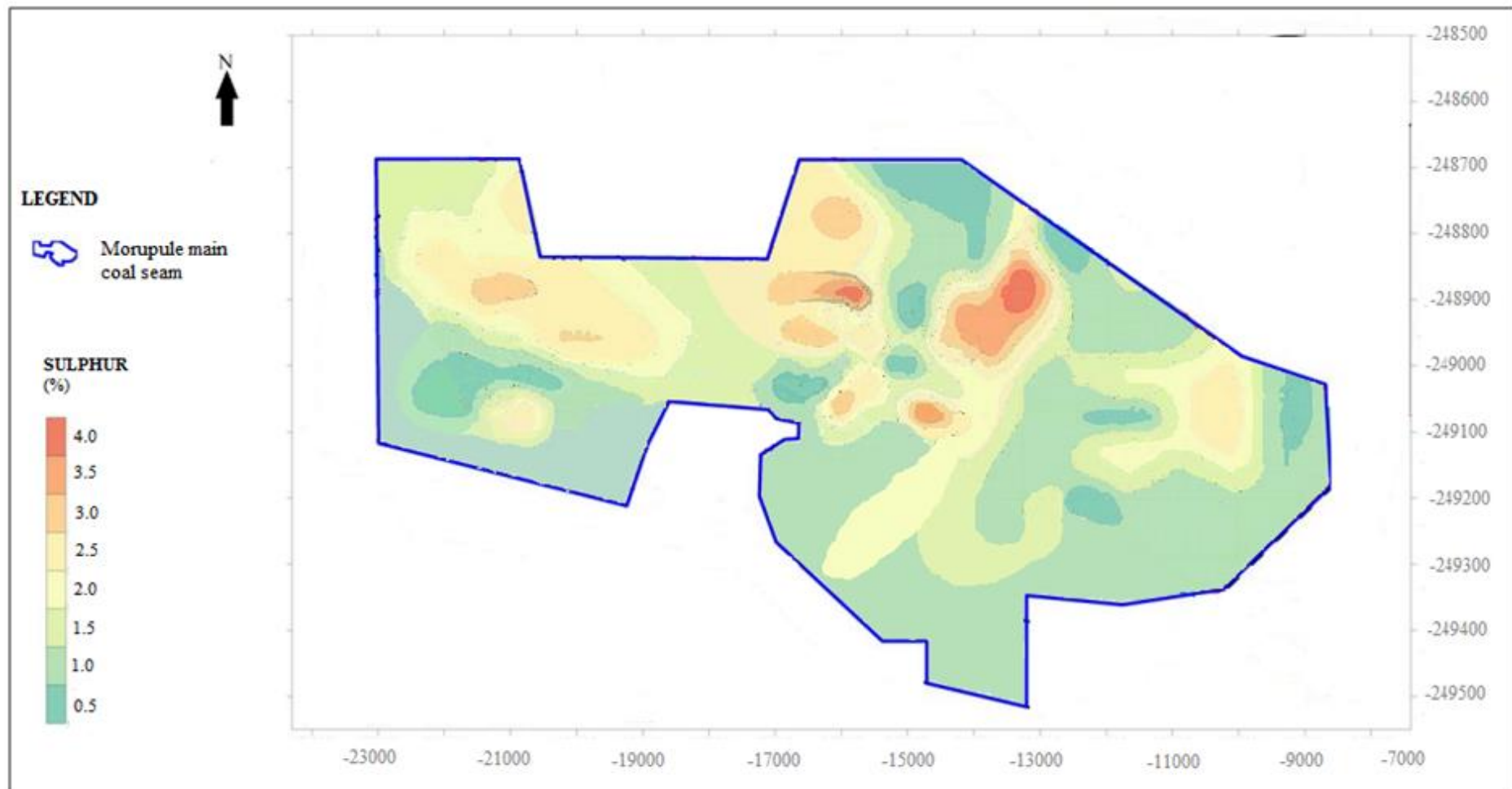


Figure 5.8 Spatial Prediction Map for the Ordinary Kriging of Sulphur Content (%) of Morupule Main Coal Seam

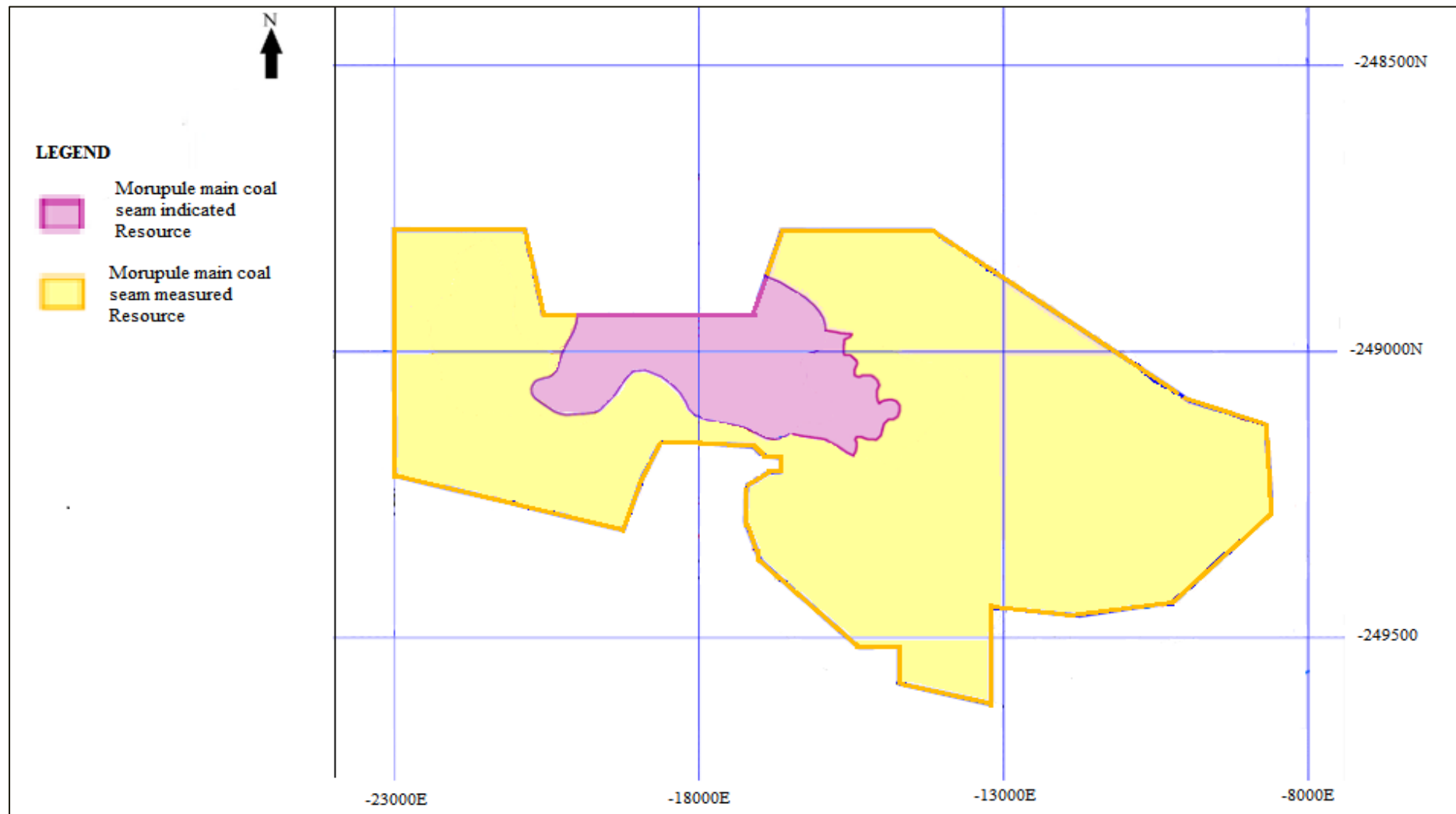


Figure 5.9 Morupule Main Coal Seam Resource Classifications

Table 5.4 MCM2 Morupule Main Seam Coal Resource Classification Estimate

Resource Classification	Seam	Geo Loss	Minable Tonnes	Seam Thickness	Raw Coal Qualities on an Air-dried Basis				
		(%)	(tonnes)	(m)	Raw RD	Raw CV	Raw Ash	Raw Carbon	Raw Inherent Moisture
					(g/cm ³)	MJ/kg	(%)	(%)	(%)
Measured	Morupule	8	714,514,738	5	1.3	25.9	16	58	4.0
Indicated	Main Seam	12	97,433,828	1.5	1.5	25.0	22.5	52	4.5
Total Coal Resource			811,948,566						

5.5 Coal Mine Design

The coal mine design was based on knowledge of the disposition of the Morupule main seam plus the content of the coal geological resource model.

5.5.1 Mining Method

The five criteria for evaluating the mining methods were: production rate, recovery rate, operating costs, safety, and environmental impact. A pairwise comparison matrix to weight the criteria according to their importance is illustrated in Table 5.5.

Table 5.5 Pairwise Comparison Matrix

Criteria	Production Rate	Recovery Rate	Operating Costs	Safety	Environmental Impact
Production Rate	1	3	2	$\frac{1}{4}$	$\frac{1}{4}$
Recovery Rate	$\frac{1}{3}$	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Operating Costs	$\frac{1}{2}$	2	1	$\frac{1}{3}$	$\frac{1}{3}$
Safety	4	2	3	1	3
Environmental Impact	4	2	3	$\frac{1}{3}$	1

Production rate is three times more important than recovery rate, and twice as important as operating costs. Similarly, recovery rate was assumed to be a third as important as production rate, half as important as operating costs, safety, and environmental impact. Environmental impact on the other hand was assumed to be four times more important than the production rate, twice as important as the recovery rate, and three times as important as operating costs.

Two types of mining operations were identified to be evaluated against the criteria: underground mining and surface mining. Table 5.6 shows how each mining method scored for each criterion:

Table 5.6 Mining Method Score against Each Criterion

Mining method	Criteria				
	Production Rate	Recovery Rate	Operating Costs	Safety	Environmental Impact
Underground mining	0.7	0.7	0.4	0.5	0.4
Surface mining	0.8	0.8	0.7	0.7	0.6

Surface mining was assigned a production rate score of 0.8, a recovery rate score of 0.8, an operating cost score of 0.7, a safety score of 0.7, and an environmental impact score of 0.6. Similarly, a production rate score of 0.7 for underground mining, a recovery rate score of 0.7, an operating cost score of 0.4, a safety score of 0.5, and an environmental impact score of 0.4. Table 5.7 shows the preference ranking for the two types of mining operation based on the scores assigned in Table 5.6.

Table 5.7 Preference Ranking for the Mining Methods

Method	Net Flow
Surface mining	2.6
Underground mining	2.2

Surface mining has the higher net flow compared to that of underground mining, indicating that it performs better. Based on the preference ranking, surface mining was selected as the most suitable mining method for exploiting the Morupule main seam on the MCM2 block. Additionally, the commonly used method of surface mining coal is the open cast mining operation, which was also adopted in this study.

5.5.2 Mine Equipment

Mining equipment was selected to support open cast mining from start up to a production rate of approximately 2 Mtpa ROM coal. Production will ramp up to a steady production rate of ± 3 Mtpa. The following criterion was used to evaluate and compare different equipment options for open-cast mining (Table 5.8). Production capacity is high from both the continuous mining technology and the dragline, but the continuous mining system has lower environmental impact.

Table 5.8 Evaluation of Different Equipment Options for Open-cast Mining

Criteria	Continuous mining technology (Bucket wheel excavator)	Shovel dumper technology	Dragline
Production Capacity	High	Medium	High
Power Requirements	High	Low	Medium
Operating Costs	Medium	Low	Medium
Maintenance Costs	Medium	Low	Medium
Environmental Impact	Low	Medium	Medium
Safety Features	Advanced	Basic	Advanced
Adaptability and Flexibility	Low	High	Medium
Technological Advancements	Advanced	Moderate	Advanced
Durability and Reliability	High	Medium	High
Supplier Support and Service Network	Moderate	Moderate	Moderate

Key: Low, Medium, High OR Basic, Moderate, Advanced

Table 5.9 demonstrates the assigned relative weights to each criterion based on their importance using the Analytic Hierarchy Process (AHP) (as described in the methodology). The highest weight is assigned to environmental impact as it is regarded the most important criterion to ensure sustainable mining with minimal impact to the environment. The lowest weight is assigned to supplier support and service network which is the least important criterion in this operation.

Table 5.9 Assigned Relative Weights to each Criterion

Criteria	Weight (Scale: 1-9)
Production Capacity	8
Power Requirements	6
Operating Costs	6
Maintenance Costs	6
Environmental Impact	9
Safety Features	8
Adaptability and Flexibility	6

Technological Advancements	8
Durability and Reliability	8
Supplier Support and Service Network	4

Appendix 3 shows a list of some of the equipment alternatives for open-cast mining operations: this table presents a sample list of some equipment alternatives that were considered for open-cast mining operations. It includes several types of equipment such as excavators, haul trucks, loaders, and drill rigs. The manufacturer, model, size/capacity, and key specifications are provided to offer a comprehensive overview of the equipment options available for evaluation and comparison.

Table 5.10 shows the evaluation of equipment alternatives against the identified criteria using the engineer's experience. A higher score indicates better performance or alignment with the criterion, for instance, for technological advancement, the continuous mining system was assigned the highest score of 9 out of 10 as it is a system that has more advanced technology features and offers automation features compared to the other equipment options.

Table 5.10 Equipment Alternatives against Identified Criteria

Criteria	Continuous mining technology (Bucket wheel excavator)	Shovel dumper technology	Dragline
Production Capacity	8	7	9
Power Requirements	6	8	7
Operating Costs	7	9	8
Maintenance Costs	8	7	6
Environmental Impact	7	6	8
Safety Features	9	8	9
Adaptability and Flexibility	7	9	8
Technological Advancements	9	7	8
Durability and Reliability	8	9	7
Supplier Support and Service Network	7	8	9

Table 5.11 shows the calculated preference values for each equipment option and criterion. The preference values were derived based on the criteria weights and the evaluations provided in previous tables.

Table 5.11 Calculated Preference Values for each Equipment Option

Criteria	Weight (Scale: 1-9)	Continuous mining technology (Bucket wheel excavator)	Shovel dumper technology	Dragline
Production Capacity	8	0.67	0.33	1.00
Power Requirements	6	0.33	1.00	0.67
Operating Costs	6	0.67	1.00	0.33
Maintenance Costs	6	1.00	0.67	0.33
Environmental Impact	9	0.33	0.00	1.00
Safety Features	8	1.00	0.67	1.00
Adaptability and Flexibility	6	0.33	1.00	0.67
Technological Advancements	8	1.00	0.33	0.67
Durability and Reliability	8	0.67	1.00	0.33
Supplier Support and Service Network	4	0.33	0.67	1.00

Performing a sensitivity analysis aided the evaluation of the robustness of the results obtained from the PROMETHEE method by examining how changes in criteria weights or alternative evaluations affected the final rankings. Table 5.12 shows the sensitivity analysis results. The table includes the original criteria weights and evaluations obtained from the PROMETHEE method, as well as the final ranking of the equipment alternatives. These adjustments yielded different sensitivity analysis results, thus altering the final ranking of the equipment alternatives.

Table 5.12 Sensitivity Analysis of Equipment Selection Criteria

Criteria	Weight (Scale: 1-9)	Continuous mining technology (Bucket wheel excavator)	Shovel dumper technology	Dragline
Production Capacity	8	0.67	0.33	1.00

Operating Costs	6	0.67	1.00	0.33
Power Requirements	6	0.33	1.00	0.67
Maintenance Costs	6	1.00	0.67	0.33
Environmental Impact	9	0.33	0.00	1.00
Safety Features	8	1.00	0.67	1.00
Adaptability and Flexibility	6	0.33	1.00	0.67
Technological Advancements	8	1.00	0.33	0.67
Durability and Reliability	8	0.67	1.00	0.33
Supplier Support and Service Network	4	0.33	0.67	1.00
Final Ranking		2 nd	3 rd	1 st

The dragline equipment alternative ranked as the best option, the second-best alternative was continuous mining technology using bucket wheel excavators, and lastly was the shovel dumper technology. The following equipment was hence chosen for the open cast mining operation.

- 1 × 345 tonne CAT8750 Dragline
- 5 × 70 tonne CAT 374 Excavator
- 12 × 40 tonne CAT 740GC Articulated Dump Trucks
- 3 × 70 tonne CAT D10 Bull dozers
- 3 × 40 tonne CAT D8 Bull dozers
- 3 × 20 tonne CAT 140 Graders
- 3 × TLB backhoe loaders
- 2 × Water bowsers
- 2 × Diesel bowsers

5.5.3 Mine Design Layout

The mine layout design utilised blocks that were 100 m long and 40 m wide (size generated by re-blocking original block sizes). These block dimensions were chosen based on the size and shape of the ore body, the type of equipment to be used, the production capacity

required, and the geotechnical environment and environmental considerations. The open cast mine will start with an initial box cut in the furthest west position of the Morupule main coal seam (Figure 5.10). This will be expanded in two directions, to the east and south, to enable multiple active areas of mining thus facilitating a rapid ramp-up in production. For the open cast mine, a minimum seam thickness cut-off of 1.0 m was applied. With an average seam thickness of 5 m, the Morupule main seam was considered well suited for exploitation through open cast mining.

Opencast Pit Parameters

Opencast pit dimensions were assumed based on geotechnical information and equipment selected for mining operations (Table 5.13). Considering the opencast pit parameters, the final slope design was determined. Open cast mine will have a series of benches with a width of 20 m. Catch benches will be strategically placed every 30 m vertically to enhance slope stability and allow safe access.

Table 5.13 Opencast Pit Parameters

Parameter	Value
Overall pit length	1,500 m
Overall pit width	800 m
Maximum pit depth	300 m
Bench width	20 m
Bench height	15 m
Bench slope angle	38°

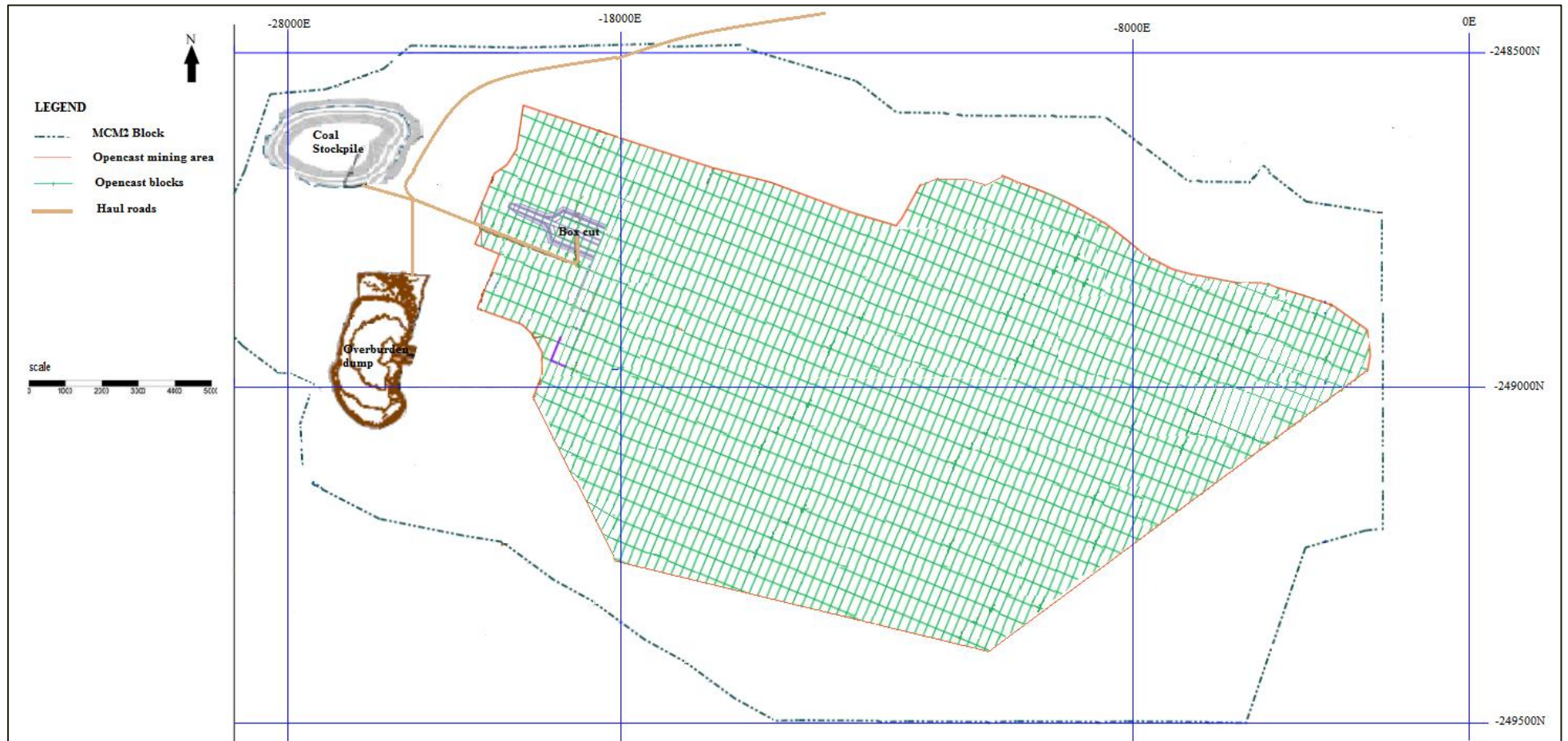


Figure 5.10 Morupule Main Coal Seam Mining Layout

Slope Design Outcome

A geological assessment of the site revealed the presence of three coal seams (Serowe bright, Lotsane and Morupule main) interspersed with layers of sandstone and mudstone. The coal seams have average thicknesses of 2 m, 3 m, and 5 m, respectively. Based on the geotechnical assessment and slope stability analysis, a target factor of safety of 1.5 was selected for the slope design. The critical failure surface was determined to be planar sliding along the weakest bedding plane within the sandstone. Figure 5.11 shows a schematic diagram of the outcomes of the slope design generated from the Slope Stability Analysis software.

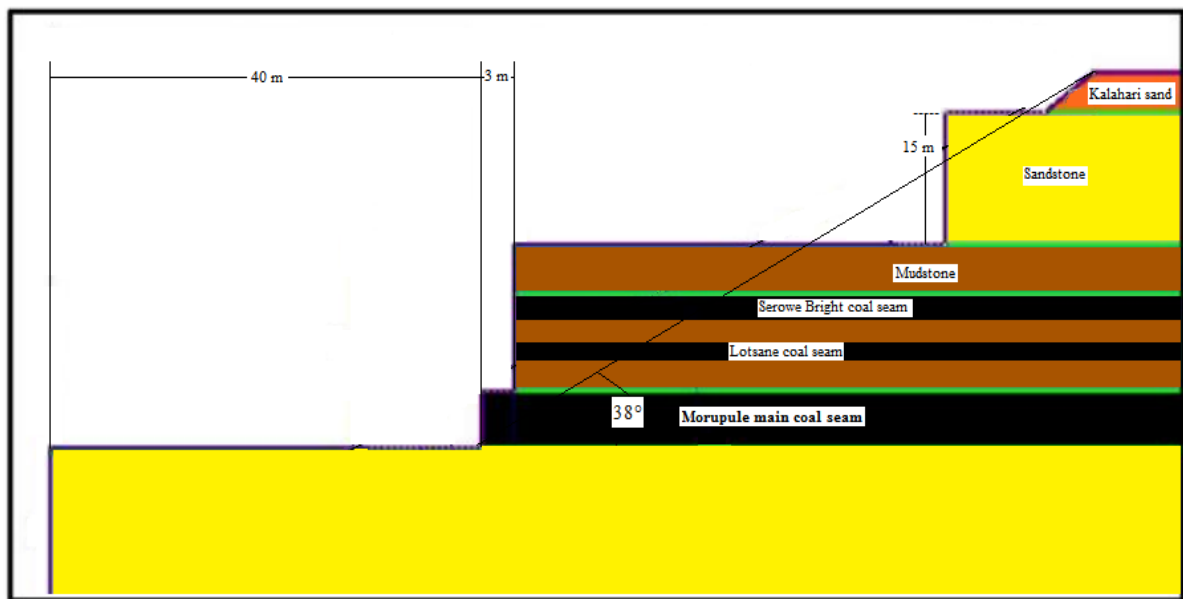


Figure 5.11 Slope Design for Opencast Mining of Morupule Main Coal Seam

The Kalahari sands layer needs to pre-strip to at least 10 m in advance to ensure that it does not collapse onto the crest of the high wall. The pre-strip distance can be increased to cater for the varying depth of the Kalahari layer as it has increased depth in some areas. The weathered sandstone layer can be constructed to a maximum height of 15 m and a width of 40 m on a separate bench to separate it from the dark mudstone zone. If possible, the sandstone bench can be constructed vertically with the face cleaned and dressed thoroughly off loose material. The mudstone layer will be separated from the Serowe bright coal seam and Lotsane coal seam with a 3 m wide bench. The mudstone face however, may not extend to more than 13 m high. The Morupule main seam high wall will be constructed vertically

to about 15 m high with a safety berm constructed on the crest of this high wall. A 3 m wide coal toe must be left in order to prevent working right under the high wall.

5.5.4 Production Schedule

The production schedule outlines the mining sequence and production rates. This will help to ensure that the mine can meet its annual production target of 3 Mtpa. The first consideration was determining an economic stripping ratio considering the coal seam thickness and depth. Table 5.14 shows the cost estimates associated with different stripping ratios. For a production target of 3Mtpa, an in-situ stripping ratio of 5:1 would be suitable for the size of operation of this open cast mine. At present, it was reflected that an in-situ stripping ratios greater than 5:1 would require underground mining techniques as these costs for open cast mining would be too high.

Table 5.14 Opencast Stripping Ratio Cut-off

Opencast Cost Estimate		
Strip Ratio (SR)	US\$ per ROM tonne	Seam Thickness (m)
1	2.75	5
2	5.47	5
3	8.21	5
4	10.92	5
5	13.65	5
6	16.37	5
7	19.10	5

The production schedule for the 3 Mtpa open cast mine is presented in Figure 5.12. During the first year, the focus will be on the removal of overburden and preparing the pit for mining operations; the production rate will be approximately 1.8Mtpa of ROM coal. During Years 2 to 5, the focus will be on the extraction of coal, aiming to increase the production rate to approximately 2.5Mtpa ROM coal.

During Years 6 to 10 these years, the focus will be on the extraction of coal from deeper levels of the pit. The production rate will be maintained at 3 Mtpa, and the mining sequence will be based on the location of the high-grade coal. From Year 11 to 15, the focus will be

on the extraction of lower grade coal and the expansion of the pit. The production rate will be maintained at 3 Mtpa, and the mining sequence will be based on the location of the ore body. In the last four years (i.e., Year 16 to 20), the focus will be on the completion of the mining operations and the rehabilitation of the mine site. The production rate will be reduced to approximately 2.5Mtpa, and the mining sequence will be based on the location of the remaining ore body.

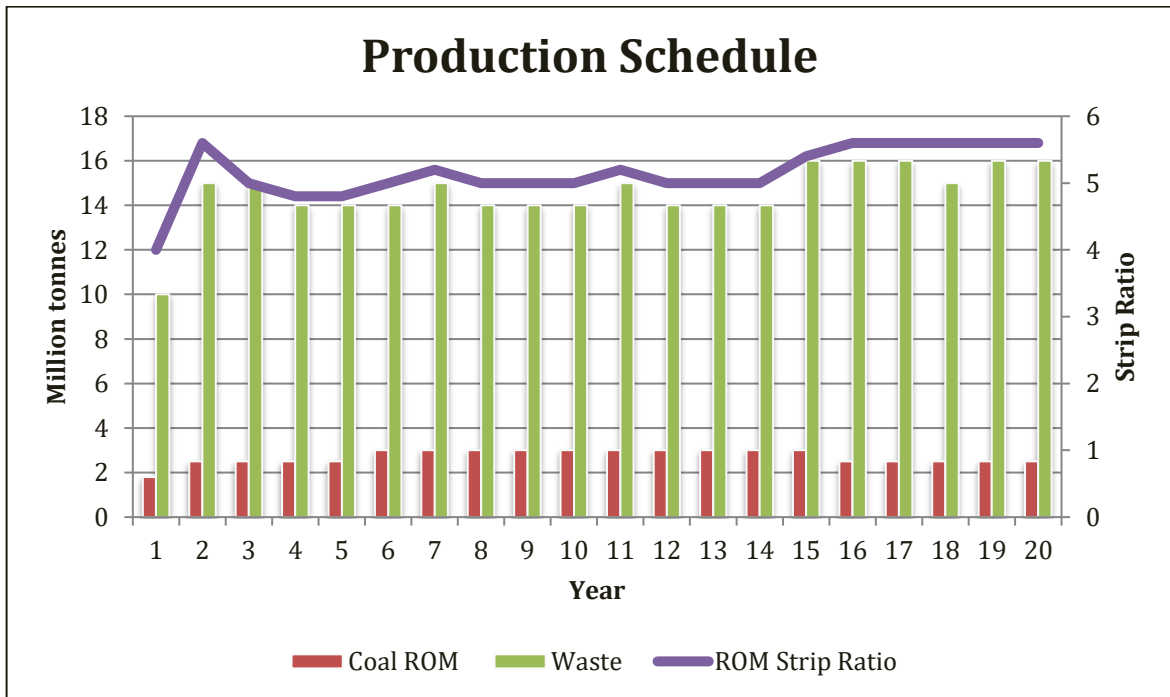


Figure 5.12 MCM2 Morupule Main Seam Open-cast Production Schedule

5.5.5 Mining Schedule

The following mining cut-offs and parameters were applied to develop the open cast mining schedule for the Morupule main seam coal resource:

- Minimum seam thickness: 1.0 m
- Strip ratio of 5:1 (waste bcm: in-situ coal tonne), based on the annual production of coal of 3Mtpa

The mining schedule for the Morupule main seam is presented in Figure 5.13. The mining sequence will follow these steps:

1. Topsoil comprising of Kalahari sand (thickness between 6.3 m and 15 m) removed and stockpiled separately.

2. Soft overburden will be removed as free dig using dragline. Hard overburden will be drilled and blasted.
3. Coal in the partings between the overburden will be drilled, blasted, and stockpiled separately; this includes coals of the Serowe bright coal seam and the Lotsane coal seam.
4. Coal in the Morupule main seam will be blasted separately and mined using the dragline.
5. Waste material will be stored initially on waste dumps outside the pit (during the box cut period), until sufficient space has been mined for waste material to be back filled into the mined-out areas of the pit.
6. Rehabilitation will take place as mining progresses and once the area has been backfilled, it will be covered with topsoil to return it to its original ground level.

5.5.6 Environmental Considerations

Based on the review of environmental impact assessments conducted around the Morupule coalfield and for the MCM3 open cast mine, several key issues were identified associated with opencast mining operations.

Key Environmental Issues

- Habitat fragmentation and loss of biodiversity because of clearing large areas of land and industrialization of the area.
- Dust emissions and other particulate matter causing air pollution around the proposed coal mine.
- Noise pollution from blasting and haulage traffic.
- Vibration pollution resulting from blasting and haulage traffic.
- Loss of agricultural land, grazing pasture, and loss of coal resource due to establishment of the mine.
- Reduction of air quality which could result in an upsurge in respiratory illnesses caused by the inhalation of coal dust.
- Possible groundwater and surface water acidification due to acid rock drainage from coal stockpiles.

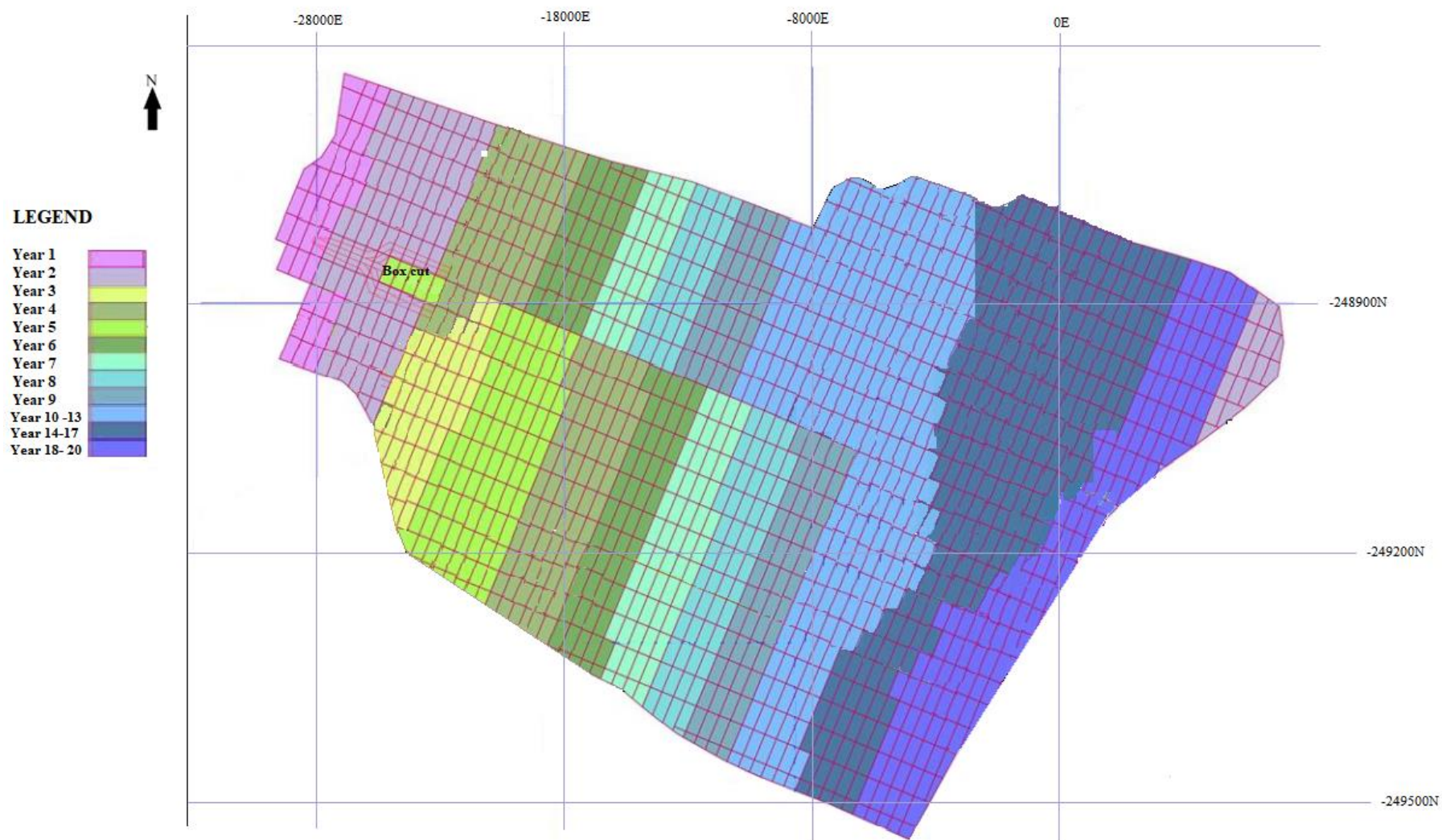


Figure 5.13 MCM2 Morupule Main Seam Open-cast Mining Schedule

Table 5.15 contains numeric values assigned to quantify the magnitude of the identified key environmental issues (values were arbitrary weighted). The magnitude value of 5 for noise pollution indicates a significant impact requiring immediate attention and mitigation efforts, while a magnitude of 3 for energy consumption suggests a relatively lower impact but still requiring appropriate management practices.

Table 5.15 Magnitude of Environmental Impact

Environmental Impact	Magnitude Value
Air pollution	3
Water pollution	4
Soil erosion	3
Biodiversity loss	3
Noise pollution	5
Waste generation	4
Energy consumption	3
Greenhouse gas emissions	4

Suggested Mitigations

- Suppress dust regularly in the mining area e.g., using water trucks.
- Minimise the presence of airborne respirable dust using mist cannons.
- Keep a topsoil stockpile for the purposes of site rehabilitation.
- Enclosing sources of significant noise; the boundaries of enclosure are dependent on the machinery used and ventilation requirements.
- All water draining off coal stockpiles or any surface waste dumps should be captured in a dirty water system and collected in a pollution control dam.

5.6 Open Cast Coal Mine Investment Cost

All costs are in the American dollar (US\$) with no escalation unless otherwise stated. The coal prices and exchange rates used in this study are merely estimates based on current and historical performances hence no assurance that they will be realised if the project is implemented into production. The exchange rate used was BWP 13.00: US\$1.00.

5.6.1 Selling Price

The selling price of washed thermal coal from Botswana exported to foreign countries varies contingent to the type and quality of the coal. In the given period of 12 months, exports of washed coal from Botswana to the export country will amount to about 2.5 Mtpa with a price average of US\$100 per tonne. It is assumed that the sale price of washed coal will be US\$100 per tonne with reference to the selling price of washed thermal coal from the neighbouring country South Africa, with almost the same coal quality.

5.6.2 Capital Investment Estimate

This is the investment fund required to acquire equipment, public services (electricity, water, and telephone), as well as other supporting facilities such as road projects. The initial capital cost of the open cast mine development amounted to US\$57 million. The expenditure spread over 5 years (starting in Year 1) and terminates when the mine achieves full production in the fifth year. Equipment comprises 60% of the total capital cost whilst, 10% is designated to infrastructure. The breakdown of the capital investment costs is shown in Table 5.16.

Table 5.16 Capital Investment Estimate

Targeted production (tonnes per year)			3×10^6	
Item	Description	Quantity	Unit Cost (US\$)	Total Cost (US\$)
1	Clearing and grubbing	1	2,000,000	2,000,000
2	Site preparation	1	5,000,000	5,000,000
3	Equipment			
3.1	Excavators	1	6,000,000	6,000,000
3.2	Haul trucks	12	1,500,000	18,000,000
3.3	Dozers	6	1,000,000	6,000,000
3.4	Loaders	3	1,000,000	4,000,000
4	Infrastructure			
4.1	Access roads	1	2,000,000	2,000,000
4.2	Water supply	1	1,500,000	1,500,000
4.3	Power supply	1	2,500,000	2,500,000
5	Contingency	1	10,000,000	10,000,000
	Total			57,000,000

5.6.3 Operating Costs Estimate

The operating cost estimate was established on a combination of reference projects (Masama coal mine) and budgetary quotes. To determine the cost of production of washed coal, the following main assumption was made:

i. Labour

This project is estimated to require a workforce of 141 workers and 59 support staff consisting of tiers of leadership and service levels. Total amount of labour was estimated to be US\$20 million annually.

The breakdown of the operating costs is shown in Table 5.17.

Table 5.17 Annual Operating Costs Estimate

Targeted production (tonnes per year)			3×10^6	
Item	Description	Quantity	Unit Cost (US\$)	Total Cost (US\$)
1	Labour	200	100,000	20,000,000
2	Fuel and lubricants			
2.1	Diesel	1,500,000	1.50	2,250,000
2.2	Oil and grease	1,500,000	0.50	750,000
3	Maintenance and repairs			
3.1	Planned maintenance	1	5,000,000	5,000,000
3.2	Unscheduled maintenance	1	2,000,000	2,000,000
4	Consumables			
4.1	Explosives	1,000,000	0.50	500,000
4.2	Tires	150	20,000	3,000,000
4.3	Ground engaging tools			1,500,000
5	Utilities			
5.1	Electricity	1	1,000,000	1,000,000
5.2	Water	1	500,000	500,000
6	Royalties			
6.1	Government royalties	1	5,000,000	5,000,000
7	Contingency	1	3,000,000	3,000,000
	Total			44,500,000

5.6.4 Working Capital Estimate

These are the funds financing the project's operating activities after the project enters the commercial operating phase. The working capital was assumed to be the amount of funds required for 12 months of production, before any funds are received from the sale of washed coal. For this project, the amount of working capital required amounted to US\$9.52 million per annum for producing an average of 2.5 Mtpa ROM coal as summarised in Table 5.18.

Table 5.18 Estimate of Working Capital

Cost area	Annual Cost (US\$)
Direct labour (3 months)	2,940,000
Operating supplies	3,220,000
Payroll overhead	1,070,000
Indirect cost (4 months)	750,000
Fixed cost (0.5% of insurance base)	10,000
Miscellaneous	1,530,000
Total working capital	9,520,000

5.6.5 Financial Evaluation

The financial analysis was prepared with no inflation (constant dollar basis). An effective tax rate of 22% of profit was applied in the analysis as calculated in 2.1. The forecasted cash flows of the project are as shown on Table 5.19.

Net Present Value (NPV)

The NPV was calculated using a discount rate of 10%, which is the cost of capital weighted average of the returns on investment considering the opportunity cost of investing by investors. Based on the cash flow estimations in Table 5.19, the results showed a positive NPV, amounting to US\$1.094 billion. The value of the NPV was positive meaning the project would be profitable.

Internal rate of return (IRR)

Using the method of trial and error, the IRR was estimated to be 16 %. The results showed that the project was feasible because it was greater than the cost of capital (10%), suggesting that the possibility for the project to be chosen was favourable.

Payback period (PP)

The cash flow projection showed that the estimated payback period for this project of washed coal export was 5 years. This meant that the investor would obtain all the investment back in a reasonable time period considering the size of the project and compared to the lifetime of the project which was estimated as 20 years.

Table 5.19 Morupule Main Seam Opencast Coal Mine Discounted Cash Flow Projections (US\$ million)

Year	Revenue	Operating Costs (up by 5% per year)	Gross Profit	Depreciation (same throughout)	Profit Before Tax	Income Tax (25%)	Profit After-tax	Depreciation (same throughout)	Cash Flow	Cumulative Cash Flow
1	0		0.00		0.00		0.00	0.00	-66.52	-66.52
2	180	45.50	134.50	0.50	134.00	33.50	100.50	0.50	100.00	33.48
3	250	47.78	202.23	0.50	201.73	50.43	151.29	0.50	150.79	184.27
4	250	50.16	199.84	0.50	199.34	49.83	149.50	0.50	149.00	333.28
5	250	52.67	197.33	0.50	196.83	49.21	147.62	0.50	147.12	480.40
6	300	55.31	244.69	0.50	244.19	61.05	183.15	0.50	182.65	663.04
7	300	58.07	241.93	0.50	241.43	60.36	181.07	0.50	180.57	843.61
8	300	60.97	239.03	0.50	238.53	59.63	178.89	0.50	178.39	1022.01
9	300	64.02	235.98	0.50	235.48	58.87	176.61	0.50	176.11	1198.12
10	300	67.22	232.78	0.50	232.28	58.07	174.21	0.50	173.71	1371.82
11	300	70.59	229.41	0.50	228.91	57.23	171.69	0.50	171.19	1543.01
12	300	74.11	225.89	0.50	225.39	56.35	169.04	0.50	168.54	1711.55
13	300	77.82	222.18	0.50	221.68	55.42	166.26	0.50	165.76	1877.31
14	300	81.71	218.29	0.50	217.79	54.45	163.34	0.50	162.84	2040.15
15	300	85.80	214.20	0.50	213.70	53.43	160.28	0.50	159.78	2199.93
16	250	90.09	159.91	0.50	159.41	39.85	119.56	0.50	119.06	2318.99
17	250	94.59	155.41	0.50	154.91	38.73	116.18	0.50	115.68	2434.67
18	250	99.32	150.68	0.50	150.18	37.54	112.63	0.50	112.13	2546.80
19	250	104.29	145.71	0.50	145.21	36.30	108.91	0.50	108.41	2655.21
20	250	109.50	140.50	0.50	140.00	35.00	105.00	0.50	104.50	2759.71

Review of financial indicators

The review of all financial indicators' for the Morupule main seam open cast coal mine is shown in Table 5.20. All the financial indicators show that the project will be feasible based on the economic analysis and cost estimates used. The project demonstrates a progressive economic outcome and ought to advance to comprehensive engineering, financing, and construction. The most substantial risks linked with a project of this nature are operating and capital cost escalation, unforeseen schedule delays, ability to finance the project, availability of employees and the fluctuation of the coal price. These are common risks that can be mitigated through detailed engineering, planning and the implementation of proactive management.

Table 5.20 Review of Financial Indicators

Financial Parameter	Results of Calculations	Criteria Worth	Decision
NPV	US\$1.094 billion	$NPV > 0$	Feasible
IRR	16%	$IRR > 10\%$	Feasible
PP	5 years	$PP < 20 \text{ years}$	Feasible

5.6.6 Sensitivity Analysis

Table 5.21 shows the results of the sensitivity tests. The analysis revealed that this project is most sensitive to the coal price as it showed a substantial increase and decrease in the NPV (the overall lowest NPV in the analysis) when subjected to the 20% variance. The NPV was highest when the discount rate was 8% and lower at a discount rate of 12%. Based on this analysis also, a higher discount rate meant lower returns so lower discount rates would be ideal for this project.

Table 5.21 Sensitivity Analysis Results

Variable	Baseline Value	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Ranking of Variables
Coal Price (US\$)	100	120	80	100	100	100	100	100	100	1
Production Rate (Mtpa)	3	3	3	3.6	2.4	3	3	3	3	2
Capital Costs (US\$ million)	57	57	57	57	57	68.4	45.6	57	57	3
Discount Rate (%)	10	10	10	10	10	10	10	8	12	4
NPV (billion)	US\$1.094	US\$1.440	US\$816.55	US\$1.341	US\$0.9	US\$1.330	US\$1.351	US\$1.597	US\$1.137	
IRR (%)	16	16.4	15.5	16.5	15.7	16.3	16.3	16.7	16.5	
PP (years)	5.0	5.1	4.6	5.2	4.6	5.1	5.1	5.2	5.1	

CHAPTER 6

FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 Discussion of Findings

The coal block evaluation aimed to assess the technical and financial feasibility of exploiting the Morupule main seam in the MCM2 coal block. The findings of the study provided insights into various aspects of the coal block, including its geological characteristics, coal quality, suitable mining methods, and economic viability. The coal resource defined in this thesis for the Morupule main coal seam of the MCM2 block was considered technically reasonable and a realistic prospect for eventual economic extraction on the following basis:

Improved Geological Understanding of the Morupule Main Seam

The study revealed important geological information about the coal block focusing on the Morupule main seam, including the coal seam thickness, depth, and continuity. This data was crucial for estimating the coal resource and determining the feasibility of mining. The findings indicated that the coal block has substantial coal resources on the Morupule main seam, with consistent seam thickness averaging 5 m and manageable depths of 220 m, making it suitable for extraction. The coal quality analysis indicated a high calorific value and low ash content, making it a valuable resource for energy production. The coals in the modelled coal seam can be further classified as being sub-bituminous as they have comparable properties to those described for sub-bituminous coals with average calorific value of 25.9 MJ/kg; total Carbon of 58% and Sulphur of 15%.

Morupule Main Seam Resource Estimation

The application of geostatistical methods such as variogram modelling and spatial interpolation resulted in more precise resource estimation of the Morupule main coal seam, as these techniques helped to identify spatial variations in coal properties and improve the modelling of the coal deposit. A total coal resource of 812 Mt was estimated for the Morupule main coal seam within the MCM2 block of the Morupule coal mine. This coal resource estimate was conducted in line with the guidelines of the SAMREC Code (2016), while further guidance on the classification of the coal resource was provided by the SANS10320:2004. The Morupule main seam was further classified as Measured and

Indicated Resources with the majority classified as Measured Resources. Discount factors of 8% and 12% were respectively applied to the resource classes to estimate for unanticipated geological losses. The 812 Mt resource was further broken down as 715 Mt Measured Resource and 97 Mt Indicated Resource.

Morupule Main Seam Coal Resource Reconciliation

Detailed coal resource reconciliation was not possible because historic resource estimates covered different coal seams. The resource tonnage of the Morupule main resources in the current estimate is less than those estimated by Shell for the same seam (811 Mt vs 1,378 Mt). It should however be noted that the area covered by the Shell's resource estimate was considerably larger than the area covered in the current resource estimate. Raw coal qualities are similar in both estimates.

Mining Method

The study used the PROMETHEE technique to assess various mining methods suitable for the coal block, considering factors such as coal seam depth, seam thickness, and mining equipment availability. The findings suggested that open cast mining is the most viable method, considering the shallow depth and thickness of the Morupule main coal seam. Opencast mining was selected as the most suitable mining method due to the Morupule main seam being a thick and continuous coal seam suitable for large-scale surface extraction. The opencast mining method was also favoured due to its potential economic benefits of higher recovery rate, lower operational costs, and efficient overburden removal. This allows for the extraction of larger volumes of coal, resulting in higher production rates and lower costs per tonne of coal extracted.

Mining method anticipated is open cast mining using a dragline and/or drill and blast techniques, roll-over mining where progressive rehabilitation is conducted as mining takes place. The opencast mining targets primarily the 5 m thick Morupule main seam. Production is expected to ramp up to a long-term steady state production rate of 3 Mtpa ROM. In the study conducted by SCOLBOT, they were envisaging a 5 Mtpa coal export operation that could be expanded to twice that capacity where production would come from 3 room and pillar underground mines, located at various parts of the Kgaswe area. The preference ranking method choosing the opencast mining method suggests that it was deemed the most suitable option based on the geological conditions and economic factors. The previous

study's selection of room and pillar mining was justified by different considerations of the coal seam characteristics, safety concerns, land availability, and the presence of infrastructure suitable for underground mining. The mining method chosen in this study, however, presents a different approach aimed at maximizing coal recovery while addressing the specific challenges and opportunities presented currently by the MCM2 deposit and the mining context.

Optimised Mine Planning for Morupule Main Seam

The use of Geovia Surpac, an advanced mine planning software enabled the development of optimised mining layouts and production schedules. The software integrated geological data with mine design parameters, allowing for efficient extraction and improved productivity. The study provided valuable insights into optimal pit design and mine sequencing, leading to better mine planning and operational efficiency.

Firstly, the analysis of pit dimensions indicated that an overall pit length of 1,500 m, width of 800 m, and depth of 300 m have been chosen based on the coal seam thickness, geotechnical considerations, and equipment capabilities. The pit dimensions have been determined to achieve optimal coal recovery while minimizing the overall waste-to-coal ratio. This ensures efficient utilization of resources and maximizes the economic value of the mining operation. The findings also highlight the importance of slope angles in the pit design. By conducting slope stability analyses, it was determined that with a target factor of safety of 1.5, a specific slope angle of 38° provides the necessary stability and safety for the opencast pit. The findings suggest that the chosen slope angle mitigates risks associated with potential slope failures, ensuring a safe working environment for the mining personnel and equipment. These findings demonstrate the commitment to optimizing mining operations, ensuring safety, and maximizing the extraction of coal resources in a sustainable and economically viable manner.

The open cast mine will start with an initial box cut in the furthest west position of the Morupule main coal seam which will be expanded to the east and south, in order to enable multiple active areas of mining thus facilitating a rapid ramp-up in production. The mining and production schedules were prepared with an anticipated life of mine of 20 years. The mining schedule was prepared to meet the set production rates, ensuring that adequate mining blocks were allocated in each year containing the desired coal grades and quality.

This mining schedule can be continuously reviewed and updated as new data becomes available or operational conditions change. The progress will be assessed regularly, and necessary adjustments made to ensure the schedule remains on track. The chosen mining layouts, production and mining schedule design reveal important insights into optimizing operations and ensuring safe and efficient extraction of coal resources.

Environmental Considerations

The study also examined the environmental impact of coal mining operations in the area. Findings highlighted the importance of implementing sustainable mining practices, including land reclamation, water management, and air pollution control. During the evaluation, it was determined that the opencast mine would result in the clearing of approximately 80,000 hectares of land. This would have a direct impact on the local ecosystem and biodiversity. The extraction process would also generate significant amounts of dust and noise. To address these concerns, various mitigations were proposed. These include the implementation of dust control measures, sound barriers, and the timely reclamation plans (as per mining schedule) to restore the disturbed land. By implementing these measures, it is expected that the environmental impact can be effectively mitigated.

The use of numeric values helped in quantifying and evaluating the extent of the environmental impact and the probable effectiveness of mitigation measures, ensuring a systematic and objective approach to environmental management. Regular monitoring and compliance with environmental regulations will be essential to ensure the on-going protection of the environment. Overall, the findings highlight the importance of environmental considerations in the planning and operation of the opencast mine.

Economic Viability of Mining the Morupule Main Seam

A comprehensive financial analysis was conducted to assess the economic viability of mining the Morupule main seam. The findings indicated positive financial indicators, such as positive cash flow projections. The study considered factors such as coal prices, operating costs, market demand and taxes, including royalties to determine the profitability of the mining operation. The results showed that the coal block is economically feasible and has potential to generate substantial revenue. The proposed opencast mine has a production capacity of 3 Mtpa, targeting a coal selling price of US\$100 per tonne. Based on these parameters, the estimated annual revenue is US\$ 300 million. The operating costs, including

mining, processing, maintenance, and labour expenses, were calculated at $\pm$ US\$50 million per annum.

A financial analysis was conducted to determine the project's viability. The NPV was calculated to be US\$ 1.094billion over a 20-year period, using a discount rate of 10%. The IRR was determined to be 16 %, surpassing the required rate of return of 10%. The payback period for the initial capital investment was estimated at 5 years. These findings indicate that the opencast mine shows promising economic viability. The positive NPV, favourable IRR, and reasonable payback period suggest the potential for long-term profitability.

This study provided a comprehensive assessment of the technical and financial feasibility of exploiting the Morupule main seam on the MCM2 coal block. The findings stated above indicate favourable geological characteristics, desirable coal quality, suitable mining method, efficient mining schedule and production rate and positive financial indicators. The study also emphasises the importance of environmental sustainability. These findings serve as a valuable basis for decision-making, supporting potential development and utilization of the coal block while ensuring responsible and sustainable coal mining practices. The coal present in the Morupule main seam is of suitable seam thickness, quality, continuity, quantity, and depth to be mined using open cast mining method currently in use in the adjacent MCM3 block.

6.2 Conclusions

Over the past 50 years, significant advancements have been made in methodologies and technologies for coal deposit evaluation studies. These advancements have led to improved accuracy, efficiency, and effectiveness in assessing and evaluating coal deposits. The first major improvement applicable to this study was the application of geostatistical modelling using geostatistical techniques such as kriging and variogram analysis which improved the estimation and modelling of the coal resource and coal quality parameters. These techniques account for the spatial variability and enabled interpolation and extrapolation of data to generate dependable resource models. Another major improvement incorporated in the study was the use of integrated data management software/applications, the main one being Geovia Surpac. The use of this software for advanced data management enhanced the organisation, integration, and analysis of vast amounts of geological data.

The use of decision-making techniques in the selection of the suitable mining method and equipment facilitated making informed decisions regarding mine development and operation. By combining the capabilities of the mine software with decision making techniques like PROMETHEE, this coal evaluation study became more comprehensive, accurate, and efficient. This re-evaluation study hence provided a more reliable estimation of the coal resource, facilitating better resource management and planning.

The economic analysis incorporated updated coal prices, production costs, and market demand. The cash flow analysis and sensitivity analysis provided comprehensive understanding of the financial viability of the Morupule main coal seam of the MCM2 block. This analysis facilitated better decision-making regarding resource allocation, investment opportunities, and long-term profitability. This study further placed stronger emphasis on environmental considerations as up to date standards and regulations related to environmental impact assessments, reclamation and sustainability have been taken into account. The findings emphasise the importance of sustainable mining practices and minimizing the environmental footprint of coal mining operations as well as addressing the environmental impacts relevant to this study.

The findings from the study have demonstrated significant improvements in methodologies, authenticity, and accuracy of results. The study has provided a more comprehensive understanding of the coal deposit, enabling better decision making in terms of resource management, mine planning, and sustainable coal mining practices. These improvements in methodologies and technologies have resulted in more accurate and reliable coal block evaluation study, enabling better decision making in terms of mine planning, resource estimation, and the overall optimization of coal mining operations. These findings are invaluable for future development and utilization of the coal block while considering economic and environmental factors.

6.3 Recommendations

The author believes that the open cast mine is a minimal risk and attractive project in the current economic climate. If all the assumptions included in this study are valid, and based on the technical and economic assessment, the project should be advanced to extensive geotechnical analysis and then production.

It is recommended that:

- i. Even though coal seam continuity has been proven, further exploration is recommended over the Indicated Coal Resource category in order to increase the geo-scientific confidence and upgrade it to Measured Resource status.
- ii. The modelled seam thickness and qualities must be compared to actual mining results to verify and update the coal resources if there are any indicated variations.

REFERENCES

- African Energy., (2018). Power generation and coal export project development. Retrieved from <https://africanenergyResources.com/wp-content/uploads/2016/05/2018-08-15-AFR-Investor-Presentation-Read-Only.pdf> (July 2021).
- Amstrong, W., (1984). Feasibility study for the mining of coal at Kgaswe lease area, Botswana.
- Azis, M., Hastriawan, H., Kasuma, J., Darma, D. C., (2020). Coal prices and financial performance toward coal mining company value. *International Journal of Pschosocial Rehabilitation*, Vol. 24 (4), pp. 8926- 8936.
- Baruya, P. and Kessels, J., (2013). Coal prospects in Botswana, Mozambique, Zambia, Zimbabwe and Namibia. *IEA Clean Coal Centre*, Vol. 20, pp. 103-115.
- Bertelsmann, S., (2022). BTI 2022 Country Report — Botswana. Retrieved from https://Btiproject.org/fileadmin/api/content/en/downloads/reports/country_report_2022_BWA.pdf (October 2022).
- Bierman, H., and Smidt, S., (2007). The Capital Budgeting Decision, Economic Analysis of Investment Projects. *Routledge*, Ninth Edition.
- Botswana Investment and Trade Centre., (2016). Investor factsheet: investment Opportunities in the coal sector. Retrieved from https://www.bitc.co.bw/sites/default/files/bitc_fact_sheet_-_coal_value_proposition_-_final.pdf (March 2022)
- Budeba, M., Joubert, J., and Webber-Youngman, R., (2015). A proposed approach for modelling competitiveness of new surface coal mines. *Journal of the Southern African Institute of Mining and Metallurgy*, Vol. 115(11), pp. 1057-1064.
- Cao, D., Lin, Z., Wei, Y., Li, X., Zhang, J. and Zheng, Z., (2011). Types and models of coal-deposit exploration in China. *Energy exploration & exploitation*, Vol. 29(4), pp. 495-515.
- Chisenga, C., Fadel, I. and Meijde, M., (2016). Basement geology of Botswana: an update based on ground and airborne Physics. *International Geological Congress*, Cape Town, South Africa.
- Dearman, W. R., (2013). Engineering geological mapping. *Elsevier*, pp. 19-23. Retrieved from https://books.google.com/books/about/Engineering_Geological_Mapping.html?id=D9v8BAAAQBAJ (August 2021)

- Department of Public Enterprises., (2019). Roadmap for Eskom in a Reformed Electricity Supply Industry. Retrieved from https://www.gov.za/sites/default/files/gcis_document/201910/roadmap-eskom.pdf (September 2020).
- Dipu, D., (2013). Capital costs of Indian coal mining project- an analyst view. Retrieved from <http://www.coalspot.com/news/1888/capital-costs-of-indian-coal-mining-project/1> (November 2021)
- Engineering Toolbox., (2003). Conveyors - Belt Speed. Retrieved from: https://www.engineeringtoolbox.com/conveyor-belt-speed-d_506.html (March 2022).
- Erarslan, K., (2005). A system for virtual reality applications on 3-D geological models and mine designs. *The 19th International Mining Congress and Fair of Turkey*, pp. 299-303.
- Fichani, K. (2003). Modelling the international competitiveness of Botswana's coal. *ProQuest Dissertations and Theses* (West Virginia University). Retrieved from <https://www.proquest.com/dissertations-theses/modelling-international-competitiveness-botswanas/docview/305280011/se-2?accountid=16522> (October 2020).
- Ghebremusse, S.(2018). Good governance and development in Botswana - The democracy conundrum. *Law and Development Review*, Vol. 11(2), pp. 913-938.
- Ghadernejad, S. Jafarpour, A. and Ahmadi, P. (2019). Application of an integrated decision-making approach based on FDAHP and PROMETHEE for selection of optimal coal seam for mechanization; A case study of the Tazareh coal mine complex, Iran. *International Journal of Mining and Geo-Engineering*, Vol. 53(1), pp. 15-23.
- Goodman., J. (2016). Coal, climate, and development: comparative perspectives. Retrieved from <https://opus.lib.uts.edu.au/bitstream/10453/64392/4/0669E023-E95E-42B2-BD40-F43CDB8D55D4%20%20am.pdf>(July 2022)
- Grynberg, R., (2012). Coal exports and the diversification of Botswana economy. *Botswana Institute for Development Policy Analysis Publication Series*, pp. 1-46.
- Hancox, P.J., (2016). The coalfields of South-Central Africa: A current perspective. *Episodes*, Vol. 39(2), pp. 407-428.
- Hanson, C., Thomas, D. and Gallagher, B., (2005). The value of early geotechnical assessment in mine planning in Naj Aziz and Bob Kininmonth. *2005 Coal Operators' Conference*, (University of Wollongong).
- Harvey, R. G. (2015). From diamonds to coal? Critical reflections on Botswana's economic future. *The Extractive Industries and Society*, Vol. 2(4), pp. 827-839.

- Hydrogeology of Botswana.(2022). *MediaWiki*. Retrieved from http://earthwise.bgs.ac.uk/index.php?title=Hydrogeology_of_Botswana&oldid=57387 (October 2022).
- IEA., (2020), Coal 2020, IEA, Paris. Retrieved from <https://www.iea.org/reports/coal-2020> (September 2021).
- IEA., (2022), Coal 2022, IEA, Paris. Retrieved from <https://www.iea.org/reports/coal-2022>(September 2022).
- Investor Factsheet.(2016). Investment opportunities in the coal sector. *BITC research department report*. Retrieved from <https://www.gobotswana.com/sites/default/files/BITC%20%20Coal%20Value%20Proposition.pdf> (May 2021).
- Kabelo, O. (2018). Petrographic and geochemical characterization of part of a Permian coal deposit of the South-Eastern Kalahari sub-basin, Moiyabana area, eastern Botswana (*Doctoral dissertation, Botswana International University of Science and Technology (Botswana)*).
- Kang, L., (2009). Coal exploration and mining. *Coal, Oil Shale, Natural Bitumen, Heavy Oil and Peat*, Vol. 1, pp. 92-112.
- Kumar, D. and Kumar, D., (2015). Management of coking coal resources. *Elsevier*, 1st Edition, pp. 261-287.
- Lewin, M. (2011). Botswana's success: Good governance, good policies, and good luck. *Yes, Africa Can*, World Bank Publications, pp. 81-90.
- Lomberg, K. and Rupprecht, S.M. (2017).The 2016 SAMREC Code. *Journal of the southern African Institute of Mining and Metallurgy*, Vol. 117(12), pp. 1095-1100.
- Maatla Energy., (2018). Unlocking Botswana in Coal Mining. Retrieved from https://www.bb.org.bw/common_up/business-botswana/doc_1544449743.pdf (February 2021).
- Machete, M. (2012). A History of Coal and the Morupule Colliery, 1973-2005. *Botswana Notes and Records*, Vol. 44, pp.45-59.
- Modie, B., (2007). The Palaeozoic palynostratigraphy of the Karoo Supergroup and palynofacies insight into paleo environmental interpretations, Kalahari Karoo Basin, Botswana *Doctoral dissertation* (Brest).
- Mohutsiwa, M., (2015). Estimation of capital costs for establishing coal mines in South Africa. *Master's thesis*, University of Witwatersrand, South Africa.
- Morupule Coal Mine (2020). Morupule Coal Mine Report. Retrieved from https://mcm.co.bw/documents/MCM_company_profile.pdf (November 2022).

- Pollet, B., Staffell, I. and Adamson, K. A. (2015). Current energy landscape in the Republic of South Africa. *International Journal of Hydrogen Energy*, Vol. 40(46), pp.16685-16701.
- Rangel, A., Santos, J. and Savoia, J., (2016) Modified profitability index and internal rate of return. *Journal of International Business and Economics*, Vol 4. (2), pp. 13-18.
- Rupprecht, S., (2004). Establishing the feasibility of your proposed mining venture. *The International Platinum Conference 'Platinum Adding Value*. The South African Institute of Mining and Metallurgy. pp. 243-247.
- SADC Major Achievements and Challenges., (2005). 25 years of regional cooperation and integration. Retrieved from <https://www.sadc.int/fr/file/3888/download?token=OkfW1Tyl> (October 2021).
- Sanchez, F. and Hartlieb, P., (2020). Innovation in the mining industry: technological trends and a case study of the challenges of disruptive innovation. *Mining, Metallurgy & Exploration*. Vol. 37, pp.1385-1399.
- Sefemo, M., (2021). The 2018/19 Botswana mineral accounts technical report. Retrieved from The 2018-19 Botswana Mineral Accounts Technical Report.pdf (bgi.org.bw) (April 2022).
- Souza (2014). Number of samples in geostatistical analysis and kriging maps of soil properties.
- Statistics Botswana (2019). Botswana environment statistics. *Climate Digest*. Retrieved from <https://www.statsbots.org.bw/sites/default/files/publications/Climate%20Digest%20%202019.pdf> (May 2022).
- Sullivan, W., Wicks, E. and Koelling, C., (2012). Engineering Economy. 15th Edition, Prentice Hall.
- Tate, R., Shearer, C. and Matikinca, A., (2021). Tracking global coal mine proposals. Retrieved from https://globalenergymonitor.org/wpcontent/uploads/2021/05/CoalMines_2021_r4.pdf (April 2022).
- Thomas, L. J., and Thomas, L. P. (2013). Coal Geology. *John Wiley and Sons*. 3rd Edition, pp. 169-201.
- Ukwazi Mining Studies. (2017). Morupule South: Mining section of the pre-feasibility study. Shumba Energy.
- Unver, B. (2018). Fundamentals of 3-D modelling and Resource estimation in coal mining, *Journal of Mining and Environment*, Vol. 9(3), pp. 623-639.

- Van Deventer, K., (2017) Minergy Coal; Masama coal project, Botswana: West block coal Resource, independent competent persons report. Minergy Coal (Pty) Ltd.
- Wang, T., Sun, J., Lin, Z., Fang, H., Wang, Y. and Liu, Y., (2021). Coordinated exploration model and its application to coal and coal-associated deposits in coal basins of China. *Acta Geologica Sinica-English Edition*, Vol. 95(4), pp. 1346-1356.
- Ward, C. R., (1998). Coal geology and coal technology. Retrieved from <https://www.osti.gov/biblio/5555914> (November 2020).
- Xiao, D., Tuan Le, B., Mao, Y., Jiang, J., Song, L., and Liu, S. (2016). Research on coal exploration technology based on satellite remote sensing. *Journal of Sensors*, Vol. 2016, (Article ID 8214801), pp. 1-9.
- Zhai, M., Totolo, O., Modisi, M. P., Finkelman, R. B., Kelesitse, S. M. and Menyatso, M. (2009). Heavy metal distribution in soils near Palapye, Botswana: an evaluation of the environmental impact of coal mining and combustion on soils in a semi-arid region. *Environmental geochemistry and health*, Vol. 31(6), pp. 759-777.

APPENDICES

APPENDIX 1

Physical Description of Coal Seams in the Morupule Lease Area

(Source: Armstrong, 1984)

Coal Seam	Cover Depth (m)	Cleat	Inclusions	Coal Appearance	Pyrite Content
Serowe Bright Seam	55 - 110	Moderate to well-developed cleat with calcite infilling, sub-vertical with two sets at right angles	Dirt parting 0.1 m to 0.2 m thick, some 0.15 m to 0.7 m below the roof	Generally bright coal	Nodules and some veinlet infilling the cleat. Abundant locally, particularly in the upper leaf
Lotsane Seam	120 - 160	Moderately developed with some calcite infilling sub-vertical, trending parallel to regional structure	Isolated stone rolls	Alternating bands (0.1 m thick) of bright and dull coal	-
Morupule Main Seam	160 - 300	Poorly developed sub-vertical trending parallel to the regional structure. Better developed in bright coal bands. Coal is blockier than other two seams	Frequent thin partings of shaly carbonaceous material	Generally, dull with few bright bands up to 1.0 m thick	Discrete nodules

APPENDIX 2

Data Tables

1. Collar Excel File (Collar.csv)

Hole Id	Northing (y)	Easting (x)	Elevation (z)	Max depth (m)
C8	-2489778.81	-9267.11	953.97	267
C84	-2490204.58	-10686.37	954.35	210.4
C94	-2483977.29	-13820.53	957.17	258.65
C101	-2491953.48	-11139.76	966.12	251.19
C102	-2490748.1	-12587.03	969.49	209.4
C104	-2492834.53	-10187.27	969.92	232.18
C105	-2487882.65	-10488.2	973.31	226.81
C106	-2487173.37	-12045.72	973.31	234.09
C107	-2488610.24	-12624.45	976.3	226.74
C113	-2493683.07	-8285.71	976.44	220.54
C121	-2489287.72	-14642.26	976.56	188.98
C122	-2485888.06	-13241.6	980.71	249.6
C123	-2488218.99	-14965.29	980.8	232.49
C124	-2487529.41	-13093.44	982.64	238.55
C125	-2485478.89	-11666.17	984.4	236.35
C130	-2485145.16	-18191.08	984.48	293.2
C133	-2485902.96	-21013.51	985.94	313.81
C134	-2485195.18	-22577.03	986.31	341
C135	-2484112.04	-19191.78	986.94	319.97
C149	-2488765.31	-9570.83	987.75	197.74
C150	-2491657.16	-9536.11	989.15	226.94
C151	-2485356.24	-15264.41	989.94	266.98

C152	-2489458.18	-11918.37	989.96	210.3
C154	-2486567.63	-12622.75	990.92	225.98
C156	-2487012.4	-14027.31	991.22	252.73
C157	-2484987.9	-14133.95	992.45	256.59
C160	-2488311.32	-11614.15	992.94	222.6
C161	-2485754.3	-16682.17	993.45	275.03
C162	-2486197.18	-18254.8	993.75	287.57
C163	-2486741.3	-10942.78	995.58	219.9
C165	-2485513.71	-19449.28	995.58	309.11
C168	-2487530.01	-15640.56	995.73	241.75
C170	-2488409.76	-13981.89	996.69	225.22
C175	-2489038.52	-10648.76	998.01	214.03
C177	-2484177.37	-14738.3	998.31	273.25
C178	-2486242.4	-11595.54	998.31	239.16
C179	-2484521.91	-15962.99	1000.39	281
C192	-2488889.26	-14283.11	1001.17	220.72
E12	-2493088.14	-6862.65	1002.22	137.85
E16	-2491262	-6580.23	1002.22	183.1
E18	-2491344.44	-7813.83	1002.77	143.57
E22	-2488989.7	-8477.89	1002.86	190.05
E33	-2483618.15	-9629.75	1003.07	172
E34	-2487105.054	-5908.99	1003.63	170
E35	-2482108.04	-12283.11	1003.98	242.94
E37	-2485607.84	-6037.11	1005.29	157.56
E42	-2487048.82	-8144.96	1005.56	196.64
E49	-2486282.31	-9536.41	1007.3	205.58
E53	-2493014.11	-5788.92	1008.36	183.28

E55	-2486631.935	-4588.539	1008.72	150
E57	-2484305.22	-11428.87	1010.08	213.3
E58	-2486908.067	-7090.911	1011.5	180
E59	-2484264.51	-8077.93	1011.63	165.5
E60	-2484606.94	-10036.31	1015.27	193.41
E61	-2484280.447	-5973.661	1020.19	165
E62	-2485467.39	-8740.3	1020.69	184.68
E63	-2483667.47	-11078.03	1023.47	205.41
E64	-2485969.59	-7471.29	1025.04	168.57
E69	-2491592.606	-5136.145	1027.88	170
E71	-2490266.01	-8417.07	1028.49	199.23
E73	-2485818.53	-10339.14	1035.89	215.45
E75	-2489322.13	-7404.06	1036.17	182.03
E81	-2486258.1	-8345.54	1040.12	188.38
E84	-2484942.58	-10861.34	1045.09	204
E85	-2485490.2	-9735.39	1052.51	204.7
E87	-2484750.2	-11674.97	1053.05	219.42
E89	-2485347.24	-7117.55	1060.16	171.81

2. Survey Excel File (Survey.csv)

Hole Id	Max depth (m)	Dip (°)	Azimuth (°)
C8	267	-90	180
C84	210.4	-90	180
C94	258.65	-90	180
C101	251.19	-90	180
C102	209.4	-90	180
C104	232.18	-90	180

C105	226.81	-90	180
C106	234.09	-90	180
C107	226.74	-90	180
C113	220.54	-90	180
C121	188.98	-90	180
C122	249.6	-90	180
C123	232.49	-90	180
C124	238.55	-90	180
C125	236.35	-90	180
C130	293.2	-90	180
C133	313.81	-90	180
C134	341	-90	180
C135	319.97	-90	180
C149	197.74	-90	180
C150	226.94	-90	180
C151	266.98	-90	180
C152	210.3	-90	180
C154	225.98	-90	180
C156	252.73	-90	180
C157	256.59	-90	180
C160	222.6	-90	180
C161	275.03	-90	180
C162	287.57	-90	180
C163	219.9	-90	180
C165	309.11	-90	180
C168	241.75	-90	180
C170	225.22	-90	180

C175	214.03	-90	180
C177	273.25	-90	180
C178	239.16	-90	180
C179	281	-90	180
C192	220.72	-90	180
E12	137.85	-90	180
E16	183.1	-90	180
E18	143.57	-90	180
E22	190.05	-90	180
E33	172	-90	180
E34	170	-90	180
E35	242.94	-90	180
E37	157.56	-90	180
E42	196.64	-90	180
E49	205.58	-90	180
E53	183.28	-90	180
E55	150	-90	180
E57	213.3	-90	180
E58	180	-90	180
E59	165.5	-90	180
E60	193.41	-90	180
E61	165	-90	180
E62	184.68	-90	180
E63	205.41	-90	180
E64	168.57	-90	180
E69	170	-90	180
E71	199.23	-90	180

E73	215.45	-90	180
E75	182.03	-90	180
E81	188.38	-90	180
E84	204	-90	180
E85	204.7	-90	180
E87	219.42	-90	180
E89	171.81	-90	180

3. Sample Excel File (Sample.csv)

Hole Id	Sample Id	Depth from (m)	Depth to (m)	Calorific value (MJ/kg)	Moisture (%)	Ash (%)	Volatiles (%)	Fixed carbon (%)	Total Sulphur (%)
C8	C8 MARS	89.4	122.9	26.21	2.24	18.54	27.37	51.85	0.74
C8	C8 LOTS	141.2	150.1	26.38	4.18	14.85	32.4	48.58	0.66
C8	C8 LOTS	156.5	160.9	25.12	4.16	17.45	30.89	47.5	0.79
C8	C8 LOTS	163.1	172.6	24.35	6.35	17.76	30.06	45.83	0.69
C8	C8 NO2	177	187	27.31	3.8	12.09	26.49	57.62	0.32
C8	C8 MORU	187	201.1	24.44	2.94	19.52	24.91	52.63	0.13
C84	C84 SERO	91.02	91.54	23.95	4.92	19.87	32.96	42.25	1.69
C84	C84 SERO	91.68	92.44	27.32	5.5	10.6	40	43.9	0.75
C84	C84 SERO	92.44	93.14	27.53	6	9.3	34.3	50.4	0.92
C84	C84 D	93.14	110.96	22.72	4	24.6	32.7	38.7	3.03
C84	C84 E	110.96	123.1	19.04	3.47	35.4	24.95	36.18	0.59
C84	C84 F	136.4	144.68	25.78	4.6	14	31.3	50.1	0.68

C84	C84 LOTS	144.68	146.3	25.76	3.74	15.35	32.93	47.99	1.01
C84	C84 H	146.3	158.46	19.32	3.4	30.38	26.86	39.36	0.59
C84	C84 LOTS	158.46	161.24	18.08	3.94	33.62	25.45	36.99	0.46
C84	C84 LOTS	162.94	163.96	20.79	3.56	25.72	32.28	38.44	0.55
C84	C84 NO2	176.78	178.43	23.19	4.9	17.95	21.7	55.46	0.14
C84	C84 NO2	178.43	180.08	27.01	4.93	10.31	23.38	61.38	0.16
C84	C84 NO2	180.08	181.4	21.71	4.34	24.62	21.91	49.13	0.14
C84	C84 NO2	181.4	183.44	24.64	4.36	15.67	24.02	55.95	0.18
C84	C84 NO2	183.44	185.48	26.28	4.26	11.27	26.49	57.97	0.31
C84	C84 MARM AG	185.48	186.76	20.95	3.72	27.31	22.8	46.17	0.31
C84	C84 MORU	186.76	188.8	22.73	3.84	23.81	22.72	49.63	0.28
C84	C84 MORU	188.8	190.88	21.44	4.4	24.62	21.29	49.68	0.27
C84	C84 MORU	190.88	192.96	25.61	3.89	14.36	25.21	56.54	0.41
C84	C84 MORU	192.96	195.04	27.05	4.1	11.07	25.02	59.8	0.31
C84	C84 MORU	195.04	197.12	27.55	3.77	9.92	26.63	59.68	0.25
C84	C84 MORU	197.12	199.2	27.47	3.32	10.9	27.14	58.63	0.4
C84	C84 MORU	199.2	200.74	23.01	3.22	22.48	48.98	23.01	0.27
C94	C94 MORU	240.12	250.2	26.5	5.4	12.13	24.93	57.54	0.27

C101	C101 SERO	108.3	109.8	26.19	3.91	15.56	32.88	47.65	0.81
C101	C101 LOTS	163.6	165.4	25.69	3.68	18.09	31.48	46.75	0.78
C101	C101 LOTS	165.4	166.5	26.25	3.81	15.48	34.24	46.36	0.66
C101	C101 D	217.55	219.86	25.13	3.91	17.5	22.49	56.1	0.31
C101	C101 MORU	219.86	223.12	28.51	3.75	9.64	27.77	58.84	0.31
C101	C101 MORU	223.12	226.26	27.9	3.73	11.51	24.02	60.74	0.26
C101	C101 MORU	226.26	227.46	22.6	2.4	27.71	26.12	43.77	0.25
C102	C102 SERO	73.76	74	23.53	2.98	23.29	33.34	40.3	3.4
C102	C102 SERO	74	74.13	25.55	3.75	17.54	32.79	45.92	0.84
C102	C102 SERO	74.13	75.8	27.11	3.83	13.44	36.48	46.26	1.24
C102	C102 C	125.24	127.08	26.21	2.24	18.54	27.37	51.85	0.74
C102	C102 LOTS	131.05	132.62	26.38	4.18	14.85	32.4	48.58	0.66
C102	C102 LOTS	132.62	133.27	20.98	3.33	29.81	26.64	40.23	0.93
C102	C102 MORU	190.3	192.96	27.45	3.5	12.3	27.49	56.7	0.26
C102	C102 MORU	192.96	195.8	27.73	3.5	11.52	26.22	58.75	0.27
C102	C102 MORU	195.8	198.75	27.93	3.04	11.49	26.65	58.82	0.29

4. Sample excel file (Sample.csv)

Hole Id	Sample Id	Depth from (m)	Depth to (m)	Calorific value (MJ/kg)	Moisture (%)	Ash (%)	Volatiles (%)	Fixed carbon (%)	Total Sulphur (%)
C8	C8 MARS	89.4	122.9	26.21	2.24	18.54	27.37	51.85	0.74
C8	C8 LOTS	141.2	150.1	26.38	4.18	14.85	32.4	48.58	0.66
C8	C8 LOTS	156.5	160.9	25.12	4.16	17.45	30.89	47.5	0.79
C8	C8 LOTS	163.1	172.6	24.35	6.35	17.76	30.06	45.83	0.69
C8	C8 NO2	177	187	27.31	3.8	12.09	26.49	57.62	0.32
C8	C8 MORU	187	201.1	24.44	2.94	19.52	24.91	52.63	0.13
C84	C84 SERO	91.02	91.54	23.95	4.92	19.87	32.96	42.25	1.69
C84	C84 SERO	91.68	92.44	27.32	5.5	10.6	40	43.9	0.75
C84	C84 SERO	92.44	93.14	27.53	6	9.3	34.3	50.4	0.92
C84	C84 D	93.14	110.96	22.72	4	24.6	32.7	38.7	3.03
C84	C84 E	110.96	123.1	19.04	3.47	35.4	24.95	36.18	0.59
C84	C84 F	136.4	144.68	25.78	4.6	14	31.3	50.1	0.68
C84	C84 LOTS	144.68	146.3	25.76	3.74	15.35	32.93	47.99	1.01
C84	C84 H	146.3	158.46	19.32	3.4	30.38	26.86	39.36	0.59
C84	C84 LOTS	158.46	161.24	18.08	3.94	33.62	25.45	36.99	0.46
C84	C84 LOTS	162.94	163.96	20.79	3.56	25.72	32.28	38.44	0.55
C84	C84 NO2	176.78	178.43	23.19	4.9	17.95	21.7	55.46	0.14
C84	C84 NO2	178.43	180.08	27.01	4.93	10.31	23.38	61.38	0.16
C84	C84 NO2	180.08	181.4	21.71	4.34	24.62	21.91	49.13	0.14
C84	C84 NO2	181.4	183.44	24.64	4.36	15.67	24.02	55.95	0.18
C84	C84 NO2	183.44	185.48	26.28	4.26	11.27	26.49	57.97	0.31

C84	C84 MARM AG	185.48	186.76	20.95	3.72	27.31	22.8	46.17	0.31
C84	C84 MORU	186.76	188.8	22.73	3.84	23.81	22.72	49.63	0.28
C84	C84 MORU	188.8	190.88	21.44	4.4	24.62	21.29	49.68	0.27
C84	C84 MORU	190.88	192.96	25.61	3.89	14.36	25.21	56.54	0.41
C84	C84 MORU	192.96	195.04	27.05	4.1	11.07	25.02	59.8	0.31
C84	C84 MORU	195.04	197.12	27.55	3.77	9.92	26.63	59.68	0.25
C84	C84 MORU	197.12	199.2	27.47	3.32	10.9	27.14	58.63	0.4
C84	C84 MORU	199.2	200.74	23.01	3.22	22.48	48.98	23.01	0.27
C94	C94 MORU	240.12	250.2	26.5	5.4	12.13	24.93	57.54	0.27
C101	C101 SERO	108.3	109.8	26.19	3.91	15.56	32.88	47.65	0.81
C101	C101 LOTS	163.6	165.4	25.69	3.68	18.09	31.48	46.75	0.78
C101	C101 LOTS	165.4	166.5	26.25	3.81	15.48	34.24	46.36	0.66
C101	C101 D	217.55	219.86	25.13	3.91	17.5	22.49	56.1	0.31
C101	C101 MORU	219.86	223.12	28.51	3.75	9.64	27.77	58.84	0.31
C101	C101 MORU	223.12	226.26	27.9	3.73	11.51	24.02	60.74	0.26
C101	C101 MORU	226.26	227.46	22.6	2.4	27.71	26.12	43.77	0.25
C102	C102 SERO	73.76	74	23.53	2.98	23.29	33.34	40.3	3.4
C102	C102 SERO	74	74.13	25.55	3.75	17.54	32.79	45.92	0.84
C102	C102 SERO	74.13	75.8	27.11	3.83	13.44	36.48	46.26	1.24
C102	C102 C	125.24	127.08	26.21	2.24	18.54	27.37	51.85	0.74

C102	C102 LOTS	131.05	132.62	26.38	4.18	14.85	32.4	48.58	0.66
C102	C102 LOTS	132.62	133.27	20.98	3.33	29.81	26.64	40.23	0.93
C102	C102 MORU	190.3	192.96	27.45	3.5	12.3	27.49	56.7	0.26
C102	C102 MORU	192.96	195.8	27.73	3.5	11.52	26.22	58.75	0.27
C102	C102 MORU	195.8	198.75	27.93	3.04	11.49	26.65	58.82	0.29
C102	C102 MORU	198.75	199.36	26.62	2.36	18.22	28.63	50.79	0.49
C104	C104 SERO	100.42	100.82	25.32	3.94	18.16	33.78	44.12	0.95
C104	C104 SERO	100.82	102.48	28.46	4.82	8.77	34.4	52.01	0.63
C104	C104 LOTS	156.7	159.36	27.53	4.54	11.32	34.3	49.83	0.49
C104	C104 MORU	207.28	208.41	25.81	4.33	15.06	23.47	57.13	0.33
C104	C104 MORU	208.41	212	27.73	4.63	10.88	26.13	58.35	0.31
C104	C104 MORU	212	215.5	27.55	4.49	11.06	26.84	57.6	0.34
C105	C105 MORU	203.28	215.7	26.64	2.58	14.45	25.17	57.8	0.34
C106	C106 MORU	202.66	216.61	26.85	3.98	14.15	24	57.87	0.38
C107	C107 MORU	206.72	217.4	26.5	3.38	14.41	25.21	56.99	0.25
C113	C113 SERO	79.19	79.83	23.04	3.45	23.44	29.45	43.66	1.63
C113	C113 SERO	79.83	81.5	27.42	3.72	11.2	33.42	51.66	0.81
C113	C113 AF	140.1	141.14	24.86	3.16	19.48	27.97	49.39	0.26
C113	C113 AE	141.14	142.58	28.69	3.98	7.39	33.34	55.29	0.27
C113	C113 Z	142.58	143.54	27.47	3.67	10.57	32.91	52.84	0.29
C113	C113 MORU	193.2	195.04	26.33	3.43	13.27	24.43	58.86	0.02

APPENDIX 3

Equipment Alternatives for Open-cast Mining Operations

Equipment Alternative	Equipment Type	Manufacturer	Model	Size/ Capacity	Specifications
Excavator 1	Dragline	Caterpillar	8750	345 tons	Boom length: 132.5 m, Bucket capacity: 116 m ³
Excavator 2	Excavator	Komatsu	PC2000-8	95 tons	Boom length: 11.7 m, Bucket capacity: 5.5m ³
Excavator 3	Bucket wheel excavator	Noen	KR400Nk	90 tons (15 buckets)	Boom length: 6 m, Bucket capacity: 0.1 m ³
Haul Truck 1	Haul Truck	Liebherr	T 264	240 tons	Engine power: 2,700 HP, Payload capacity: 240 tons
Haul Truck 2	Haul Truck	Caterpillar	797F	363 tons	Engine power: 4,000 HP, Payload capacity: 363 tons
Loader 1	Loader	Hitachi	EX3600-6	22 cubic meters	Operating weight: 355 tons, Bucket capacity: 22m ³
Loader 2	Loader	Volvo	L350H	12.5 cubic meters	Operating weight: 50 tons, Bucket capacity: 12.5m ³
Drill Rig 1	Drill Rig	Sandvik	DR560	Hole diameter: 251-406mm	Depth capacity: 75m, Engine power: 567 Kw
Drill Rig 2	Drill Rig	Atlas Copco	Pit Viper	Hole diameter: 229-311mm	Depth capacity: 30m, Engine power: 597 kW